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Project: Innovative Integration of Virtual Reality in Chemical Engineering Education

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Report 02

The best practices and knowledge to be processed in the curriculum, collection of requirements, functioning concepts and regulations relevant to the VR platform

Document developed as part of the tasks in the VRChem project:

Work package n°3 - Creating of an inter-university platform for VR courses

Activity 3.1: Gathering the best practices and knowledge to be processed in the curriculum, collection of requirements, functioning concepts and regulations relevant to the VR platform

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1. Introduction

Many jobs in high demand today didn't exist a decade ago. With ***rapid technological advancements*** fueling globalization and digital innovation, educators play a key role in equipping students with the skills needed for future careers. Integrating digital learning tools into higher education institutions can enhance student engagement, enable teachers to refine their teaching strategies, and support personalized learning experiences. These tools also help students develop critical 21st-century competencies. Technologies such as virtual classrooms, videos, augmented reality, virtual reality (VR), extended reality and robotics make lessons more dynamic and promote inclusive learning environments that encourage collaboration and curiosity while giving teachers valuable insights into student performance.

Nevertheless, adopting educational technology comes with challenges, particularly in implementation and practical use. Additional concerns include managing screen time, ensuring teachers are effectively trained to use these tools, and addressing issues of technological equity.

Within the framework of the implemented project, the project partners wish to ***develop technologies that will support education in the field of chemical engineering***. It is an area of science diverse and experimentally driven, playing a critical role in addressing the needs of fast-evolving industries, energy-efficient technologies, and environmental sustainability. Its advancement is closely linked to experimental research, which is often limited by factors such as slow reaction rates, high costs, safety risks, and the unique challenges posed by materials and processes. Furthermore, traditional ***chemical engineering education*** faces significant hurdles, particularly the lack of opportunities for students to interact with full-scale industrial equipment. This limitation stems from the immense scale of industrial systems and the technical and safety restrictions that make direct, hands-on experience impractical. As a result, chemical engineering students primarily focus on theoretical knowledge, which can be difficult to apply effectively in real-world contexts. This disconnect between theoretical learning and practical application often hampers the development of essential engineering skills.

It seems that *virtual reality technologies* can be *very helpful* in teaching chemical engineering at universities. Among other technologies, virtual reality has emerged as a particularly effective tool. VR provides an immersive, interactive environment that engages multiple senses, enabling students to visualize and comprehend complex chemical engineering processes in a dynamic and intuitive way. *By incorporating VR into chemical engineering curricula*, educators can offer students hands-on learning experiences that simulate real-world industrial scenarios. This approach not only enhances understanding but also equips students with the practical skills needed to excel in their field, bridging the gap between theory and application while preparing them for the demands of a rapidly changing industry. By *integrating VR technology into education*, institutions can revolutionize how students learn, fostering a deeper understanding, practical competence, and readiness for the challenges of the industry.

Referring to the project *VRChem: Innovative Integration of Virtual Reality in Chemical Engineering Education* main objectives, students' VR experiences can make chemical engineering more interesting and allow them to *develop their skills*, thus stimulating innovative learning and teaching practices. What's more, VR enables students to explore 3D elements engagingly and interactively, offering experiences that are typically limited to traditional teaching methods, such as lectures, textbooks, and videos. These methods often rely on passive absorption of information, which can lead to superficial understanding and limited recall over time. In a VR environment, it is possible to create highly realistic and immersive simulations that provide a sense of spatial awareness far surpassing the capabilities of traditional video. One of the *biggest advantages* of educational virtual reality is that it reinforces material taught through other channels, which increases the long-term retention of course material.

Virtual reality technology embodies the dual aspirations of driving digital innovation and advancing sustainability within higher education. By reducing dependency on physical resources and facilitating immersive, interactive learning experiences, VR paves the way for a more sustainable and efficient educational landscape. Yet, incorporating *VR into university curricula is not without its challenges*, particularly for educators who may be unfamiliar with this cutting-edge technology. Key obstacles include the scarcity of high-quality VR content that

aligns with pedagogical standards and the need to *adapt or redesign teaching methodologies to harness VR's immersive potential* effectively.

The VRChem project seeks to address these challenges by enhancing the digital capabilities of partner universities through the exchange of expertise in VR implementation. This collaborative initiative emphasizes the creation of robust resources, high-quality educational materials, and *discipline-specific VR content* for education in chemical engineering. These efforts aim to equip educators with the confidence and skills required to seamlessly integrate VR into their teaching practices. By fostering international collaboration and sharing best practices among partner institutions, the project will empower educators and students alike to unlock the transformative potential of VR technology in higher education.

2. Project assignments to be carried out in WP n°3

Thriving in today's workplace demands more than a mastery of fundamental skills—students must also be well-versed in the tools and practices they will encounter in their professional lives. By seamlessly incorporating technology into the curriculum, educational institutions may equip students with the competencies needed to excel in their careers, ensuring their success extends far beyond graduation. Implementation the new VR technology into the curriculum at universities *requires professional tools* for lecturers and researchers but also because of the difficulties in developing high-quality materials, especially for people who are not familiar with this technology. Therefore, within the framework of the "VRChem" project an inter-university platform for VR courses will be created. This task is included in project's *Work package n°3 - Creating of an inter-university platform for VR courses* which consist of the following activities:

- *Activity 3.1: Gathering the best practices and knowledge to be processed in the curriculum, collection of requirements, functioning concepts and regulations relevant to the VR platform*.

- *Activity 3.2 Purchase, preparation and implementation of the hardware environment in VR laboratories.*

- *Activity 3.3 Creating of an inter-university platform for VR courses.*

- *Activity 3.4 Creating tasks and games in VR courses.*

- *Activity 3.5 Feedback and quality check, improvement round for VR courses.*

The leaders of work package n°3 are Lodz University of Technology (VOXEL Research Lab) and the University of Aveiro (Digimedia's XR lab). They will have the challenge of creating these and other features of the VR platform that will be made openly available to the academic community, and where anyone, after registering, will be able to explore the materials posted freely and without restrictions. The participating universities in VRChem project, which possess extensive and valuable experience in VR technology, will also collaboratively participate in this work package based on their academic expertise.

3. The main assumptions of the report

In collaboration with the project partners, this document outlines internal agreements on the key content deemed essential for inclusion in the VR platform. It will integrate insights from the most effective practices and cutting-edge developments in VR technology, ensuring that the solutions proposed align with current trends and innovations. Special emphasis will be placed on addressing the unique educational requirements within chemical engineering and related disciplines, where complex concepts, processes, and equipment often necessitate advanced teaching tools to enhance understanding and engagement.

By combining theoretical knowledge with practical applications, the document **will provide clear guidelines and recommendations** on designing VR platform, including considerations for content quality, technical specifications, and pedagogical methodologies. It will also address potential challenges, such as the cost of VR technology, accessibility issues, and the need for educator training, proposing actionable solutions to overcome these barriers. Ultimately, this resource aims to empower educators, institutions, and stakeholders to harness the transformative potential of VR, fostering a more interactive, immersive, and effective learning environment in chemical engineering and beyond.

