IMMERSIVE DIGITAL TWINS OF AN INDUSTRIAL FORGE ENGINEERING EDUCATION

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ABSTRACT

The rapid and relentless pace of technological advancement over recent years has had a profound impact on the realm of education. This dynamic transformation has paved the way for a host of new possibilities and innovations that are reshaping the educational landscape. One of the most noteworthy developments within this technological revolution is the advent of virtual and augmented realities. These immersive technologies have become pivotal in shaping the evolution of educational tools and systems across universities worldwide. For examples of this phenomenon, one can refer to recent works such as Sandyk et al. (2023) and Kontio et al. (2023). The "JENII project" is an example of initiative in the sphere of immersive education, which is being spearheaded by the Arts et Metiers Institute of Technology. This project is set on a course to revolutionize engineering education by designing a suite of immersive and interactive digital twins. While Engineering Learning Workplaces are not physically present, the immersion enabled by the technology, when coupled with a machine's digital twin, closely replicates the genuine interaction an engineering student would encounter in an industrial environment. Thus, within the framework of the Conceive-Design-Implement-Operate (CDIO) approach, these immersive digital twins are envisioned as virtual counterparts to the workplaces described in Standard 6. However, immersive digital twins are not static; instead, they offer the prospect of continuous optimization to provide engineering students with a dynamic learning experience. A important attribute of these digital twins is their potential to catalyze Active Learning, a fundamental component of CDIO (Standard 8). They offer students unfettered access to a set of realistic exercises, during both classroom sessions and independent study. These exercises are meticulously designed to simulate actions that students would undertake on actual machines, fostering a hands-on learning environment. What sets these digital twins apart is their ability to allow students to repeat exercises as many times as needed, replicating real-world scenarios. This affords a unique opportunity for students to refine their skills and gain mastery over complex engineering tasks.

KEYWORD: Digital Twins, Virtual Reality, Engineering Education, Cognitive Psychology, Immersive Learning, CDIO Standards: 6, 8.

INTRODUCTION

In the era of Industry 4.0, Engineering Education faces the ongoing challenge of integrating emerging technological trends used in the industry into its curricula (Coşkun et al., 2019; Neaga, 2019). This challenge underlies the growing interest in Engineering Education Research (EER), which focuses on understanding how to effectively introduce digitalization concepts to future engineers. The question about digitalization not only involves learning about the transformation of the industry but also how to implement these digital tools in engineering practice (Evtushenko et al., 2023). In this evolving landscape, CDIO-based education and project-based learning have emerged as natural methodologies to achieve these goals, demonstrating a solid alignment with the anticipated challenges and technological trends in engineering (Goncharov et al., 2019; Säisä et al., 2017). However, the CDIO standards underwent significant adjustments in their 3.0 iteration to keep pace with the evolving industry demands. A notable change is the evolution of Standard 6, which previously focused solely on physical workplaces, to include digital workplaces (Malmqvist et al., 2019).

At the heart of these digitalized learning environments lie immersive technologies, which have become central in shaping the evolution of educational tools and systems across universities worldwide. For instance of this phenomenon, one can refer to recent works such as Sandyk et al. (2023) and Kontio et al. (2023). A notable example is the "JENII project" at the Arts et Metiers Institute of Technology, which aims to revolutionize engineering education by developing immersive and interactive digital twins. This project leverages active and immersive learning via simulations, enabling learners to acquire not only disciplinary knowledge but also personal and interpersonal skills and competencies in product, process, system, and service building within a virtually replicated environment. This project illustrates the shift from physical engineering learning workplaces to immersive, technology-enabled environments ensuring realistic interactions that an engineering student would typically encounter in an industrial setting. Within the CDIO framework, these digital twins act as virtual analogues to the physical workplaces, as outlined in Standard 6, and are designed for continuous optimization to enrich the learning experience.

