CHARMING
EU MSCA-ETN

Policy Brief

Immersive tools for teaching and training in a science and technology environment

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Introduction. There is little doubt that recent improvements in digital technology can positively impact learning and teaching, especially in the domain of science and technology. For instance, immersive technologies such as Augmented Reality (AR) and Virtual Reality (VR) can be employed to interactively visualize certain structures (e.g., viruses) or processes (e.g., the birth of a star) that would otherwise not be observable for students. They can also play a role in training operators in industry for emergencies that otherwise would be difficult or expensive to safely simulate in reality. However, the projected effects still need to be carefully evaluated in context.

Assessing the effects of these immersive learning technologies requires multiple strands of investigation, such as exploring new display techniques, interaction modalities (e.g., AR, VR) and ways to approach or use digital artifacts (e.g., simulation, tools, play, games). This can be done by building on existing theory from, for instance, educational research, such as levels of fidelity, motivation, engagement and self-regulation. There are also open and challenging questions such as the alignment of learning goals with more (interactive) learning activities.

Researching and designing effective immersive learning environments is complex as it requires technical, educational, design and content expertise. To this end, projects focusing on this field of research should be composed of researchers from multiple disciplines. The authors of this policy brief are partners in the MSCA-ITN CHARMING project (www.charming-etn.eu) which studies immersive learning for chemistry and chemical engineering learning. The consortium consists of researchers from computer science, educational science, games development, human-computer interaction, chemistry and chemical engineering. In this policy brief they share their insights in opportunities and challenges for immersive learning of, in particular, chemistry and chemical technology.

European Commission

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Immersive technologies and learning environments

Immersive technologies give their users the subjective impression that they are participating in a realistic experience. These experiences, when learning is their target, are known as immersive learning environments. There are different types of immersive learning environments and they can leverage different types of immersive technologies. These technologies differ depending on how the user interacts with the experience. AR technologies overlay digital elements on top of the real-world. For example, virtual science experiments composed of digital beakers and test tubes can be displayed on a touch screen, overlaid on real world objects being captured by the device's camera. Users can then interact with virtual experiments using the touch screen. VR on the other hand completely immerses the users in a virtual world with no parts of the real world visible. By putting on a VR headset, a learner can find themselves immersed in a virtual chemical plant while standing in their own living room. Users can interact with this virtual world using their hands, which are tracked by a camera positioned on the VR headset or with controllers which have buttons, touch pads, joysticks and other physical interactive elements. As technology advances, the lines between AR and VR become more blurry, with mixed realty (MR) headsets offering a combination of AR and VR features.

Immersive learning environments for children

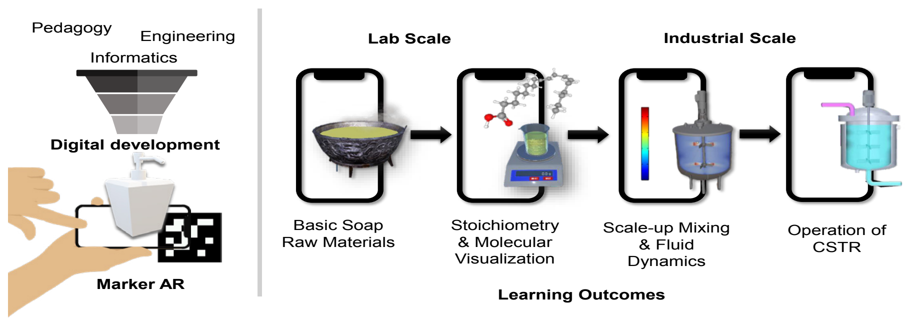
There is significant value in exploring the potential of immersive learning environments from the angle of interest development for primary school students. Immersive technology has the potential to help younger students engage intuitively with abstract concepts with the aim of making learning more fun. These experiences can be tailored to the age and ability of individual students or groups and they can be designed to ensure broad curriculum coverage. If necessary, they can also include elements of gamification. The games and playful experiences can increase the interest in chemistry content and chemistry or chemical engineering as a potential career path.

The immersive digital fume hood

The CHARMING project is developing a VR chemistry fume hood to provide elementary school children an environment where they can safely experience and individually perform chemistry experiments within a classroom. Here, the researchers are not only focusing on bringing immersive chemistry experiences to children in a safe manner, but also trying to reduce the burden that a high-end virtual system may bring to the teachers when using this in a classroom environment. The fume hood consists of a box with a VR headset mounted inside to provide an interface between the physical outside and the virtual inside. Additionally, a hole is provided to allow for manual interactions in the virtual environment. Finally, by approaching this project from a game designer's point of view, the researchers aim to find directly implementable guidelines for the game designers and developers, to help them create an optimal chemistry VR experience for children.