4. Detailed arrangements for the VR platform

In collaboration with the project partners, using the MS Teams platform and during joint project progress meetings *collection of requirements, functioning concepts and regulations* relevant to the VR platform has been created:

a. All applications, programs, and materials generated during the project should be placed on the VR platform so that its users can access all materials. Also, in future when the project partner's universities will develop this VR platform, it should be possible for its users to access new materials. For this reason, the entire platform *will be placed on the server* of the Cracow University of Technology as the leader of the VRChem project. Due to the agreement concluded with the National Agency, the Cracow University of Technology is obliged to maintain the continuity of both the project website and the materials related to this project for a period of 5 years, therefore the decision to place the materials on the PK server is as reasonable as possible

b. The proposed VR platform should have the functionality of its *trouble-free future development*, i.e. adding new materials. It should rather take the form of a repository enabling the posting of new programs and applications developed by partner universities.

c. Because the VRChem project is financed by the European Union, the developed platform *will be available to anyone* outside the partner universities. Access to it will be *unlimited and free of charge*. However, access will be possible after *prior registration* in the appropriate place (the conditions for registration and logging in to the platform will be established during its physical implementation).

d. The language of the VR platform for testing before implementation stage should be *English*, however it should be possible to upload other languages of the project partners.

e. VR platform should be a *collaborative learning space* which offer multiplayer capabilities where students and instructors can interact in real-time, work on group projects, and discuss concepts in a shared virtual space. This feature will foster teamwork and communication skills of students, mirroring real-world engineering projects.

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f. The proposed VR platform is intended to be for students studying chemical engineering; due to the presence of chemical devices and equipment in this installation, the user should be able to perform *simplified measurements* of such devices or rooms where such devices are located or distance.

g. The environment in VR platform that students will use should enable the implementation of *hotspots* inside the chemical installation plant that will be able to for example: transfer the user to the content provided during the VR platform configuration related to watching a film or browsing content; allows additional information to be obtained like cross-sections/interiors/additional information for selected devices on the chemical installation.

h. Due to the size of the planned chemical VR installations, consideration should be given to the issue of *moving around the installations*, i.e. by walking or teleporting or possibly using hotspots.

i. The functionality of the platform should consider the fact that there are currently many devices on the market that are used to work in virtual reality. If possible, the platform *should support many devices-goggles* with different technical specifications.

j. Another functionality of the VR platform should be the ability to upload open-source applications from *Meta platform*. The META platform offers several opportunities for educating engineers in the field of chemical engineering, including: advanced simulation tools, virtual laboratories, interactive modules that cover core topics in chemical engineering, such as thermodynamics, reaction engineering, and process design. Also the platform facilitates partnerships with industry leaders, providing learners with practical insights and exposure to real-world challenges.

k. Another VR platform feature proposed by the project partners should be the ability to *virtually "cut open" industrial equipment and devices*, providing an unparalleled view of their internal components and alternatively processes. By virtually slicing open reactors, pumps, heat exchangers, or distillation columns, users can see detailed internal structures such as baffles, catalysts, or heat transfer surfaces and better understand complex systems. This helps in grasping how each component contributes to the overall function of the device. The VR environment enables real-time visualization of chemical

and physical processes taking place inside the equipment, such as fluid flow patterns, heat transfer, phase changes, or chemical reactions. For example, learners can observe how reactants mix in a stirred-tank reactor or how vapor rises and condenses in a distillation column. Virtual exploration makes it possible for students and professionals to engage with equipment they might not have access to physically, such as large-scale industrial machinery or specialized lab apparatus.

l. It was proposed to create at least *three to six 3D models on the platform of chemical plant facilities* released for conducting VR courses.

m. Because immersion in realistic environments enables learners to better understand complex chemical engineering concepts and retain information longer, it was also proposed to prepare *several tasks and games in VR courses* which will be useful in educating students in chemical engineering e.g. regarding orientation in space, searching for a given device according to a 2D plan.

n. It was also proposed to place materials on the VR platform regarding *360° virtual tours of industrial installations* related to chemical engineering which the project partners have at their disposal.

o. Additional aspects that should be considered when creating the VR platform are the inclusion of *additional applications related to chemical engineering*, for example those related to molecules, chemical compounds or chemical laboratories, due to the fact that such free applications are available. (Examples: Drug design https://www.ddl.unimi.it/cms/index.php?Software_projects:VEGA_ZZ; Chemical laboratory: https://nova.disfarm.unimi.it/labsim/index_en.htm)

5. VR platform additional aspects

5.1. Best practice of VR content design process

Virtual Reality (VR) has become a powerful tool for creating immersive experiences in various domains, including education, training, therapy, and entertainment. The design of VR content requires a strategic approach to ensure usability, effectiveness, and engagement. ***Below are 12 best practices that guide the VR content design process to achieve high-quality outcomes.***

1. User-centered design (UCD)

Effective VR design begins with a deep understanding of user needs, preferences, and behaviors. An iterative approach, combined with usability testing and continuous feedback, ensures an intuitive and engaging experience. This process involves conducting user research through surveys, interviews, and observational studies to gain insights into how different users interact with VR environments.

Designing with accessibility in mind requires considering diverse user demographics, including individuals with disabilities. Features such as adjustable interface sizes, alternative input methods, and customizable settings enhance ***inclusivity***. Frequent testing with real users helps refine each iteration, improving usability and comfort. Techniques like A/B testing, prototype evaluations, and real-time analytics further optimize user interactions.

Personalization also plays a key role in user engagement. Adaptive learning systems, responsive environments, and AI-driven modifications allow the experience to dynamically adjust to individual behaviors and preferences, creating a more seamless and user-friendly interaction.

2. Immersion and presence

Creating a strong sense of presence in VR is essential for immersion. This is achieved through high-quality graphics, responsive environments, realistic spatial audio, and intuitive interaction methods. Realistic textures, dynamic lighting, and environmental effects enhance immersion, while haptic feedback reinforces the sensation of physical realism. User

interactions should mirror real-world behaviors, allowing for natural object manipulation and movement within the virtual space.

Beyond visual fidelity, carefully crafted world-building plays a crucial role in sustaining presence. Detailed environments, consistent physics, and dynamic elements—such as weather effects and object deformations—contribute to realism. *Lifelike character animations and AI-driven behaviors* further enhance engagement, making the virtual world feel more authentic.

Spatial sound design is another key factor. Accurate 3D audio enables users to perceive distances and directions, reinforcing their sense of presence. Sound should dynamically respond to user movements and environmental changes, creating an auditory experience that feels natural and immersive.

Interaction is equally important. Full-body tracking, realistic hand interactions, and responsive UI elements strengthen the user's connection to the virtual environment. The ability to manipulate objects in an intuitive and physically consistent manner fosters deeper engagement and a greater sense of agency.

Finally, *eliminating immersion-breaking* elements is essential. Avoiding graphical glitches, unrealistic physics, and latency issues ensures a seamless experience. Smooth scene transitions, stable frame rates, and well-integrated feedback mechanisms all help maintain an uninterrupted sense of presence, allowing users to fully engage with the virtual world.

3. Performance optimization

VR applications require high performance to *prevent latency and ensure smooth interactions*. Optimizing assets, reducing polygon counts in 3D models, and implementing Level of Detail techniques help maintain high frame rates. Efficient rendering methods such as foveated rendering, occlusion culling, and optimized shaders contribute to a seamless experience by reducing the computational load on both the CPU and GPU, preventing lag that could disrupt immersion.