In this paper, we delve into a brief yet comprehensive overview of cognitive psychology as it relates to the process of learning, examining how the integration of immersive technologies can further enhance the learning experience. Furthermore, we provide insights into the ongoing development of an immersive digital twin designed for an industrial forge, offering a practical demonstration of how these technologies can be implemented in a specific context. Finally, we explore the myriad educational applications of these immersive tools, detailing how they can be seamlessly integrated into the curriculum to facilitate effective learning. Additionally, we discuss potential innovative features and enhancements that hold the promise of revolutionizing the educational landscape even further, ensuring that students are equipped with the skills and knowledge they need to thrive in our rapidly evolving technological world.

A remarkable attribute of the digital twins is their potential to catalyze active learning, a fundamental component of CDIO (Standard 8). They provide students comprehensive access to realistic exercises applicable in the classroom and independent study contexts. These exercises are meticulously designed to simulate actions that students would undertake on actual machines, fostering a hands-on learning environment. The unique capability of these digital twins to facilitate repeated practice of these exercises mirrors real-world scenarios, offering students unparalleled opportunities to refine their skills and master complex engineering tasks.

In the following sections of this article, we outline the benefits and limits of immersive and interactive digital twins, as well as their implications for individual study and their potential in terms of additional pedagogical features. To illustrate each of these points, we will provide examples based on an existing digital twin that we are developing, simulating an industrial forge (see Figure 1).

Figure 1. Screenshot of the Industrial Forge Digital Twin

PEDAGOGICAL, ORGANIZATIONAL & MATERIAL BENEFITS

Since some studies show positive effects of Virtual Reality (VR) on learning and others show negative or neutral effects, it is necessary to understand what differentiates them in order to identify the situations in which this type of medium is relevant. Immersive technologies appear to have potential whenever training requires users to feel a sense of social presence, i.e. the feeling of “being there” with a “real” person (Oh, Bailenson and Welch, 2018). This feeling is supported by stereoscopic 3D, immersion and consistent representation of the people we are with. In this case, individuals' emotional responses are analog to those measured in real-life situations. VR also has the capacity to generate a feeling of physical presence. A visually realistic environment is an effective way to provide a believable virtual experience. This means that VR can also familiarize the learners to a specific working place.

Through headset and gamepad position tracking, and through other parts of the body when adequate devices are used, VR is a medium that can lead users to adopt postures that are more or less equivalent to those they would adopt when carrying out a similar activity in a real situation. It is therefore particularly suitable for learning technical gestures or procedures. Immersive technologies can therefore be a way to make some learning more attractive. Finally, many studies show that course sequences based on immersive technologies often improve course attractiveness and learner satisfaction. For example, a VR anatomy course by Stepan et al. (2017) does not make any difference to the traditional course regarding anatomy knowledge, but it is considered more engaging, enjoyable, useful and motivating for students.

In some cases, making courses attractive is important for trainer satisfaction, students engagement and institutional image.

VR is often used to learn safety behaviors. Obviously, carrying out this learning with a digital simulator rather than in a real situation allows learners to test several configurations in a trial-and-error approach and to go as far as the accident without taking any risks for themselves or for the machines. Some educational scenarios can be developed specifically in this way, although it is not imaginable in a real situation. VR makes it possible to experience the accident more realistically than a non-immersive device (Fleury et al., 2023).

Investing in technological platforms at industrial scale for educational institutes can quickly turn out to be very expensive. One solution to reduce these costs is pooling between several campuses or educational institutes, or even with research laboratories. But other problems with student travel or management of shared resource planning may arise. Having a VR replication allows to have a lower-cost installation, accessible at any time and remotely. Even if digital technology cannot replace the physical environment in the concrete manufacturing of mechanical parts, preliminary tests to experiment some configurations in order to validate feasibility are also a source of budgetary savings. In forging, for example, when it comes to comparing and understanding the rheological behavior of different materials, it is possible to consider real shaping on a common material, like steel, whereas the same experiment for a more expensive material, like copper, could be carried out in the digital twin.