Immersive learning environments for young adults

The potential of immersive learning environments can also be explored for high schools and universities. Immersive learning environments can help students understand and visualize more easily abstract concepts which are often difficult to grasp, such as fluid dynamics, gas-liquid equilibria or molecular interactions. The normal strategy for teaching these concepts is to show pictures, videos, textbook descriptions, and in some cases computer simulations alongside lecturing. Immersive learning environments can present these concepts in three dimensions and enable the learner to interact with them in novel ways. Immersive technologies can enhance learning experiences, not only by making the concepts easier to understand but also increasing students' motivation to learn and potentially improve academic performance. Fundamental research is needed to explore the best way to design such experiences and how they can be used alongside and in some cases replace current strategies. Immersive learning environments can also help in tackling structural problems faced by institutions providing chemistry and chemical engineering education. Nowadays, chemistry and chemical engineering is a popular educational field, and the students need to have and expect practical laboratory sessions. However, universities are struggling to accommodate and guide new students in their existing laboratories with the existing staff, and the cost of building new labs and attracting new staff is often prohibitive. This means that the amount of time university stu-



The AR soap application

In the CHARMING project, an AR prototype is developed to teach chemical engineering concepts using a liquid-soap synthesis process, as inspired by the fact that the use of soap is crucial in the COVID-19 pandemic. The learning environment aims to guide students to perform different tasks involved in the process of soap production, from lab to industrial scale. Handbook solutions, molecular structures, computational fluid dynamics simulations and process simulators are utilized in multiple scenes to illustrate an inclusive case study on complex chemical processes. The learning tasks are designed to support inquiry-based learning activities: hypothesize, explore, validate, discuss and explain scientific ideas. It provides further evidence that engineering simulations with AR technology may facilitate versatile and sustainable educational tools to operate active learning environments.

Want to know more about this prototype?

Read the full paper here:
https://doi.org/10.1016/j.ece.2021.01.007.
Green access: https://papers.sim2.be/assets/uploads/files/05a94-digitalization_post.pdf

The AR prototype is freely available for Android devices on Google Play at:
https://play.google.com/store/apps/details?id=com.Charming.SoAppMaking

dents spend in laboratories is reducing. Furthermore, a lot of universities are already struggling with a lack of space, which means that even if additional funding was allocated to a university for new laboratories, there is often just no room for expansion. Immersive technologies can help solve this problem as they enable us to build either VR or AR virtual labs, in which students can handle chemicals and perform procedures and experiments. These virtual labs do not necessarily replace the physical learning environment, however, they do go a long way in solving the problem of diminishing lab times of undergraduate chemistry and chemical engineering students.

Related to this point, another challenge faced by universities which wish to offer top class chemistry and chemical education programs is that they cannot easily offer students access to process equipment representative of what is used in industry (e.g., heat exchangers, pumps, etc.) or pilot plants that can facilitate the understanding of key chemical processes. This type of practical knowledge is extremely relevant for students and the industry they will soon be working in. Thanks to immersive technologies, it is now possible to build entirely virtual and interactive chemical plants which can allow students to experience, first hand, how processes work in a space no larger than a small classroom.