Dynamic resolution scaling is a crucial strategy for maintaining stable frame rates by adjusting the rendering resolution based on GPU workload. Foveated rendering further enhances performance by focusing rendering quality on the user's direct line of sight while

reducing detail in peripheral vision, significantly improving efficiency without noticeable visual loss.

Managing assets efficiently plays a key role in maintaining performance. Texture compression reduces memory consumption and loading times, while procedural generation of environments and the use of baked animations lower computational demands. Optimized physics simulations contribute to realism without excessive processing costs. Simplified collision models, precomputed physics data, and inverse kinematics for character animation reduce CPU load, ensuring smooth and responsive interactions.

For multiplayer VR applications, *predictive modeling and interpolation techniques* minimize network latency, creating fluid interactions between users. GPU workload can be further optimized through shader simplification and efficient lighting strategies such as baked lighting, shadow maps, and deferred rendering, all of which reduce real-time computational costs. Occlusion culling improves performance by rendering only visible objects, significantly decreasing draw calls.

Considering hardware variability is essential for accessibility across different devices. Allowing users to adjust graphical settings and providing multiple quality presets optimize performance for lower-end systems while preserving high visual fidelity for advanced hardware. Continuous profiling and performance monitoring throughout development help identify bottlenecks and refine optimization strategies, ensuring a consistently smooth and immersive VR experience.

4. Comfort and motion sickness prevention

Designing for comfort in VR is essential to minimizing motion sickness. Teleportation can be a more comfortable alternative to continuous movement, while limiting acceleration, maintaining a stable horizon, and keeping frame rates above 90 FPS all contribute to a smoother experience. Features such as dynamic field-of-view reduction during movement (tunneling effect) and smooth camera transitions help reduce discomfort. Balancing user control with guided motion further enhances comfort by preventing disorienting or unpredictable movements.

Motion sickness in VR, often referred to as simulator sickness, results from a mismatch between the visual and vestibular systems. To mitigate this, developers should limit rotational and translational acceleration, reducing the disconnect between perceived and actual motion. Providing user-customizable comfort settings is another effective approach, allowing individuals to choose their preferred locomotion method, whether teleportation, joystick movement, or natural walking. Options such as vignetting, which reduces peripheral vision during movement, and snap turning instead of smooth rotation can significantly decrease discomfort.

The design of VR environments also plays a *crucial role in preventing motion sickness*. Wide-open spaces with clear reference points create a sense of stability, while enclosed environments with unpredictable motion may increase *disorientation*. Bright, well-lit environments with high-contrast textures further support spatial orientation, making navigation more comfortable.

Maintaining a *high and stable frame rate is critical*, as fluctuations or dropped frames can disrupt the visual experience and trigger nausea. Optimizing rendering performance minimizes latency and ensures smooth head tracking, reducing the risk of discomfort. Haptic feedback and sound cues can further enhance the sense of movement without relying solely on visual input. Subtle vibrations when a user moves or interacts with objects reinforce immersion while helping to prevent disorientation.

Encouraging periodic breaks and allowing users to gradually extend session lengths can also improve comfort over time. Gentle reminders to rest the eyes and reorient can prevent fatigue, helping users acclimate to virtual environments and enjoy a more comfortable and immersive experience.

5. Effective navigation methods

Different VR applications require *navigation solutions tailored to user needs* and the specific context of the experience. Teleportation, room-scale movement, joystick-based locomotion, and gaze-based interactions should be carefully evaluated to determine the most effective approach for the target audience.

Navigation in VR should prioritize user comfort, ease of use, and natural movement. Teleportation is widely adopted as it minimizes motion sickness by instantly relocating the user to a target position, avoiding the vestibular mismatch associated with continuous movement. It is particularly effective for large virtual environments and enhances accessibility by reducing the need for extensive physical space.

Room-scale movement offers an intuitive and immersive experience by allowing users to walk within a designated area. However, its effectiveness is limited by physical space constraints. ***To ensure safety***, proper boundary visualization systems, such as the Oculus Guardian or SteamVR Chaperone, help prevent collisions with real-world objects.

Joystick-based locomotion is commonly used in VR gaming, providing continuous movement controlled through hand-held controllers. If not implemented correctly, it can ***induce motion sickness***. Smoother acceleration, head-based movement direction, and customizable speed settings can improve usability and reduce discomfort, making the experience more comfortable for a broader range of users.

Gaze-based navigation is particularly useful for hands-free interactions, especially in mobile VR applications. By allowing users to move or interact by focusing on specific points in the environment, it provides a simple and efficient method of control. However, it may lack precision and should be paired with confirmation mechanisms to prevent unintended activations.

A hybrid approach that combines multiple navigation techniques can provide greater flexibility, accommodating diverse user preferences and physical limitations. Allowing users to switch between teleportation and smooth locomotion enhances adaptability, while visual path indicators, such as highlighted movement routes or virtual footsteps, improve orientation in complex environments.

Further refinement can be achieved through motion prediction techniques that adjust navigation based on user intent and behavior. Clear feedback mechanisms, such as auditory cues or haptic signals, reinforce user actions and create a more intuitive experience. Continuous testing with a diverse range of users ensures that navigation systems remain accessible, comfortable, and effective across different VR applications.

6. Interactive and Intuitive Interfaces

Traditional menus do not always translate well into VR, requiring designers to explore spatial interfaces, hand gestures, and gaze interaction for a more natural and seamless experience. Instead of overlaying 2D menus, spatial interfaces integrate UI elements directly into the 3D environment. Wrist-mounted menus, floating panels, and holographic displays allow users to interact without breaking immersion, making navigation feel more intuitive.

Hand gestures provide an organic way to engage with VR content, enabling users to grab, swipe, or point at objects using gesture recognition. To ensure ease of use, gestures should be simple, ergonomic, and consistent throughout the application, minimizing fatigue and reducing the learning curve. Gaze-based interaction offers another effective input method, allowing users to select objects or activate features by looking at them. This hands-free approach is particularly beneficial for accessibility-focused applications. To enhance precision, gaze-based controls should incorporate dwell-time adjustments and visual feedback to confirm user intent.

Voice commands further enhance interaction by enabling hands-free control through natural speech. This method is especially useful for applications requiring complex tasks or situations where traditional input methods are impractical. Adaptive UI systems also improve accessibility by allowing users to customize interface elements such as layout, size, and opacity, ensuring a personalized and comfortable experience.

Providing multiple interaction methods ensures flexibility, allowing users to choose what works best for them. To create a seamless experience, designers should prioritize usability testing to refine responsiveness and prevent unintended activations. Regular feedback loops, error prevention mechanisms, and clear affordances help guide user actions effectively, resulting in a more intuitive and immersive VR interface.

7. Realistic physics and object interactions

To enhance immersion, VR environments should replicate real-world physics, ensuring that objects respond naturally to user interactions such as grabbing, throwing, or colliding with surfaces. Accurate collision detection is essential for realism, requiring the use of physics engines like NVIDIA PhysX, Havok, or Unity's built-in physics system. These tools enable

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objects to behave according to their material properties, whether bouncing, shattering, or rolling upon impact.

Simulating object weight and mass further improves believability. Lightweight objects, such as paper, should be easy to move, while heavier ones, like boulders, should require more effort. Implementing weight mechanics allows users to experience the physical differences between objects, reinforcing immersion. Haptic feedback adds another layer of realism by mimicking texture, resistance, or impact forces. Subtle vibrations in VR controllers can simulate tactile sensations, while advanced systems like force feedback gloves provide an even deeper level of interaction.

