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ADVANCING EDUCATION THROUGH VIRTUAL REALITY IN THE MANAGEMENT AND PRODUCTION ENGINEERING FIELD OF STUDY

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Purpose: The purpose of this paper is to explore the application of virtual reality (VR) as an innovative tool for education in the field of Management and Production Engineering. It aims to demonstrate how VR can be effectively integrated into laboratory classes to enhance students' learning experiences and practical skills. Additionally, the paper highlights the role of the teacher in guiding and supporting students in using VR technology for educational purposes.
Design/methodology/approach: The paper utilizes a case study approach to examine the use of a specific virtual reality application in the field of Management and Production Engineering. The study involves the implementation of VR-based laboratory classes, where students engage in various training modules of the given selected VR application, including both theoretical and practical tasks in a simulated production environment. The methodology includes a presentation of the VR application's modules, the tasks for students, the organization of VR-supported laboratories, and the role of the instructor in facilitating the learning process.
Findings: The study showed that it is possible to use virtual reality in higher education, especially in the context of classes in the field of management and production engineering. The possibility of creating and implementing VR applications that realistically reproduce the production environment and enable conducting training and classes for students of technical studies has been confirmed. The research results confirmed that VR is a practical tool for teaching production lines, technological processes, machine parameters, equipment operation, quality control, and safety rules in the production hall. All these elements can be effectively implemented under controlled conditions in the university, without the need for physical presence in the industrial plant.
Originality/value: This paper offers a perspective on integrating virtual reality into laboratory classes within the field of Management and Production Engineering, highlighting its transformative potential for traditional teaching methods. The study emphasizes VR's value as a modern educational tool that enhances applied learning by providing hands-on practice in addition to theoretical knowledge, allowing students to engage actively and perform tasks independently.
Keywords: virtual reality, production engineering, education, management, technology, production line, machines.
Category of the paper: Research paper.

1. Introduction

Knowledge and technology development, strongly observed in recent years, has profoundly impacted various fields of human activity, including education. Among immersive emerging new technologies virtual reality (VR), often associated with entertainment including games, gained significant attention for its potential to enhance the learning experience. It gives a chance for interactive education. Virtual reality offers a growing range of applications, including the entertainment industry (Rogers et al., 2021; Stecuła, 2022), but also professional safety trainings (Makransky, Klingenberg, 2022; Norris et al., 2019; Stecuła, 2023), advanced specialist and on-the-job trainings (Baniasadi et al., 2020; Hsiao et al., 2021), marketing ways of popularization (Ozdemir, 2021; Shen et al., 2020; Zhu, Wang, 2022), as well as education (Brown et al., 2021; Dergham, Gilányi, 2019; Pinto et al., 2019). In technical, engineering, mechanical and industrial disciplines, virtual reality can offer unique opportunities to improve traditional teaching methods. Virtual reality technology can provide its users with an immersive and interactive environment; this means that it has the potential to be used as novel activation for students in education. Education needs to be improved by using new devices and tools. The proper use of virtual reality can enrich education by fully engaging students and immersing them in a created virtual world. There, they can see and virtually touch many objects (depending on the scenario) and interact with them. It is very important to select appropriate scenarios that will be compatible with the class program and schedule. Also, virtual reality allows for real-time feedback, which is important for students' experience, enables teachers to monitor progress and learning outcomes, as well as provide support.

The Management and Production Engineering field of study requires a deep understanding of complex production and technological processes, machine operations, managing manufacturing environments, enterprise, different resources and many more. What is more, this field educates engineers of the XXI century that needs different skills, predispositions and knowledge – both practical and theoretical (Kaźmierczak, 2016). All the mentioned aspects require different methods and tools from than oral lectures and theoretical discourses. In technical courses, it is necessary to use methods that will allow students to familiarize themselves with the taught program in a practical way and as closely related to the real production environment as possible. Hence, physical laboratories, workshops, and industrial visits are an efficient way of understanding the studied aspects. However, these methods often face limitations, including accessibility, safety concerns, and the logistical challenges of providing all students with this experience. Virtual reality presents a solution to these challenges by enabling the creation of immersive, simulated environments that replicate real-world production settings. Through VR, students can engage in interactive learning experiences that allow them to explore production lines, operate machinery, and understand production processes in a risk-free environment. This not only enhances their theoretical understanding but also allows them to develop practical skills that are essential for their future careers.