Immersive learning environments for professional training

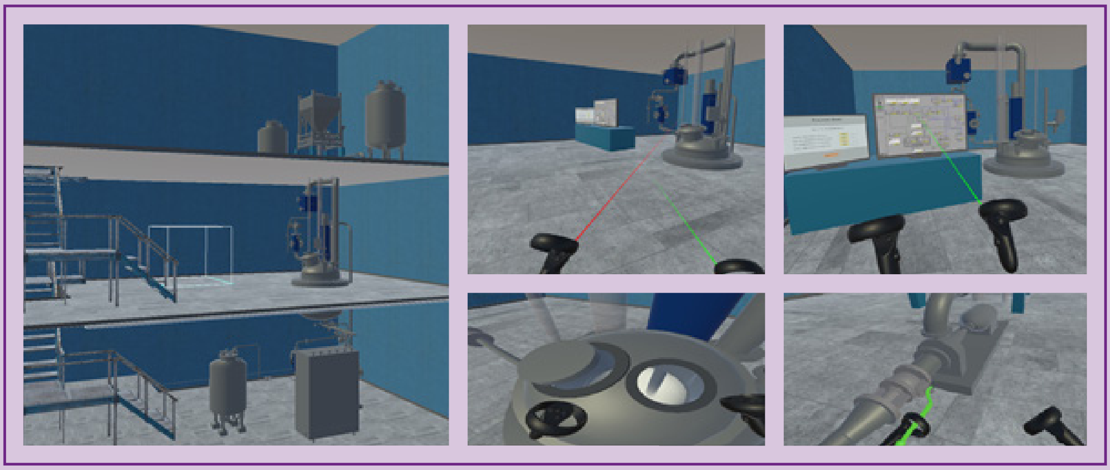
The potential of immersive learning environments for professional training can be explored in the chemical industry for those operations which are normally too hazardous or costly to train in reality. Training is one of the most effective ways to reduce mistakes and accidents. Therefore, it is crucial that effective training is ensured and that learners are motivated to learn. However, currently, training in the chemical industry is facing significant challenges, such as high costs, safety limitations and time constraints. Also, employees may lack engagement and motivation during mandatory training, due to the high amounts of information they need to learn which can result in long and tedious training sessions. Currently, these sessions often take place in traditional classroom settings or through e-learning environments, far away from the context in which the new knowledge and skills being learned can be applied. It should be noted that there are chemical companies that have well established and effective training processes, from the use of pilot plants and simulations, to strong mentorship programs, but even there immersive learning can form an additional asset.

The advantage of immersive technologies for professional training is not limited to increasing engagement and motivation among employees. They also enable employees to safely practice tasks which would normally be too dangerous, too expensive or even impossible to recreate in real life. For example, trainees could learn and practice emergency situations involving chemical spills, fires, reactor explosions or any other imaginable event. In these simulated situations, the employee is immersed in the experience, which in turn stimulates stress and anxiety relatable to the real event. Furthermore, immersive learning environments in part solve the problem of limited training capacity as also described in the section related to higher education.

Research in immersive learning

When looking to evaluate an immersive learning environment design, researchers can conduct usability testing (e.g., how users experience this environment). In addition, to evaluate the effectiveness of immersive learning, they can focus on two types of comparison research: 1) media comparison, which compares learning with vs. without immersive technology, and 2) value-added comparison, which compares learning with vs. without a specific design feature. Furthermore, immersive learning researchers typically compare three types of outcomes, namely learning (or training transfer), motivation and emotion.

Research on media comparison is popular. For instance, previous meta-analyses generally agree that compared with non-VR or non-AR, VR and AR lead to better learning in schools and higher education but disagreed whether it leads to better workplace training. By contrast, research on value-added research is sparse and only a limited number of design features have been investigated. For example, adding feedback to VR and AR experiences may enhance learning and adding narrative may enhance motivation. Furthermore, research in motivation and emotions is also sparse. Media comparison research comes with challenges. For example, conceptually, research may confound media (e.g., immersive technology) with methods (i.e., instructional methods) (Clark-Kozma “media-effects” debate) because it is hard to attribute learning effects to immersive technology or instructional methods alone. Although media do have different affordances which may lend themselves to particular educational strategies, it is argued that media (e.g., immersive technologies) can be better thought of as mere vehicles for delivering instruction. Just as a vehicle being used to deliver pizza has no impact on the nutritional value of the meal, technology used to deliver instruction does not influence achievement. Therefore, it is unnecessary to separate methods from media because together they cause



Operate your own reactor

The CHARMING project is developing a VR prototype for the training of operators in the chemical industry. The virtual chemical production takes place in a universal batch reactor, which is common in the chemical industry. This makes the acquired skills of the training easier to transfer between companies. The virtual reactor has been designed using information from real models provided by industrial partners in the CHARMING project (Merck and Arkema) to represent the same situation that a chemical operator would experience in a real plant.

The learning objectives of the prototype is focused on how to operate a chemical reactor, follow safety procedures and how to respond to emergencies. With this prototype the chemical operator can interact with the plant from the safety of their office or home, and repeat the procedure as many times they want.

The development of a VR training environment for the operation of a chemical reactor requires more than just the learning content and technological design. Other design elements are implemented in the training that supports both the trainee’s needs and the needs of the organisation, such as game-based learning elements, learning analytics and assessment methods.

Want to know more about this prototype?

Read the full paper here:

https://doi.org/10.1016/j.ece.2021.01.014

Green access: https://papers.sim2.be/assets/uploads/files/2f4bf-manuscript_towards-design-guidelines-for-virtual-reality-training-for-the-chemical-industry_postprint-version.pdf learning. To this end, perhaps a better question to ask when researching immersive learning environments is, How do we optimise immersive learning environments for a particular task or group of students? We can use value added comparison research to help answer this question which supports the idea that effective immersive learning environment design integrates immersive technology design with instructional design.