VR makes it easier to access certain work situations for people with disabilities. Even if, in certain cases, real workstations are not able to be adapted for security reasons, understanding an operational workstation allows them to better understand upstream work in a design department or in a process department, for example. Therefore, digital twins open new perspectives for these people who could not have been able to access these jobs before.

VR attracts the curiosity of younger populations, particularly through video games. In this context, immersing young learners in a virtual educational environment representing an industrial work situation could generate the same enthusiasm. These realistic situations will also make it possible to demystify bias about certain professions, and perhaps give rise to desires or vocations to continue graduate studies on specific training courses. For example, in the case of forging, the demonstrations given to undergraduate students showed that a blacksmith does not only work hot metal manually in free forging, but that industrial processes, with automated machines, exists and that the shaping is more a matter of physical phenomena than of force and/or chance. The profession is then identified more as an engineer's job and less as a craftsman one. Then, students can modify their choice of orientation accordingly. Professional sectors promote the development of these new educational tools which can attract talent where recruitment becomes difficult due to an unjustified bad image.

LIMITATIONS OF IMMERSIVE DIGITAL TWINS

Currently, virtual reality headsets, not being common tools for students like computers or smartphones, require users to familiarize themselves with immersive digital twins' interaction modalities (especially controllers and buttons). Depending on the application's ergonomics and the guidance provided by the instructor, this learning curve may adversely affect the user experience or divert attention from content and learning processes. This limitation is more pronounced for immersive and interactive tools because they are less familiar in this context.

Therefore, it is essential to implement a user-centered design approach for digital twins to optimize the usability of these devices as much as possible.

This lack of democratization is also evident at the level of educational institutions. Higher education establishments today have "computer rooms" equipped with computers, but not all of them are equipped with "virtual reality rooms." However, providing such equipment is necessary as not all students have access to it. Additionally, this type of equipment imposes significant space constraints, with manufacturers often recommending around 9 square meters for a user to move and perform movements without space-related difficulties. In these conditions, it is challenging to envision having spaces large enough to accommodate virtual reality headsets for as many students as typically found in a practical session group (often one dozen students). In practice, the most likely scenario involves compromises in terms of space and the quantity of available equipment. For this reason, having an alternative version of the digital twin accessible on a computer, can be operated with a keyboard and a mouse, offers more possibilities for teachers because it is easier to allocate one computer per student. However, if ideal hardware conditions are met (small groups with an adequate number of headsets and ample space), the pedagogical potential is significant. Collaborative immersive practical work with monitoring by the instructor on a computer or even guidance by the instructor in virtual reality, for example (see Figure 2), becomes possible.

Figure 2. Illustrations of possible classroom situations with an immersive digital twin and a group of student supervised by a teacher.

Finally, practical work in engineering schools is generally connected to other pedagogical sequences: a theoretical lecture beforehand and a data analysis and debriefing phase afterward. VR is not a suitable tool for theoretical lectures preceding practical work because these lectures require students to take notes. However, note-taking in VR is complicated. Similarly, data analysis is usually carried out either with dedicated software or with a generic spreadsheet, for which VR is not the suitable medium. Once again, VR allows for a richer experience with presence and 1:1 scale visualization, which is really appropriate for practical sequences with the digital twins. For the more theoretical sequences, the existence of an alternative version on a computer/screen is crucial to fully implement a pedagogical scenario.

INDEPENDENT STUDY

The work carried out by students at home or in open campus workspaces (such as libraries or study rooms) for revision before exams is a significant factor in the success of their studies (Keith, Diamond-Hallam & Fine, 2004). This personal work may be based on teachers' requests for revision, exercises, or projects, for example. It also corresponds to students' "spontaneous" work, where in their learning process, they allocate time to review their courses to reinforce their learning and achieve good grades in exams.

This personal work, whether spontaneous or prescribed, usually takes the form of reviewing student notes or course handout, or engaging in exercises based on course notes. It is often impractical for learners to replicate practical work at home, such as conducting a lab experiment, as they lack the necessary equipment. For instance, redoing a forging experiment would require machinery that they do not possess, and this holds true for most practical exercises (in chemistry, electricity, etc.). Undertaking independent personal work on campus to redo practical exercises is generally also unfeasible. Students cannot freely access potentially fragile and/or hazardous equipment, such as forge machinery, without supervision.