This article discusses a practical example of using virtual reality to conduct classes in the field of study of Management and Production Engineering. The author has characterized a selected application intended for training and educational purposes, from the perspective of using it in laboratory classes. The application consists of several training modules – both theoretical and practical. The practical modules contain various tasks that must be performed in the virtual environment of production plants. The trainee (student), among others, familiarizes themselves with selected machines, their functionalities, parameters, and selected technological lines. Their tasks include, among others, creating a layout of the technological line, operating a CNC machine, changing the parameters of the selected machine, carrying out a product quality control, and many others. This article presents an example application and describes how to use it in classes, the learning effects of the proposed laboratories, and the benefits of using the selected VR application in studying. Then, the role of the teacher (trainer) performed during classes using virtual reality is emphasized. The teacher not only transfers knowledge, but also supports students in using the new medium, helps them fully use the potential of VR, provides guidance on tasks, monitors their progress continuously, and also ensures the safety of those using VR

2. A proposal of using the selected VR application in laboratories

2.1. Characteristics of the VR application "Production Plant"

The application, which was chosen for use in the Management of Production Engineering course, was developed by EpicVR (EpicVR, 2024), a company specializing in creating applications for virtual and augmented reality (AR), but also mixed reality (MR). The selected application, named "Zakład produkcyjny" ("Production plant") is dedicated to virtual reality, which means that the user must have VR goggles, visualizing the virtual world and its elements designed in the application, as well as controllers that act as virtual hands. Thanks to the controllers, the user can interact with virtual objects. The application presents a production plant and consists of several modules, including a theoretical module and practical modules. Being in the virtual world of the application, the user can select specific modules from the application level. The application consists of:

- general instructional module,
- Occupational Health and Safety (OHS) module (theoretical and practical),
- practical modules.

General instructional module

The application offers a general training module that aims to familiarize users with the virtual environment and learn how to move around in this kind of world. In this module, the participant learns step by step how to use the goggles and controllers, performing activities such as moving, grabbing and dropping objects, passing through different spaces, turning on and stopping the line, etc. For beginners, this may be a challenge, because moving around in the virtual world has its own specifics, but it is relatively intuitive. Completing this module is crucial for further use of virtual reality. People who have already had contact with VR technology can skip this module.

OHS module (theoretical and practical)

The OHS module consists of four parts:

- occupational health and safety engineering,
- hazards in production plants,
- personal protective equipment,
- fire hazard.

This module, first of all, contains of slides with the basic knowledge in the given topic (one of four topic mentioned above). After the knowledge section there are test questions. These multiple-choice questions allow the trainee to answer questions related to the production environment in the context of occupational health and safety in VR. After answering, the user sees their result: the number of correct answers. These parts are therefore used to learn and verify knowledge – in a virtual environment. If the user passes the theoretical part, they are transferred to the production hall, where they must perform practical tasks related to the given topic. For example, in the section on fire hazards, the user must put out the fire in a production plant. The user is in the production plant and must perform some tasks, for example, put on personal protective equipment, turn on the alarm, find a fire extinguisher and perform other activities, and finally – put out the fire. Figure 1 shows the screenshot of the menu in the OHS module.