Learning Analytics

An advantage of immersive learning environments is that they enable the automatic measurement, collection, analysis and reporting of user activity data with the goal of optimising learning. This process, called learning analytics, not only benefits learners, but also teachers, trainers and those charged with making broader decisions around education and training within an organisation, be that a school or a company.

For example, imagine for a moment the arrival of a global pandemic and the subsequent need for the creation, production, distribution and administration of a new vaccine and all the essential steps in between. This would impact the chemical process industry, which would play a vital role in scaling up the vaccines production.

An immersive learning environment can be designed which quickly trains staff on new production procedures and safety protocols required to make the vaccine. By incorporating learning analytics into the design of this immersive learning environment, employees are able to receive immediate feedback from a virtual agent and do not have to rely entirely on their supervisors for support. Meanwhile, the trainers themselves can be provided with a learning analytics dashboard which displays an overview of all the employees and their progress on the training. They can use these learning analytics data to make informed decisions about who to offer additional individual support and who can continue training independently. From a company-wide perspective, learning analytics can also provide insight into training dynamics such as the average amount of time an employee takes to learn all new procedures related to the vaccine's production and allocate resources accordingly.Although learning analytics has enormous potential, there is still a lot of research to be done. For example, the best way to design feedback derived from learning analytics for immersive learning environments remains an open question. The majority of learning analytics research has been performed in the context of higher education and with e-learning platforms. How this research translates to immersive learning environments for schools and workplaces is not clear.

Another key challenge is to ensure that the data being collected and analysed is accurate and useful. The application of learning analytics systems is limited to the quality of the data being processed. Therefore, developing robust methods of assessment and data collection is vital. Furthermore, knowing what data is useful and what can be ignored depends on the questions key stakeholders want answered.

There are challenges surrounding ethics and data privacy. There is huge potential to use biometric data as an input for learning analytics. However, there are considerable ethical concerns. Recent research has shown that user behaviour within certain immersive learning environments is as identifiable as an individuals' fingerprint. It is uncertain what steps need to be taken to ensure that these data are protected from misuse while also taking advantage of all they have to offer to optimise learning.

Summary

Immersive technologies such as AR and VR can positively impact learning and teaching. This policy brief reviewed advantages and challenges of these new technologies for application in schools, higher education and industry, with a special focus on chemistry and chemical engineering learning. To further enhance the beneficial application of immersive tools, we recommend to:

- Complement single-focus research with holistic approaches that includes technical, educational, design and content expertise.

- First conduct value-added comparisons to create well-designed immersive learning environments and then if needed, media comparisons with robust experimental design.

- Benefit from the potential of including learning analytics in the learning environment.

Key project information:
Project type: EU H2020 MS-CA-ETN
Project duration: 4 years (2018-11-01 to 2022-10-31)
Website: http://charming-etn.eu
EU contribution: M€4.06
Coordination: KU Leuven

The chemical industry in Europe faces stiff competition as it fights to strengthen its position in the global marketplace. Europe's greatest asset is its human capital, but the people working in such a technology-based environment, with the rise of the "smart factories" of Industry 4.0, need to be very well qualified. The situation of yesteryear, where a person could be trained to carry out a job for the whole of their career has long since gone; now the situation is one of developing skills and competencies, but then being able to adapt, re-learn and be able to cross sectors and disciplines in a world of work that is dynamic and subject to constant change. Continuous professional development, the stimulation of creative thinking and the motivation of youngsters for science & technology are high on the EU's agenda. Recent developments in immersive learning technologies are providing exciting new tools for teaching and training programmes, yet they remain underutilised in science & technology education, and nowhere is this truer than in the field of chemistry and chemical engineering. CHARMING, the European Training Network for Chemical Engineering Immersive Learning, takes on this challenge by developing learning strategies, content and prototypes for the application of games and virtual/augmented reality for motivating, teaching and training children, students and employees in chemistry, chemical engineering and chemical operations. The inter-sectorial and interdisciplinary CHARMING ETN consists of leading universities and industry participants and trains 15 ESRs in the areas of innovative chemical engineering, instructional psychology & pedagogy and immersive technology. CHARMING's success will be based on integrating the chemical engineering, the instructional psychology & pedagogy and the immersive technology, in order to provide Europe with its highly trained young experts who are ready for exciting careers in the European chemical industry and beyond.

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