With the help of an interactive digital twin of the forge, learners have the opportunity to redo practical exercises from home or on campus whenever they wish for revision. This tool goes beyond a simple video presentation of the content because students can actively replicate the actions, such as handling metal pieces, themselves (see Figure 3).

Figure 3. The learner manipulates a billet using a wrench

One challenge of students' personal work is to achieve a sufficient level of engagement to elicit these behaviors. Umaralieva (2021) actually advocates the use of multimedia documents to promote personal work. The positive effects of immersive technologies on the pleasurable and motivating nature of the activity also offer a potential that can be interesting for independent learning and revision. In cases where learners have the freedom to do exercises for practice or not to do so, having access to an attractive practice tool can make a difference to the amount of practice done.

ADDITIONAL PEDAGOGICAL FUNCTIONALITIES

The immersive and interactive digital twins in the JENII project offer educational benefits through their facilitation of active and experiential learning (Standard 8) and by proposing a pedagogical approach that incorporates professional engineering issues (Standard 7) while aiding knowledge acquisition through specific features. The present section will explore a range of these potential features within this learning medium: attentional guiding, pedagogical agents, visualization of invisible phenomena and generative learning features.

Attentional guidance is a means of ensuring that learners select the right information at the right moment. Active learning is generally considered positive for students in terms of satisfaction and efficiency (standard 8). However, this active learning must be conducted under relevant conditions to enable the creation of a coherent mental model. In VR, the addition of spatialized annotations in the 3D scene is a way to facilitate the selection of information (Vogt, Albus & Seufert, 2021). Similarly, when learners need to perform a series of actions, it is possible to add exogenous guidance, such as highlighting an object to manipulate, for example.

Pedagogical agents (PAs) representing virtual entities with social skills are increasingly considered valuable in education (Dai et al., 2022). These PAs excel in delivering content that is not only relevant but also engaging in virtual learning environments, enhancing interaction with students. This approach is grounded in the social agency theory, suggesting that educators' social signals boost student engagement and foster a more profound desire to learn. Consequently, a PA effectively employing these social cues can significantly improve learning outcomes (Sinatra et al., 2021). Key attributes of effective PAs include utilizing a human-like voice instead of a synthetic one (Craig & Schroeder, 2017), exhibiting a range of facial expressions rather than maintaining a neutral expression (Bringula et al., 2018), employing specific gestures (Davis & Vincent, 2019) and presenting an appearance that aligns with the study topic (Schmidt et al., 2019). PAs serve not merely as instructional tools but as dynamic entities that fit into the complex social setting of integrated learning experiences. Their adeptness in both verbal and non-verbal communication facilitates the transmission of knowledge and situates this learning within a socially engaging context. Integrating Large Language Models (LLMs) such as GPT can significantly enrich interactions between students and PAs (Pataranutaporn et al., 2022). This enhancement facilitates knowledge sharing but also aids in developing interpersonal skills and familiarizing future engineers with sophisticated human-machine interfaces.

Figure 4. Virtual embodiment of the instructor

In the digital twin scenario of the forge, the PA is envisioned as an interactive virtual embodiment of the instructor, enabling real-time, dynamic interactions with learners in the virtual environment (Figure 4). Moreover, when powered by generative AI, the PA can be transformed into an ideal professional role model, offering students a multifaceted learning experience.