Grabbing and throwing mechanics should feel natural, with precise hand tracking enabling intuitive interactions. Physics-based throwing should account for object weight, angle, and velocity, making actions feel responsive. Techniques such as velocity-based motion scaling can help fine-tune these mechanics, ensuring that throwing behaves as expected. While rigid body physics are common in VR, incorporating soft body physics enhances realism for materials like fabrics, liquids, and organic objects. Simulating water ripples, cloth movement, or deformations in soft objects provides a more dynamic and believable experience.

Objects should also respond realistically to their environment. Breaking a window should result in glass shards scattering, while fire should cause wood to burn. These dynamic environmental interactions contribute to a sense of presence and make virtual worlds feel more alive. Physics-driven animation further enhances realism by allowing characters to react dynamically to interactions rather than relying solely on pre-recorded animations. Ragdoll physics, for example, can make character movements appear more organic when they collide with objects.

Since realistic physics can be computationally demanding, *optimization is crucial*. Techniques such as baking physics for static objects, reducing unnecessary calculations, and implementing Level of Detail (LOD) physics ensure a balance between realism and performance. By carefully integrating these physics-based interactions, VR environments become more lifelike, offering users a deeper sense of immersion and engagement.

8. Adaptive content for diverse users

Inclusive design in VR ensures accessibility for users with diverse abilities, allowing for broader usability through customizable settings for comfort, language, interaction styles, and difficulty levels. Providing adjustable motion sensitivity, multiple locomotion methods such as teleportation or smooth movement, and dynamic field-of-view adjustments helps accommodate different levels of experience and sensitivity to motion sickness.

Multilingual and culturally adaptive content enhances accessibility by offering localized text, voiceovers, instructional guides, and culturally relevant elements. Ensuring that content is adapted for different languages and cultural contexts makes VR experiences more inclusive for global users. Customizable interaction and control options further improve accessibility, enabling users to remap buttons, choose hand-tracking preferences, or use adaptive controllers. Alternative input methods, such as gaze-based selection and voice commands, provide additional ways for individuals with physical disabilities to navigate and interact comfortably.

Adaptive difficulty settings and personalized learning paths cater to users with varying skill levels. *AI-driven adaptation* can modify challenges based on user performance, ensuring a balanced experience that remains engaging without becoming frustrating. Visual and audio accessibility features, such as high-contrast modes, subtitles, closed captions, and adjustable audio balance, allow individuals with visual or auditory impairments to fully engage with the experience. Colorblind-friendly palettes and scalable text further enhance readability.

Providing diverse avatar customization options allows users to see themselves represented in virtual environments, fostering a sense of belonging, particularly in social or collaborative VR experiences. Managing cognitive load is also essential, with options to adjust complexity, reduce distractions, and offer guided tutorials to support users with cognitive impairments or learning differences. Presenting information through multiple formats—visual, auditory, and interactive—ensures that VR applications accommodate a variety of learning styles.

AI-driven analytics can enhance personalization by assessing user preferences and behaviors to offer real-time content recommendations. Systems that dynamically adjust difficulty, pacing, or content layout based on individual needs create more engaging and user-

friendly experiences. By integrating these inclusive design principles, VR applications become more accessible, fostering meaningful interactions for a wide range of users.

9. Audio design for spatial awareness

Spatial audio plays a crucial role in enhancing realism and immersion, making virtual environments feel more natural and interactive. Sound should be directional, dynamic, and responsive to user actions, with well-designed 3D soundscapes increasing the sense of presence and aiding navigation.

Binaural audio techniques allow VR experiences to replicate how sound waves interact with the human ear, creating a realistic perception of distance and direction. This enhances immersion by making auditory cues feel as if they originate from their true spatial positions. Environmental audio should also adapt dynamically to user actions and surroundings. Footsteps should change based on surface type, while echoes and reverberation effects should reflect the scale and openness of an environment, reinforcing spatial awareness.

Object interactions should produce realistic sound responses based on material properties and collision intensity. A metal object dropping should create a different auditory response than a wooden one, and real-time audio physics can further refine these interactions. Directional sound cues can also serve as an intuitive navigation tool, guiding users toward specific locations or objectives. Volume adjustments and panning effects help indicate directional changes, reducing the need for visual aids.

HRTF (Head-Related Transfer Function) algorithms simulate how sound is altered by the shape of the head and ears, allowing users to perceive sounds coming from above, below, or behind them with greater accuracy. This enhances spatial awareness and deepens immersion. In complex VR environments with multiple sound sources, adaptive audio mixing techniques help prioritize important cues while managing background noise, preventing sensory overload and ensuring that critical information remains clear.

Voice feedback and interactive sound responses further enrich the user experience. AI-driven voice assistants or dynamic character dialogues that react to user actions add contextual awareness and engagement. Ensuring accessibility for users with hearing

impairments is equally important, with features such as visual sound indicators, customizable volume settings, and subtitle options making VR experiences more inclusive.

By integrating these spatial audio techniques, VR environments become richer and more immersive, reinforcing presence and engagement through realistic and interactive sound design.

10. Engagement through gamification

Applying game design principles such as challenges, rewards, and progression systems enhances motivation and engagement, even in non-gaming VR applications. *Integrating achievement systems encourages users* to pursue goals by earning points, unlocking badges, or completing tasks. In gamified learning environments, structured achievement-based progression fosters skill development while maintaining user interest.

Introducing competition through leaderboards or rankings can further boost motivation, especially in social VR experiences where friendly competition allows users to challenge friends or compare progress with others. A structured progression system that includes leveling up or unlocking new content keeps engagement sustained over time. Adaptive difficulty ensures that tasks remain appropriately challenging, preventing both frustration and boredom.

A strong narrative structure can also transform VR interactions, making them more immersive and purpose driven. Storytelling elements guide users through tasks in a compelling way, often providing a richer experience than traditional instructional approaches. Timed challenges, daily rewards, and seasonal content updates introduce variety, encouraging repeated engagement and keeping the experience fresh.

Balancing extrinsic motivators such as points and rewards with intrinsic motivators like curiosity, mastery, and autonomy creates a sustainable engagement model. Ensuring that gamification enhances rather than forces interaction leads to a more meaningful experience. In social VR environments, virtual economies and collectible systems allow users to earn or trade digital goods, adding an additional layer of incentive through avatar customization or unique virtual items.

Encouraging user-generated content fosters a sense of ownership and investment. Providing tools for modding, custom content creation, or collaborative experiences extends the lifespan of VR applications and deepens engagement. Immediate feedback mechanisms, including congratulatory messages or haptic reinforcement, further enhance motivation by recognizing achievements, no matter how small.

By embedding these gamification strategies, VR applications can increase user motivation, extend session durations, and create more engaging, rewarding experiences.

11. Safety and ethical considerations

VR experiences should be designed with ***ethical considerations to prevent psychological distress, sensory overload, and unintended bias***. Avoiding unnecessary stress or anxiety is essential, as intense visual effects, sudden loud noises, or excessive motion can cause discomfort, particularly for users with anxiety disorders or PTSD. Adjustable comfort settings allow users to modify environmental intensity according to their personal tolerance levels, ensuring a more inclusive and comfortable experience.