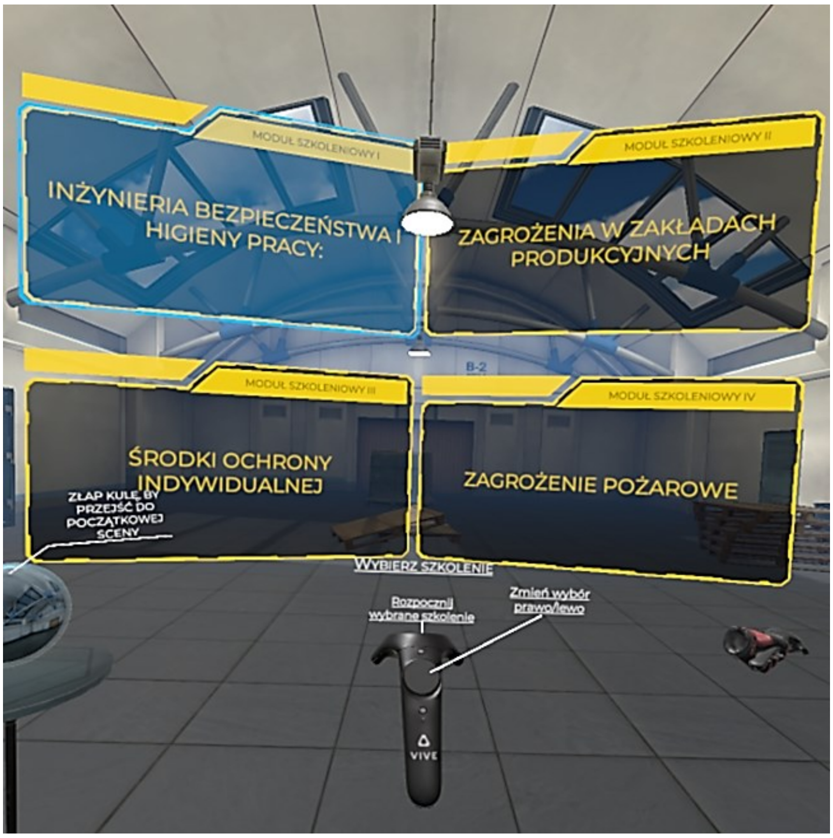

Figure 1. Screenshot of the OHS module of the VR application "Production plant" developed by EpicVR.

Practical modules

The practical modules include the following:

- furniture production,
- SMT systems production,
- CNC production,
- aluminum profile production.

By selecting one of the four available modules in the virtual world, the user is automatically transferred to the selected area, where they stand in front of a production line layout. On this layout, their task is to correctly arrange the machines so that they create the correct technological line, consistent with the theme of the given module. Using virtual hands (controllers), the user grabs miniatures of machines and places them in the appropriate positions. After completing the arrangement of machines, the user clicks a green button, which is used to confirm the arrangement, and then receives feedback on the correctness of the created technological line. Machines that have been placed correctly are highlighted in green, while those placed incorrectly are highlighted in red. Additionally, when grabbing each machine, the user sees its name and a short description, and also has the ability to rotate it in the hand to view it from every side. This task has no time limit, which allows the user to spend as much time as they need to complete it. Because of this, if they make a mistake, they will be able to understand where the mistake occurred, which will make it easier to remember the correct solution in the future.

The next task in each of the modules is to change the parameters of the given machines. The user must download a given machine (machine miniature) from the layout and then change the selected parameter, which is, for example, the processing speed in the case of a machine tool. It is worth noting that the choice of parameters depends on the specifics of the machines and the task.

After correctly arranging the production line, the user is transferred to a full-size technological line, where the machines are mapped on a 1:1 scale. In this virtual environment, the user can approach each machine and see the entire technological line up close.

In each of the modules, the user must also start a given technological line and perform subsequent tasks, which are provided in the form of verbal (in Polish) and visual (subtitle) instructions. Additionally, some elements are highlighted to make it easier for the user to find the appropriate components or buttons to use. Thanks to this, step by step, the user learns how a given technological line works, which allows them to better understand the technological processes, imagine the machines and acquire practical skills.

In addition to the above-mentioned tasks, each module also contains additional tasks that vary depending on the specifics of the module. In some modules, in addition to the tasks listed (laying out a technological line on a mock-up, changing machine parameters, starting a technological line), the user must perform other tasks that are intended to deepen their knowledge and skills. These additional tasks allow for an even more comprehensive understanding of production processes, which makes each module unique and adapted to different aspects of production management and engineering.

In the furniture production module, the user gets to know with the following machines: two milling machines, two edge banding machines and a drilling machine, and from these five machines the user needs to create two technological lines.

In SMT systems production module, the user gets to know Surface Mount Technology (SMT). This module shows the subsequent operations performed on Printed Circuit Boards (PCBs). The user deals with machines such as versaprint (for precisely applying solder paste to PCBs using a screen-printing process), nxt (placing components), hotflow (reflow over for melting solder paste onto PBC to create permanent solder joints), and check station (for inspection of the quality of solder paste applied or soldered components on PCB). In this module, another task is to change the size of six PCBs. This module includes also a quality control process. The user must perform a quality control of all boards on the check station to pass the module.

In the CNC products module, users can familiarize themselves with the operation of various machines, such as CNC machines, lathes, and a robotic arm. After setting up the technological line and entering the appropriate machine parameters, the user, located on the full-size technological line, must pick up the element and place it in the appropriate place in the CNC machines and the lathe, one by one. The user must place the part in the appropriate place in the machine. Then the machine must be closed, and the machining process must be start. After the machining is finished, the user must safely open the machine, remove the element, and place it on the conveyor belt. This must be done several times. The next task is also to place the processed elements safely in the box. At the next station, where the robot arm is, the user has the task of controlling the robot arm. Figure 2 (a) shows the task of placing four machines on the layout. Figure 2 (b) shows the finished task – the technological line is properly prepared. Figure 3 (a) shows placing the detail in the CNC machine, and Figure 3 (b) presents the already processed detail placed in the machine.