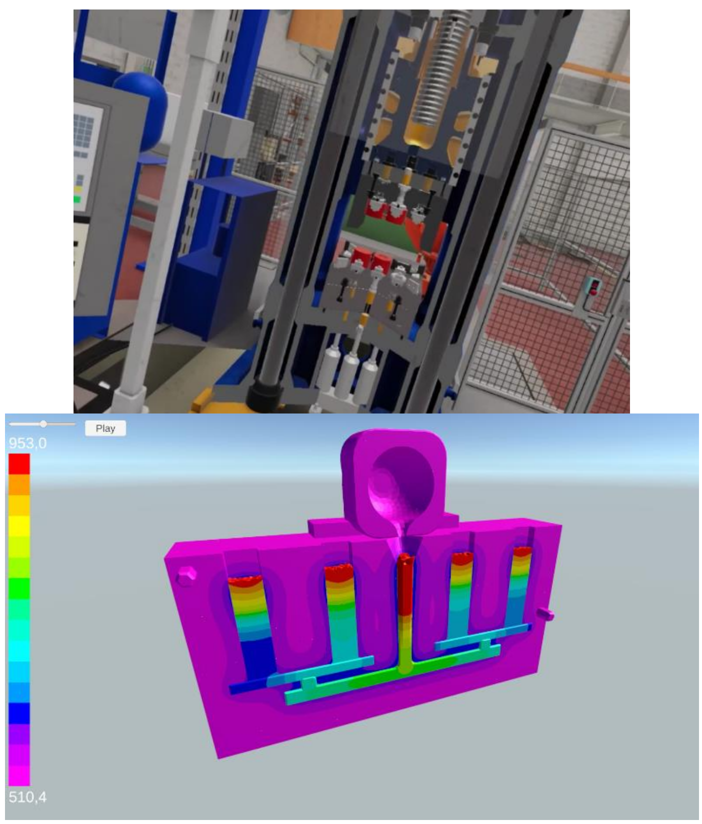

Figure 5. Cross-section of a screw press in operation (left) and visual representation of part cooling dynamics.

3D representations allow the **visualization of invisible phenomena in realistic context**: cross-sectional views of machines in operation or even representations of invisible physical phenomena (airflow, heat distribution, *etc.,* see Figure 5). VR provides the additional advantage of allowing the visualization of phenomena from a first-person perspective and at a 1:1 scale, also paving the way for intuitive interaction with the data (Christmann et al., 2022).

Engaging in behaviorally active learning situations does not automatically ensure cognitive engagement for learners. One effective method to address this is the application of **generative learning strategies**, which facilitate the reorganization and assimilation of new knowledge (Fiorella & Mayer, 2016). Such strategies typically involve synthesizing knowledge through written summaries, a process that helps structure and solidify the learning. However, immersive virtual environments often do not support traditional notetaking, leading learners to remove their VR headsets for writing activities in the physical realm (Klingenberg et al., 2023; Parong & Mayer, 2018). This shift creates a disconnection between the practice environment and the space where the reflection occurs. To bridge this gap in our digital twins, we have developed a feature that enables learners to record their voice and interactions with the environment using their avatar's embodiment. This user-friendly feature includes interfaces for starting and stopping recordings (Figure 6). The generative nature of this activity presents two critical advantages over standard notetaking. First, it stimulates two learning modalities to build a robust mental representation: verbalization through self-explanation and physical enactment. Second, the activity occurs within the learning environment, integrating the knowledge in a realistic setting.

Figure 6. User interfaces included in VR app for recording and visualization functionalities

To maximize the pedagogical benefits of this feature, the recordings are stored and available for review. The reviewing function allows students who engage with this functionality during practical exercises to access their recordings later on alternate devices, such as VR systems or PC. For example, students can record their techniques and thoughts while shaping a metal piece in the virtual forge. Later, they can review these recordings to analyze their methods and decision-making process, deepening their understanding of forging and identifying improvement areas. This reflective practice, firmly rooted in the immersive environment, enriches practical skills and cognitive learning.

DISCUSSION

We have observed that Digital Twins have a number of advantages and limitations. Additionally, we have discussed additional potentialities that could be realized with some technical developments. However, as highlighted by Mayer, Makransky, and Parong (2023), it is crucial to adopt a cautious and rational approach, grounded in evidence, when selecting effective digital tools.