Managing sensory input is equally important to prevent overload. Excessive stimuli, such as flashing lights, overwhelming soundscapes, or rapid camera movements, can lead to disorientation and discomfort. Gradual introductions to complex environments and the use of clear focal points help users adapt without feeling overwhelmed. Ensuring that content aligns with ethical standards is particularly crucial in educational, therapeutic, or social VR applications. Age-restricted access, content moderation, and parental controls help protect users from exposure to violent, distressing, or exploitative material.

Prolonged immersion in VR can pose health risks, including eye strain, fatigue, and behavioral addiction. Implementing session time reminders, automatic breaks, and real-time monitoring of usage statistics encourages healthier VR habits and prevents excessive use. Inclusivity in VR design is another critical aspect, requiring careful attention to representation. Avoiding gender, racial, or cultural stereotypes, providing diverse avatars, and supporting multiple language options contribute to a more welcoming and equitable environment.

User privacy and data security must also be prioritized, as many VR applications collect movement tracking, speech recognition, or biometric information. Secure data storage,

transparent privacy policies, and clear user consent mechanisms help protect sensitive information from misuse. In multiplayer environments, ensuring safe social interactions is essential. Tools such as mute and block options, customizable personal boundaries, and real-time moderation create a respectful and harassment-free community.

By addressing these ethical considerations, VR developers can create safer, more inclusive, and responsible experiences that benefit users from diverse backgrounds while fostering trust and engagement.

12. Iterative development and testing

Continuous testing with real users throughout development is essential for refining VR experiences, addressing bugs, and making improvements based on feedback. Agile methodologies support this iterative process, ensuring that user interactions remain intuitive and polished over time. ***Early prototyping*** allows designers to explore core interactions before committing to complex implementations. By starting with low-fidelity prototypes such as paper sketches, wireframes, or simple VR environments, usability issues can be identified and addressed before significant development effort is invested.

Gathering user feedback through usability studies and A/B testing provides valuable insights into how different design variations affect engagement and functionality. Comparing multiple versions of an interface or interaction helps determine the most effective solution while ensuring accessibility for a diverse range of users. ***Automated testing*** plays a crucial role in detecting glitches, inconsistencies, and performance issues. Performance monitoring tools track frame rates, latency, and hardware usage, allowing developers to optimize experiences before release.

Ensuring cross-platform and hardware compatibility is another critical step in the testing process. VR applications should be evaluated across different devices, including standalone headsets, PC-based systems, and mobile platforms. Testing for compatibility across various input methods, processing capabilities, and control schemes enhances accessibility and usability. In multiplayer and social VR applications, network performance must be rigorously assessed. Stress tests with multiple concurrent users help identify synchronization issues, latency problems, and potential server overloads before deployment.

Real-world usability testing provides further insights by observing users in natural environments rather than controlled lab settings. Evaluating interactions in different lighting conditions, movement constraints, or distraction-filled spaces reveals how people engage with VR in diverse contexts, helping fine-tune design decisions. Even after launch, iterative development continues through post-release monitoring and updates. Analytics tracking, user feedback collection, and regular software patches ensure that the experience evolves to meet user needs while maintaining engagement.

By following a structured, iterative development approach, VR designers and developers can create immersive and user-friendly experiences that adapt to real-world use, ultimately leading to a more refined and polished final product.

Conclusion

Designing VR content requires a balance between technical efficiency, user experience, and engagement. By following these best practices, developers can create high-quality, immersive experiences that maximize user satisfaction and effectiveness. Whether for education, training, or entertainment, applying these principles ensures that VR applications are both innovative and functional.

5.2. VR platforms – a technical guide to create, develop and share virtual environments

Immersive educational environments based on VR are a valuable resource for enriching educational experience, promoting playful learning for students, and encouraging their motivation to explore program content, customizing the learning environment, cocreate, and solve problems (Cleto et al, 2023). However, the creation and use of VR environments poses numerous challenges and difficulties for teachers and students.

Before facing challenges of an exclusively technological nature, **teachers still must face the difficulties of requiring knowledge of 3D modeling and animation**, or coding skills that the VR development workflow typically requires (Rodríguez et al.,2021). Furthermore, developing 3D content such as 3D models, material textures, and sound can be a very time-consuming creative and technical activities. Another problem that teachers also face is related to the **lack of standard technology** at the level of immersive VR environments, and therefore, interoperability between the different systems may not be effective and fluid. There are several hardware manufacturers and several web-based technologies, some of which are popular at a given moment, only to disappear the next moment and give way to something entirely new, making the VR ecosystem quite dynamic and unpredictable.

Thus, the main concern that drives this guide is to present the main steps and processes for the creation and use of VR technologies, seeking to focus the reader on solutions, sometimes less sophisticated, but faster, easier, and more economical.

A. HARDWARE

The Quest range, especially the latest version 3, from the company Meta offers the device at a relatively low cost, good performance and good technical characteristics, such as the digital resolution of the screens, the optical quality, and a high focal length. Added to this is the fact that Quest glasses are portable, which translates into an important advantage for a school. The hardware must be quite well thought out. Various models and manufacturers are available with units suitable for each case.

1) Cost Vs Portability Vs Performance

Generally, there is a tradeoff between the performance and cost of the equipment and the performance resulting from its technical characteristics. If we ignore the quality of the software, such as higher resolution graphic processing capacity, perceptual immersion can suffer from this (Resinho et al., 2024). This is a crucial aspect for a good VR user experience, since immersive 3D environments are applications that need to perform a large volume of processing in real time. When three-dimensional scenarios are very complex, and the equipment's processing capacity is not up to the simulation, the framerate drops and in turn can lead to temporal lag. Whenever this last process occurs, the user will feel a movement that does not correspond to that of a similar real situation and the phenomenon known as *scene motion occurs*, which is largely responsible for generating motion sickness in the user.

A good portion of VR equipment with high processing capacity are visualization systems physically connected to high-performance computers, such as the HTC Vive. These can run very complex three-dimensional simulations, such as 3D games, and providing users with very rich experiences. However, the system is not portable, and the tracking system is not very versatile, preventing the equipment from being used in different rooms or different situations.

There are now brands, such as Apple, that offer high-performance VR solutions that are also portable. The technical characteristics of the Apple Vision Pro are currently the highest that we can find on the market, or when compared with other similar products from other brands, such as the Quest Pro or Quest 3, however its price is quite high, reaching a cost 6 times higher than the latter.

2) VR HMD vs XR HMD

We are currently seeing a greater fusion between VR and AR devices. The boundary that separates a purely immersive VR experience is increasingly smaller and applications, benefiting from equipment capable of operating in both modalities, increasingly mix the physical elements of the interaction environment in immersive simulation.

Some high-performance AR devices based on Optical See-through technology, such as Microsoft's now-discontinued Holonlens 2, are giving way to devices with Video See-through

technology, including the Apple Vision or the Metal Quest 3. The latter, unlike the First, have the advantage of allowing the synthesis of shadows or removing parts of the real world in the synthesized field of vision and including in the virtual world, parts of the physical environment, such as tables, ceilings, walls or other everyday objects present in the physical space.

B. Web-based VR Environments

Web Immersive Environment are technologies that provide users with **web-based virtual worlds**. Due to their easy access by the public and flexibility, they have been widely used by schools and teachers in educational contexts in various areas and disciplines. In fact, they are available on numerous digital platforms and devices, and can be accessed by anyone from a simple browser to the late VR HMD.