In the last module, the production of aluminum profiles, the user has 5 machines at their disposal. The machines must be arranged in the right order in the technological line. These machines are the following: an oven, a squeezer machine, a saw, a heat treatment machine and a packaging machine.

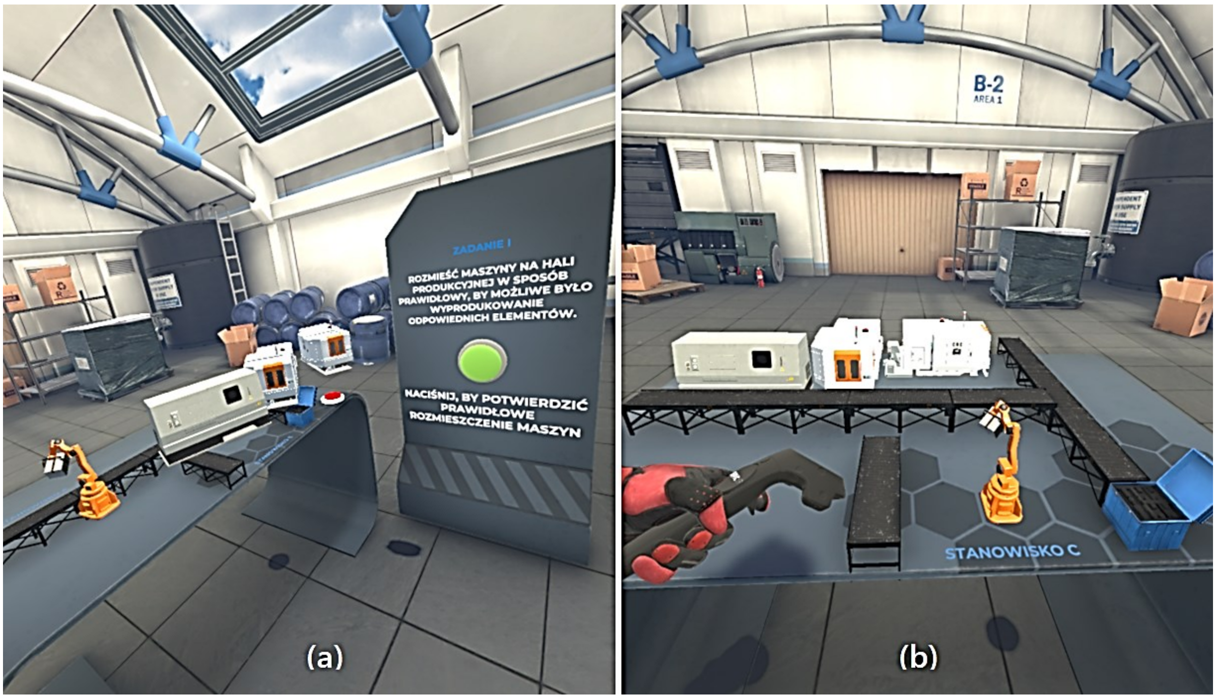

Figure 2. Screenshot of the practical module of CNC production: (a) – the beginning of the task of placing machines, (b) – finished task.

