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VR & AR IN ENGINEERING EDUCATION

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Annotation. This article shows how virtual reality (VR) and augmented reality (AR) technologies can affect the engineering learning process. It explains the main benefits of integrating these technologies into the educational process and some potential problems. Special attention is paid to the engaging, safety and practical experience that VR and AR can provide.

Keywords: Virtual reality, augmented reality, engineering education, educational technologies, safe learning, knowledge visualization, practical skills.

***Introduction*.** Digital technologies have become an essential part of modern education. The use of digital tools such as virtual reality and augmented reality can create immersive, interactive, and experiential learning environments that improve students' learning outcomes and prepare them for complex real-world tasks.

In this article, we focus specifically on how VR and AR technologies can increase student engagement, improve safety during practical training, and reduce environmental costs. However, the article also addresses some drawbacks of these technologies.

***Main part*.** Virtual reality (VR) is a technology that fully immerses a person in a virtual world. When somebody puts on a VR headset, they stop seeing the real room and find themselves inside a three-dimensional computer environment. There, they can walk around, look at objects from all sides, and interact with them.

Augmented reality (AR) is a technology that adds digital objects to the real world. It does not replace reality – it enhances it. A student looks at a real laboratory table through a tablet screen or special glasses and sees a virtual diagram, model, or instruction placed on top of the real surface. The real world stays in place, but it becomes interactive and filled with helpful digital hints.

The immersive and interactive nature of VR and AR technologies significantly increases student motivation, engagement, and active participation compared to traditional instructional methods [1]. These technologies provide the opportunity to visualize theoretical material, thereby making it easier to assimilate.

By transforming Annotation concepts into tangible 3D models, VR and AR bridge the gap between theory and practice, allowing students to interact with complex mechanisms. VR can provide full immersion, which will have a positive effect on the development of engineering students' practical skills. Greater engagement combined with improved learning outcomes will benefit the educational process.

Virtual reality also enables students to practice complex or hazardous procedures in a fully controlled environment without exposure to real-world risks, making it valuable for engineering and technical training [2].

Chemical engineering students can conduct dangerous experiments in virtual laboratories without the risk of touching toxic substances or explosion hazards. Technicians can learn to work with high-voltage equipment through realistic simulations that eliminate the risk of electrocution.

Computer engineers can work with expensive equipment without fear that it might break due to accidental errors.

Furthermore, VR and AR solve the problem of expensive infrastructure. Specialized equipment is often costly to purchase, store, and maintain.

Virtual simulations provide a cost-effective alternative by delivering a comparable practical experience, making education more affordable and accessible. Moreover, the latest industrial technologies can be replicated in a virtual environment, ensuring that the curriculum remains relevant and based on current innovations.

VR and AR technologies are already being successfully used in various fields of engineering education. In the oil and gas industry, VR simulators train workers in emergency response, allowing them to practice evacuating offshore platforms without real-world risks. In construction, students learn to work at heights and identify hazards on virtual job sites before facing real dangers [5].

In mechanical engineering, VR helps students master complex assembly procedures by interacting with virtual parts, eliminating the need for expensive physical prototypes [1].

As discussed earlier, VR and AR technologies offer numerous benefits for engineering education, including enhanced safety, cost reduction, increased engagement, and the ability to visualize complex processes. However, there are some disadvantages to these technologies.

Firstly, integrating these technologies requires significant changes to the curriculum and investment in lecturers' training. Educators must not only learn to use new hardware and software but also adapt their teaching methodologies to effectively facilitate VR-based learning [3]. This can be a time-consuming and resource-intensive process.

Secondly, despite their high degree of realism, VR and AR simulations cannot fully replace hands-on experience with physical equipment. The tactile feedback, material properties, and unpredictable variables of real-world environments are difficult to replicate perfectly [4].

Finally, the high initial cost of VR hardware and the need for regular software updates can be a barrier for institutions with limited budgets.

Looking toward the future, these technologies will likely become cheaper and more accessible, which will add certainty to the question of whether they should be widely implemented in education.

As hardware costs decrease and software becomes more sophisticated, VR and AR will move from experimental tools to standard educational equipment.

This will unlock new possibilities for distance learning, international collaboration, and interdisciplinary training. However, even now, we already have many benefits from their integration.

Conclusion. In this article, we explained what VR and AR are and reviewed their main benefits for engineering education.

We saw that these technologies increase student engagement by making learning interactive and immersive. They improve visualization of complex theoretical material, turning Annotation concepts into tangible 3D models. They enable safe practice of hazardous procedures from chemical experiments to high-voltage work without real-world risks.

They also reduce costs by replacing expensive physical infrastructure with virtual simulations and keeping the curriculum up to date with the latest industrial innovations.

We also discussed the challenges: the need for curriculum changes and lecturer training, and the limitations of virtual experience compared to real practice. These are important factors for any institution planning to adopt VR and AR technologies.

Looking ahead, as these technologies become more affordable and widespread, their potential to transform engineering education will only increase.

While they will not completely replace traditional methods, they offer a powerful tool that prepares students more effectively for the demands of modern engineering.

The benefits we already see today make a strong case for their continued integration into educational programs worldwide.

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