These platforms are the starting point for teachers and trainers who want to include this type of environment in their educational experience in a simple and quick way, as they do not require advanced 3D development skills or the need to code.

Still, digital platforms like FrameVR or Spatial allow us to include more advanced layers of development if we so wish. It is possible to include 3D models from other sources or 3D modeling software, such as Blender, Maya or 3D Studio max, or code these environments in a more advanced way through APIs.

FrameVR: https://learn.framevr.io/

Creating a simple immersive environment is a very easy process on these platforms, and one can create a fresh one from a provided template and then customize it. These two platforms also allow introduction of simple interactions through a visual interface, based on input events and output actions.

Spatial.io: https://www.spatial.io/

C. 3D Modeling and Animation

3D modeling and animation is an area that requires a lot of time investment in training to acquire the artistic skills and technical knowledge necessary to produce content that integrates immersive 3D environments. In any case, there are several alternatives available, ranging from a more accessible and easy-to-model level to more sophisticated ones. Options such as the Thinkercad platform allow you to simply, quickly, and economically build basic 3D scenes and objects that can be easily integrated into immersive web-based digital platforms. The 3D modeling and animation software Blender is currently the most popular solution in the world of game development and immersive environments, due to the fact that it is an open-source solution and has behind it a supportive community in terms of documentation and tutorials. In Blender, an important community of developers revolves around it, maintaining

the software as a state-of-the-art reference software, with performance that equals or surpasses even other commercial solutions, such as Maya, 3DStudio Max or Cinema 4D.

Other tools, also free and accessible, have offered more specialized solutions in 3D modeling components, such as Workbench, which is particularly useful for developing low-poly 3D models. In turn, alternatives such as the Spline tool allow you to create 3D models directly in the browser and also based on low-poly.
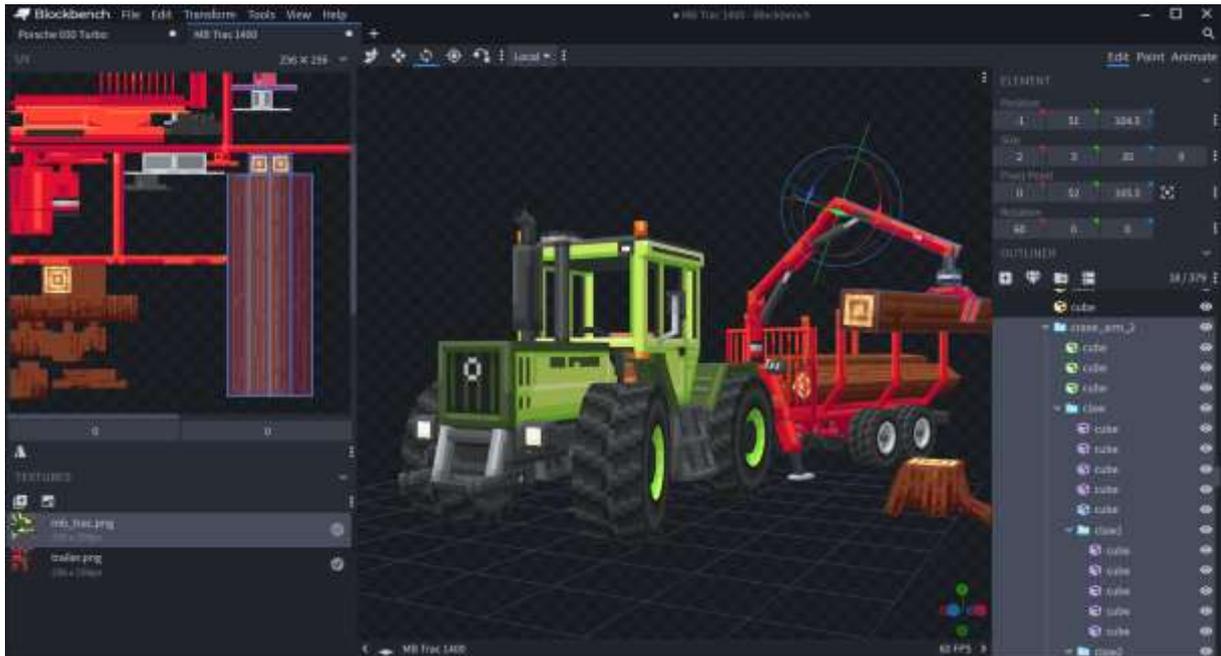
TinkerCad: https://www.tinkercad.com/

Blender: http://blender.org

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WorkBench: https://www.blockbench.net/

Spline: https://spline.design/
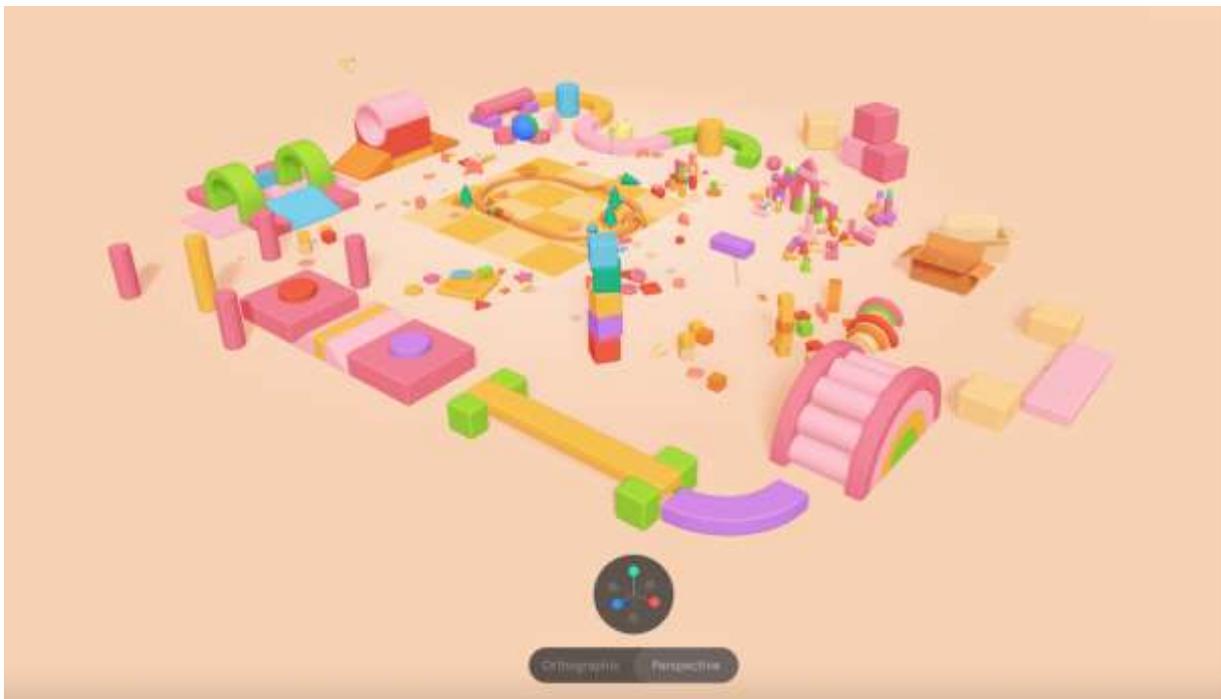

- **Game Engines**

For the development of more sophisticated immersive 3D environments with high-end graphics and high performance, the ideal is to use game engines dedicated to the

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development of this type of application. The most popular game engines currently offer free entry range solutions, namely Unity, Unreal and Godot (the last one is total free and open source). These development platforms provides a rich of diverse technical and support documentation, however advanced programming and Multimedia knowledge or computer graphics are required.