VR proves to be a suitable medium for experiential learning as it allows for immersive scenarios. For this reason, educational applications often involve step-by-step guidance, where users simply follow instructions to perform various actions. Nevertheless, learning by doing does not guarantee comprehension in every situations. We could refer to this phenomenon as the "GPS Effect": when you navigate a route guided by GPS, the journey is easy to execute, but it is not memorized by the driver. Conversely, learning the route on a map before the journey is more challenging but facilitates memorization. We believe this "GPS Effect" may occur in virtual reality learning, and step-by-step guidance might not be an optimal solution. Ongoing experiments in our research will help formalize this issue and propose alternatives.

Virtual agents represent another potential lever for enhancing learning. Our ongoing work will examine the impacts of the high interactivity made possible by generative AI on both learner satisfaction and learning performance.

Lastly, generative learning is identified as highly effective. Fiorella and Mayer (2016) have categorized possible generative learning activities. Since VR is impractical for note-taking, we have conceived a technical device that could, hypothetically, combine the advantages of multiple generative learning tasks. This system, recording immersive visual and auditory capsules, is currently under experimentation and will be the subject of a publication.

These ongoing studies, among others, will provide evidence regarding specific features that can enhance the pedagogical value of immersive digital twins for learning. Through rigorously evaluated optimizations, these types of tools can potentially become valuable alternatives in educational settings.

REFERENCE

Bringula, R. P., Fosgate, I. C. O., Garcia, N. P. R., & Yorobe, J. L. M. (2018). Effects of Pedagogical Agents on Students' Mathematics Performance : A Comparison Between Two Versions. *Journal of Educational Computing Research*, *56*(5), 701-722. https://doi.org/10.1177/0735633117722494

Craig, S. D., & Schroeder, N. L. (2017). Reconsidering the voice effect when learning from a virtual human. *Computers & Education*, *114*, 193-205. https://doi.org/10.1016/j.compedu.2017.07.003

Christmann, O., Fleury, S., Migaud, J., Raimbault, V., Poussard, B., Guitter, T., ... & Richir, S. (2022). Visualizing the invisible: User-centered design of a system for the visualization of flows and concentrations of particles in the air. *Information Visualization*, *21*(3), 311-320.

Coşkun, S., Kayıkcı, Y., & Gençay, E. (2019). Adapting Engineering Education to Industry 4.0 Vision. *Technologies*, *7*(1), 10. https://doi.org/10.3390/technologies7010010

Dai, L., Jung, M. M., Postma, M., & Louwerse, M. M. (2022). A systematic review of pedagogical agent research : Similarities, differences and unexplored aspects. *Computers & Education*, *190*, 104607. https://doi.org/10.1016/j.compedu.2022.104607

Davis, R. O., Vincent, J., & Park, T. (2019). Reconsidering the Voice Principle with Non-native Language Speakers. *Computers & Education*, *140*, 103605. https://doi.org/10.1016/j.compedu.2019.103605

Evtushenko, O., Toporkova, O., Kokhashvili, N., & Yankina, E. (2023). Digitalisation in engineering education : Practice challenges and opportunities. *E3S Web of Conferences*, *371*, 05072. https://doi.org/10.1051/e3sconf/202337105072

Fiorella, L., & Mayer, R. E. (2016). Eight Ways to Promote Generative Learning. *Educational Psychology Review*, *28*(4), 717-741. https://doi.org/10.1007/s10648-015-9348-9

Fleury, S., Bernard, F., Paquin, R., Blanchard, P., & Richir, S. (2023) Augmented and virtual reality simulation in industry. *Computer*. DOI: 10.1109/MC.2023.3283311

Goncharov, V. N., Nesmeyanov, E. E., Kolosova, O. U., Arutyunyan, V. V., & Ivashova, V. A. (2019). Analysis of the modern science and technology in the context of the concept of CDIO. *Journal of Physics: Conference Series*, *1353*(1), 012135. https://doi.org/10.1088/1742-6596/1353/1/012135

Keith, T. Z., Diamond-Hallam, C., & Fine, J. G. (2004). Longitudinal Effects of In-School and Out-of-School Homework on High School Grades. *School Psychology Quarterly*, *19*(3), 187.