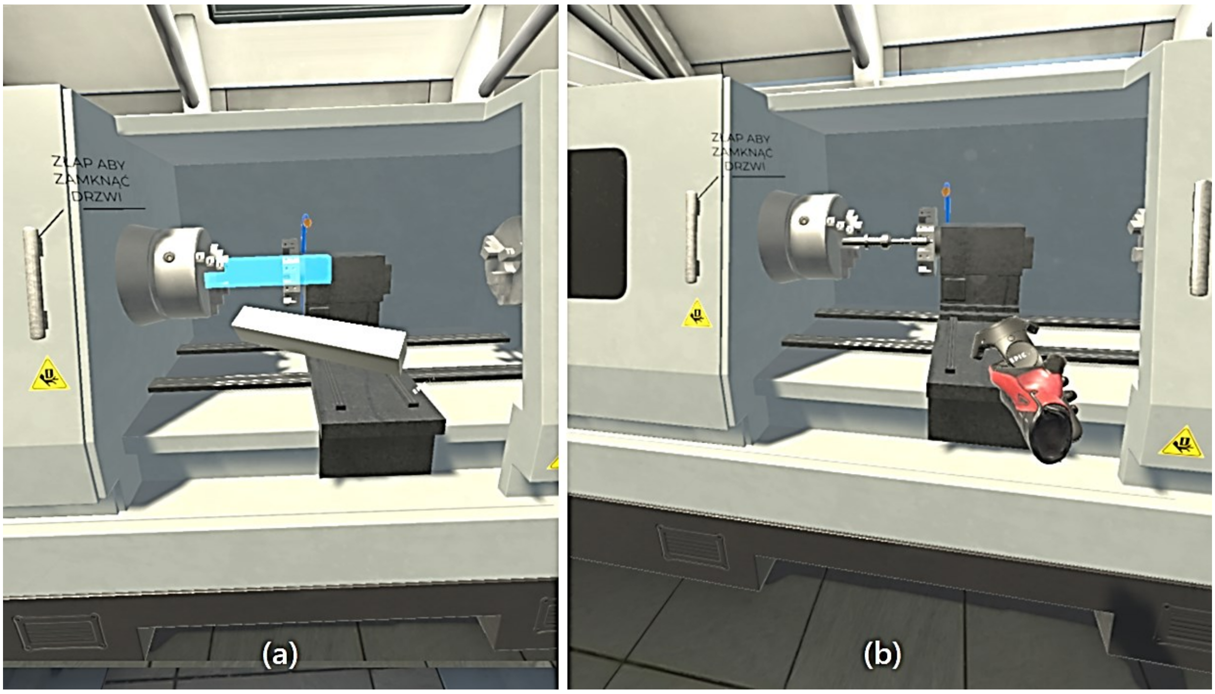

Figure 3. Screenshot of the practical module of CNC production: (a) – placing the detail in CNC machine, (b) – processed detail.

2.2. The use of VR application in laboratories from Production Engineering

In the application "Production Plant", selected production processes are generally presented, which means that their specificity is not discussed or presented in great detail. Due to this, the application is particularly suitable for first-year students of the first cycle (engineering) studies in the field of Management and Production Engineering. In the first year, these students deal with quite general topics that introduce them to the secrets of the field. Hence, the use of this application in the first semester is justified. The subject in which the implementation of this application is planned is Production Engineering, and the chosen form of classes is laboratories.

The author of this article, who teaches this subject, has prepared a set of steps that aim to implement and effectively use this application in the teaching process during laboratory classes. Due to this, students will have the opportunity to familiarize themselves with the basic issues related to production processes in the virtual reality environment, which will be the foundation for further, and more advanced education in the following years of studies. The steps include:

- **Preparing the room**

To conduct classes using virtual reality, an appropriate laboratory room is necessary. A larger room equipped with several stations with virtual reality goggles and controllers is preferred, so that several students from a smaller laboratory group can use virtual reality at the same time. Small laboratory groups (several people) are also preferred; otherwise conducting classes and monitoring students' work, as well as ensuring safety, will be very difficult. The room must be spacious, and in such a room, any objects such as desks and chairs that may pose a threat to those using virtual reality should be avoided.

- **Equipment purchase and setup**

The laboratory must be equipped with several VR stations, each consisting of VR goggles, controllers, and a designated space for students to move around safely. The goggles must be calibrated first. Each station should be preloaded with the VR application "Production Plant", ready for use.

- **Familiarization of students with regulations**

Before students put on the VR goggles, they are introduced to the safety regulations for using VR goggles, health and safety instructions and best practices for using virtual reality technology. Also, it is important to know contraindications to using virtual reality equipment and possible complications.

The instructor must ensure that all students are aware of potential contraindications, such as motion sickness or epilepsy, and verify that no student has any medical condition that could be exacerbated by the use of VR. Students are required to read and understand the safety guidelines (sign a consent form if necessary) and be briefed on emergency procedures in case of discomfort or technical issues.

- **Initial familiarization**

Each student starts with the general instructional module of the VR application (described previously in this paper). This module is crucial to ensuring that all students, regardless of their previous experience with VR, can use the technology effectively.