I. Unity3D

Link: https://unity.com/

II. Godot

Link: https://godotengine.org/

III. Unreal

Link: https://www.unrealengine.com

- **Content Repositories**

Alternatively, or at the same time, teachers can also resort to numerous repositories of 3D content and other resources, different media, ready to be integrated into a VR project, from 3D models, interactive assets, animations of humans and avatars and varied sounds.

I. Mixamo

Human Models and animations

Link: https://www.mixamo.com

II. Ready Player Me

Tool to create customized rigger avatars

Link: https://readyplayer.me

III. Skectchfab

3D Models, Materials and 3D Environments

Link: https://sketchfab.com/

IV. Freesound

Repository of music and sound effects

Link: https://freesound.org/

V.   Unity Asset Store

All types of assets ready to be integrated into the unity game engine

Link: https://assetstore.unity.com

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5.3. Introducing immersive and gamified VR experiences into the educational realm: an overview

In recent decades, immersive technologies such as Virtual Reality (VR), Augmented Reality (AR), and other Mixed Reality (MR) systems have been developed and applied across a wide range of fields. The educational sector, in particular, has been extensively explored both in academic research and by practitioners in real-world settings, with a focus on diverse target audiences, varying in age, educational background, cognitive abilities, and learning needs, to understand the potential role of immersive technologies in education. (Beck et al., 2023) (Pellas et al., 2020)

Numerous studies, as cited in this chapter, highlight the *heterogeneity* of approaches and applications within this domain, mainly focusing on VR technology –due to the topic discussed in the overall research project. Shute et al. (2017) reports studies declaring the notion that integrating VR into educational environments enhances *learning experiences*. Hamilton et al. (2021) as well conducted a systematic review on the impact of VR technology on diverse learning outcomes. Their findings highlight the technology's effects on *cognitive, procedural, and affective learning*, with significant positive impacts observed in achieving affective learning goals. It is reported then the higher level of engagement and motivation given by the application of this technology in the educational sector. (Parong & Mayer, 2018)

The review revealed that VR, using fully immersive displays, provided *learning benefits* in approximately half of the cognitive learning studies examined. These benefits were especially notable in addressing highly complex or conceptual problems that required *spatial understanding* and *visualization*. Encouragingly, most studies on procedural tasks reported advantages in utilizing VR, with evidence suggesting that skills acquired in virtual environments could be effectively transferred to real-world scenarios. Although affective behavioral change has been extensively studied in non-educational applications of immersive VR, this area remains underrepresented in educational research. The review underscores the importance of further investigation into the potential of VR for affective learning and behavioral change in educational contexts. Higher levels of *engagement* can be achieved through the educational use of VR, facilitating the attainment of cognitive learning goals more effectively (Concannon et al., 2019). The technology has been confirmed as a powerful

immersive tool for promoting **specific knowledge acquisition** and the development of **practical skills**. (Radianti et al., 2020)

Conrad et al. (2024) conducted a systematic review that examined numerous studies on the topic, focusing on how VR enhances cognitive skills and the benefits it offers when visual and spatial perception are integral to the learning activity. The researchers suggest that VR—delivered through fully immersive displays such as headsets—provides distinct advantages over other media, especially in scenarios where learners adopt a **more active role**. These advantages are attributed to VR's ability to support the development of psychomotor and practical skills within educational contexts. The study specifically emphasizes the importance of **agency** in the context of VR-based learning, referring to the learner's sense of control over the environment and their interaction with the simulation. Agency is identified from literature as a significant factor influencing engagement and the embodiment of immersive experience. (Spallazzo & Ceconello, 2024) This element is commonly observed in **gaming experiences**, including those delivered through Virtual Reality technology. Games provide players with autonomy and the freedom to navigate virtual worlds, test hypotheses, achieve goals, and foster motivation and learning through immersive interactions. (Gee, 2004)

Merchant et al. (2014) categorized VR content into three distinct instructional formats: games, simulations, and virtual worlds. Their analysis revealed that game-based VR experiences yielded the highest learning outcomes. Similarly, a systematic review by Kavanagh et al. (2017) highlighted how the inclusion of gaming elements within educational VR experiences enhances student motivation, engagement, and enjoyment during the learning process. Mitsea et al. (2023) analyzed numerous studies demonstrating how digital games enhance motivation by satisfying basic psychological needs, such as providing rewards and continuous reinforcement. This increased motivation allows gamers to experience positive emotions during the activity, fostering a sense of growth and autonomy. Games also promote the development of competence, self-efficacy, and social connections, while encouraging learners to take responsibility during gaming experiences. The review highlights that gaming in VR amplifies feelings of surprise and positive emotions, such as happiness and a state of flow. Furthermore, it underscores the role of VR gaming in facilitating the development of essential metacognitive skills, including meta-memory abilities. These games, delivered through advanced technology, demonstrate increased engagement and learning effectiveness

not only within traditional educational classrooms but also in other domains, such as cultural learning experiences. (Da Costa & Kinsell, 2023) Summarizing, numerous studies highlight the benefits of gaming experiences delivered through virtual reality technology. These experiences foster an active learning approach and are designed to promote deeper and more effective learning of competencies essential for success in today's complex, interconnected world.

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5.4. *360° virtual tours of industrial installations*

It is well-known that presential visits to industrial facilities are of great importance for undergraduate chemical engineering students. ***Industrial visits*** offer students the opportunity to witness firsthand the application of theoretical concepts learned in classrooms to real-world industrial processes. Students get to observe the challenges faced by chemical engineers in industries, such as process optimization, safety regulations, environmental concerns, and economic constraints. Besides, industrial visits allow students to familiarize themselves with various types of equipment, machinery, and control systems used in chemical industries. Finally, these first exposures to real-world applications and interaction with professionals can motivate students and help them develop a clearer understanding of their career.

For those reasons, most universities include some visits to industry in any of the academic years of the chemical engineering degree. However, the number of visits that is possible to carry out with a big group of students is normally very limited. In some cases, the movement of groups of students to industries to carry out in-person visits can be very complicated due to the lack of funding, the time required and other factors (security issues, malfunctioning of the equipment, or limited space to accommodate groups of students). On the other hand, presential visits to industry ***may have other type of limitations***: limited time for the tour, restricted areas, excess of noise in process units, difficulties to gather all students for proper explanations, unforeseen events that do not allow access to some zones, etc. 360° virtual tours can be ***a powerful complement***, allowing students to develop enhanced learning and providing a greater number of "immersions" in the industry. These virtual visits can provide information and experiences that are not possible to achieve in real visits, such as ***showing equipment in operation***, ***areas with restricted access*** or ***visualizing a drone view*** of a plant's facilities. Combining the potential of 360 cameras with drone capabilities can result in a powerful combination to improve VR experiences for users, as drones can be used in case of isolated or remoted places, confined atmospheres, dangerous places, or simply to obtain a global view from above of an industrial facility.