Klingenberg, S., Fischer, R., Zettler, I., & Makransky, G. (2023). Facilitating learning in immersive virtual reality : Segmentation, summarizing, both or none? *Journal of Computer Assisted Learning*, *39*(1), 218-230. https://doi.org/10.1111/jcal.12741

Kontio, E., Ravyse, W., Saarenpä, T., Haavisto, T., Luimula, M. Pizarro-Lucas, E., Dorado-Diaz, P. I., Sanchez, P.L. (2023). Experiences on the creation of a multi-disciplinary course in a metaverse environment. *Proceedings of the 19th International CDIO Conference,* Trondheim, Normay.

Malmqvist, J., Knutson Wedel, M., Lundqvist, U., Edström, K., Rosén, A., Fruergaard Astrup, T., ... & Kamp, A. (2019). Towards CDIO standards 3.0. In *Proceedings of the 15th International CDIO Conference* (pp. 512-529).

Mayer, R. E., Makransky, G., & Parong, J. (2023). The promise and pitfalls of learning in immersive virtual reality. *International Journal of Human–Computer Interaction, 39*(11), 2229-2238.

Neaga, I. (2019). Applying industry 4.0 and education 4.0 to engineering education. *Proceedings of the Canadian Engineering Education Association (CEEA)*. https://doi.org/10.24908/pceea.vi0.13859

Oh, C. S., Bailenson, J. N. and Welch, G. F. (2018). A systematic review of social presence: Definition, antecedents, and implications. *Frontiers in Robotics and AI*, 114.

Parong, J., & Mayer, R. E. (2018). Learning science in immersive virtual reality. *Journal of Educational Psychology*, *110*(6), 785-797. https://doi.org/10.1037/edu0000241

Pataranutaporn, P., Leong, J., Danry, V., Lawson, A. P., Maes, P., & Sra, M. (2022). AI-Generated Virtual Instructors Based on Liked or Admired People Can Improve Motivation and Foster Positive Emotions for Learning. *2022 IEEE Frontiers in Education Conference (FIE)*, 1-9. https://doi.org/10.1109/FIE56618.2022.9962478

Säisä, M., Määttä, S., & Roslöf, J. (2017). Integration of CDIO skills into project-based learning in higher education. In *Proceedings of the 13th International CDIO Conference* (pp. 18-22).

Sandyk, I., Müür, M., Kuts, V., Bondarenko, Y., Pizzagalli, S. L., Rüütman, T. (2023). Pneumatics laboratory interactive educational experience development. *Proceedings of the 19th International CDIO Conference*, Trondheim, Norway.

Schmidt, S., Bruder, G., & Steinicke, F. (2019). Effects of virtual agent and object representation on experiencing exhibited artifacts. *Computers & Graphics*, *83*, 1-10. https://doi.org/10.1016/j.cag.2019.06.002

Sinatra, A. M., Pollard, K. A., Files, B. T., Oiknine, A. H., Ericson, M., & Khooshabeh, P. (2021). Social fidelity in virtual agents : Impacts on presence and learning. *Computers in Human Behavior*, *114*, 106562. https://doi.org/10.1016/j.chb.2020.106562

Stepan, K., Zeiger, J., Hanchuk, S., Del Signore, A., Shrivastava, R., Govindaraj, S. and Iloreta, A. (2017). Immersive virtual reality as a teaching tool for neuroanatomy. In *International forum of allergy & rhinology, 7*(10), pp. 1006-1013.

Umaralieva, M. (2021). Some challenges in encouraging independent learning. *Academic research in educational sciences*, *2*(4), 1878-1882.

Vogt, A., Albus, P., & Seufert, T. (2021). Learning in virtual reality: Bridging the motivation gap by adding annotations. *Frontiers in psychology*, *12*, 645032.

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