- **Engagement with theoretical and practical modules**

Students use subsequent virtual reality modules in subsequent laboratories. During this, they learn, familiarize themselves with the theoretical and practical content developed in the application, develop, expand their imagination, and gain experience and knowledge. They also learn independent thinking, and develop problem-solving skills, logical thinking, and reasoning. It is worth mentioning that during such labs, students engage more senses than during traditional lectures.

After completing each task, students receive immediate feedback from the application. This allows students to identify and correct their mistakes. Moreover, if a student makes a mistake, they have the opportunity to retry the task without any time pressure. This iterative process helps reinforce learning and ensures that students fully understand the correct setup and operation of the technological line.

- **Broder context and discussion**

It is important that the content shown in virtual reality is also discussed during the lecture. It is suggested that individual technological lines and individual machines are discussed in more detail during the lecture.

After the VR lab session, the students meet for a debriefing session. Here, they discuss their experiences, the challenges they faced, and the lessons they learned. The instructor can also provide additional information, answer questions, and connect the VR experience to broader production engineering concepts.

- **Additional tasks**

Students are suggested to prepare additional assignments or reports related to a given technological line. The additional assignments were to supplement the knowledge acquired during the VR session. Students could be asked to write a short report or reflection on their experience, describing what they learned and how it applies to real-world manufacturing engineering scenarios. This step helps reinforce the learning outcomes and encourages a deeper reflection on the practical applications of the acquired skills.

By applying this structured approach, the VR application "Production Plant" can be effectively integrated into Production Engineering laboratories, providing students with a comprehensive, immersive learning experience that can mix theoretical knowledge and practice.

The use of the presented VR application in Production Engineering labs significantly enhances students' learning effects. Using these VR applications can improve students' comprehension and retention of complex production processes. The ability to visualize and manipulate virtual machines fosters a deeper understanding of machine operations, technological line setup, and production workflows. Secondly, the VR environment allows for immediate feedback, enabling students to learn from mistakes and correct their approach in real-time, which reinforces learning and improves the memorization process. VR application helps students to get to know and understand selected basic engineering processes and technologies and ways of solving typical engineering tasks, particularly in relation to the organization of production processes and production management - in the field of production engineering. Additionally, the the hands-on experience with virtual machines and production lines prepares students for real-world industrial settings, equipping them with practical skills and a better understanding of safety protocols, machine parameters, and production efficiency. Overall, these classes using VR technology not only make learning more engaging, but also significantly enhance the practical skills and confidence of students in the field of production engineering.

3. Benefits of using the proposed VR application

Implementing the proposed VR application in production engineering laboratories offers several significant benefits, enhancing both the educational experience and the practical skills of students. They include the following:

- Enhancement of student engagement.
- Hands-on experience with virtual production machinery.
- Safe space for experimentation and learning from mistakes.

- Possibility of repetition of tasks.
- Real-time feedback on performance.
- Adaptability to different learning levels and student needs.
- Active learning and participation.
- Immediate application of theoretical knowledge in a practical context.
- Learning through experience.
- Development of problem-solving skills in a simulated environment.
- Virtual experience in a risk-free environment.
- Preparation for advanced courses by building foundational knowledge.
- Promotion of independent learning through self-guided modules.
- Enhancement of understanding of machinery and technological lines.
- Reinforcement of learning objectives through practical application.
- Providing a new method of learning with visual, auditory, and kinesthetic elements.
- Eliminating the need to organize trips to production plants.
- Possibility to repeat a task without wear and tear on equipment.
- Integration with Industry 4.0 technologies for modern learning.
- Preparation students for real-world manufacturing and production roles.
- Familiarization of students with VR technology.
- Development of skills relevant to Industry 4.0 and smart factories.
- Enhancing CV with experience in advanced simulation tools.
- Development of critical thinking and decision-making skills.
- Increase in university capacity to offer advanced technological education.
- Enhancement of the university's reputation for innovative teaching methods.
- Enhancement of student satisfaction and engagement with modern tools.

As the list above shows, virtual reality in education brings many benefits to both students and the university.

4. The role of the teacher (trainer) during a VR session

The role of the teacher during a virtual reality session is key, transforming from a traditional teacher to an instructor, guide and mentor. In VR learning environment, the teacher's responsibilities extend far beyond conveying information.

Before beginning any VR session, the teacher must conduct a identify if any students have contraindications to using VR technology. This includes understanding if any students have conditions such as motion sickness, epilepsy, severe vertigo, or other forms of locomotion weaknesses that could be intensified by VR use. Students with these conditions might experience discomfort, disorientation, or other health risks when exposed to the immersive VR environment. What is more, due to some sickness and conditions, some of the students are not allowed to use VR.