In VR technology, 360° video-based VR consists of the 360° viewing of footage produced by special cameras that capture live images, making it possible to take virtual tours

of a multitude of environments, including industrial installations. Due to the limitations associated with real visits to industrial facilities, virtual visits are ***becoming a complement*** or ***even alternative in teaching and learning***.

In a complementary way, 360° virtual tour can also be used as a didactic resource before or after real tour, deepening the student's pedagogical experience. In this way, virtual tours activities can be a powerful complement in those subjects where visits are not scheduled, but it can also be very valuable in those subjects where real visits are scheduled, both allowing students to develop enhanced learning and providing a greater number of "immersions" in industries from different sectors. Therefore, the combination both of types of tours, real and virtual, can be a powerful tool in the improvement of teaching practices (Seifan et al., 2018; Díaz et al., 2022).

Specifically, in a pedagogical context, the use of 360° video VR has a number of ***pedagogical benefits*** from teachers and students perspective. 360° media are simply 360 panoramic images/videos, which can be viewed and navigated via a specialized viewer app or online platforms such as YouTube© that support 360° video viewing. Therefore, VR allows students to move to virtual environments and view 360° video VR, which would hardly be shown with traditional teaching resources. Further, as a consequence of the novelty and excitement that arises, it may, thereby, generate higher student engagement and focus (Robinson et al., 2009; Falconer et al., 2016). In addition, mastering these tools in any of the curricular areas of the degrees would facilitate the design of spectacular activities by incorporating, or linking, these interactive materials on the same support materials already used in classes. In addition, globally the virtual tours are very affordable in terms of staff time and production costs.

The use of 360° virtual tours in the sciences is becoming a very affordable tool to show and enhance the student experience by reducing the uncertainty around the laboratory and enabling students to learn about large-scale equipment commonly found in Chemical Engineering industry. Additionally, 360° videos present technical recording benefits compared to conventional recording. Usually, with the 360° camera, one typically does not need to worry if a part of the demonstration is out of the ***scope of view*** in the camera frame as the 360° panoramic field of view is able to capture laboratory procedures without continually moving

the camera around. Moreover, the use of 360° cameras would be advantageous because it is independent of an additional camera operator and can be performed solely by the lab instructor (Ardisara et al., 2018).

On the other hand, it is important to properly design and **build the VR experience** for industrial visits. Thus, the Best Practices to develop 360° Virtual Tours of Industrial Installations start with a work of planning and design. Before embarking on the creation of a 360° virtual tour, professors must clearly define the learning objectives and what specific knowledge or skills we want students to gain from the experience. This must guide the entire process, from selecting the appropriate industrial installation to designing interactive elements within the tour. **The choice of the right industrial installation is critical.** It should align with the curriculum and offer a representative view of the industry or process being studied. It is also important to plan the route of the virtual tour carefully, identifying key points of interest and potential learning opportunities. It is highly advisable to create a **storyboard** to outline the sequence of scenes, interactive elements, and multimedia content. It is also important to **add narration** or **background audio** to provide context and guide students through the tour, and to enhance the virtual tour with interactive elements such as information Hotspots (to provide text descriptions, images, or videos when students click on specific objects or areas), quizzes (to test students' understanding of the material) or to include 3D models or simulations to illustrate complex processes or equipment.

The drawbacks of 360° videos experienced by students with this type of resources could eventually include some kind of motion sickness, induced by the shaky or/and quick image movements produced when viewing and navigating around the videos. Fortunately, this **discomfort can be reduced** by mounting the 360° camera at a fixed position or would be resolved by holding the mobile device with both hands and placing the device on a flat surface during viewing (Kavanagh et al., 2016). Another potential problem is the **loss of focus in 360° videos**, that is, the difficulty in finding the right angle of the video at the right time. Improving on this loss of focus is challenging and requires further work. Some studies have reported a remedy by creating a **time delay** to provide buffer time for the viewer to reorientate themselves at pivotal time points in the video, e.g., when a demonstrator is conducting a critical step in an experimental procedure. From the perspective of academics, the creation of these VR resources requires time and effort, especially in terms of filming and editing with

advanced software. This fact may be highlighted by those who have not been previously exposed to the VR environment and technology, which can make it difficult to apply these virtual resources in classroom methodologies.

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6. Links/materials that can be used

In collaboration with the consortium project partners, links/materials that can be used during the implementation of the platform are listed below:

No.	Link
1	https://www.sciencedirect.com/science/article/pii/S1093326323002048
2	https://vimeo.com/456311091?from=outro-local
3	https://www.sciencedirect.com/science/article/pii/S1749772821000324
4	https://www.sciencedirect.com/science/article/pii/S1749772821000142
5	https://charming-etn.eu/2021/03/21/soapp-making/
6	https://www.sciencedirect.com/science/article/pii/S2666188824001734
7	https://www.meta.com/pl-pl/experiences/the-vr-chemistry-lab/3919613214752680/
8	https://www.meta.com/pl-pl/experiences/nanome/2038368596280231/
9	https://www.meta.com/pl-pl/experiences/mimbus-chemistry/25650020844613280/
10	https://www.meta.com/pl-pl/experiences/surrey-vr-chemical-plant/5841022942613827/
11	https://acris.aalto.fi/ws/portalfiles/portal/76292373/VRChem_A_Virtual_Reality_Molecular_Builder_11_10767.pdf
12	https://www.x-visual.com/en/visio-3d/
13	https://isci.itch.io/nsb-imd
14	https://github.com/XRChem/VRChem
15	https://www.meta.com/pl-pl/experiences/reactour/6028153617252478/
16	https://www.cetjournal.it/cet/21/86/228.pdf
17	https://air.unimi.it/retrieve/dfa8b9a2-7772-748b-e053-3a05fe0a3a96/Eye4edu%20paper%20final%20Comp%20Chem%20Eng_REVISED_white.pdf
18	https://www.ddl.unimi.it/cms/index.php?Software_projects:VEGA_ZZ
19	https://nova.disfarm.unimi.it/labsim/index_en.htm
20	https://www.youtube.com/watch?v=o4PF9ujN3bE
21	https://www.aveva.com/en/solutions/digital-transformation/xr/
22	https://www.tscsimulation.com/products/interactive-virtual-plant/
23	https://www.turbosquid.com/Search/3D-Models/petrochemical
24	https://www.artstation.com/marketplace/p/pBllG/chemical-plant-factory-oil-refinery-modular-kitbash-265-3d-models-textured-realistic-blend-gltf-format
25	https://www.flowserve.com/en/resources/tools/virtual-plant/
26	https://www.labster.com/simulations/organic-chemistry-reactivity-rules
27	https://pubs-acs-org.bibliouca.idm.oclc.org/doi/10.1021/acs.jchemed.0c00622
28	https://doi.org/10.1016/j.ece.2018.11.005

29	https://doi.org/10.1016/j.ece.2009.02.001
30	https://doi.org/10.1016/j.ece.2021.05.002
31	https://doi.org/10.1016/j.ece.2008.04.001
32	https://doi.org/10.1016/j.ece.2020.07.006
33	https://doi.org/10.1016/j.ece.2020.11.009
34	http://dx.doi.org/10.1021/acs.jchemed.8b00728
35	https://www.youtube.com/watch?v=sxvJatvqBVE