To ensure safety, the teacher should ask students if they have any known issues with VR or similar technologies and provide them with a clear explanation of what the VR experience will entail. This allows students to make informed decisions about their participation. In some cases, alternative assignments or accommodations might be necessary to ensure that all students can engage with the course content in a way that is safe and effective for them.

During the session, the teacher should remain alert, closely monitoring students for any signs of discomfort or adverse reactions, such as dizziness, nausea, or disorientation. They should be prepared to pause the VR activity immediately if a student exhibits any of these symptoms and have a plan in place to assist them, whether that involves taking a break, adjusting the settings, or switching to a different learning activity.

Additionally, the teacher should ensure that students are aware of the importance of taking breaks during VR sessions to prevent eye strain and reduce the risk of motion sickness. Regular breaks are an essential part of maintaining student well-being during extended VR use.

Then, the teacher must ensure that students are well-prepared to use the VR equipment, such as goggles, controllers, and any associated software. This includes providing detailed instructions on how to operate the technology and addressing any initial technical challenges that students may face.

As students begin to immerse themselves in the VR experience, the trainer's role becomes one of continuous support and guidance. The teacher is there to help students navigate through the virtual environment, ensuring they understand how to interact with the simulations and utilize the various features of the VR application effectively. This guidance is crucial in helping students fully engage with the learning material, allowing them to explore concepts in a hands-on, experiential manner that traditional teaching methods cannot offer.

Moreover, the teacher plays a critical role in encouraging students to think critically and solve problems within the virtual environment. By providing targeted prompts, questions, and feedback, the teacher helps students to not only complete tasks but also to reflect on their actions and decisions, deepening their understanding of the subject matter. This active engagement is essential for maximizing the educational benefits of VR, as it encourages students to apply theoretical knowledge in a practical context.

In addition, the teacher is responsible for creating an inclusive learning environment in which all students feel comfortable and supported. This includes offering assistance to students who may be less familiar with technology or who may have difficulties adapting to the VR environment. By being approachable and responsive to student needs, the teacher can help build confidence and ensure that all students benefit equally from the VR experience. In essence, the teacher's role in a VR session is comprehensive and multifaceted. It combines mainly the following:

- technical support,
- instructional guidance on tasks,
- transferring knowledge,
- learning facilitation,
- safety monitoring,
- monitoring of students' progress and engagement,
- feedback provision,
- critical thinking stimulation,
- inclusivity advocacy,
- emotional encouragement and support,
- pre-session health screening,
- break management,
- post-session debriefing,
- equipment maintenance,
- collaboration facilitation.

Through active involvement, the trainer not only enhances the effectiveness of the VR learning experience but also ensures that it is accessible, engaging, and educational for all students. This important and expanded role reflects the evolving nature of education in the digital age, where teachers must adapt to new technologies while maintaining their commitment to student learning and development.

5. Conclusions

The integration of virtual reality into the Management and Production Engineering field has the potential to modernize education, providing students with immersive experiences that traditional methods cannot match. In this paper, the author presented a VR application called "Production Plant" and showed how this application can be used in laboratories on the subject of Production Engineering. The study showed that it is possible to use virtual reality in higher education, especially in the context of classes in the field of technical studies. The research results confirmed that VR is a practical tool for teaching production lines, technological processes, machine parameters, equipment operation, quality control, and safety rules in the production hall. All of these elements can be effectively implemented under controlled conditions in the university, without the need for physical presence in the industrial plant.

By simulating real-world environments, in the mentioned example - different technological lines, virtual reality allows students to bridge the gap between theoretical knowledge and practical application, thus preparing them more effectively for the challenges of the professional world. Furthermore, VR's ability to provide a safe, controlled environment for experimenting with technological processes and machines is highly beneficial. It enables students to explore and learn from mistakes without the risks and costs associated with real-world errors. The immersive nature of VR also fosters greater engagement and motivation among students, leading to improved learning outcomes and knowledge memorizing.

As the technology continues to evolve, its accessibility and ease of use will likely increase, making VR a more integral part of educational programs in the Management and Production Engineering field. Institutions that embrace this technology early on will not only provide their students with an innovative educational experience, but also position themselves as leaders in the advancement of educational methods.

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