02

REVOLUTIONIZING TRAINING:

IMMERSIVE VIRTUAL REALITY IN THE STEEL INDUSTRY

REVOLUCIONANDO LA CAPACITACIÓN: REALIDAD VIRTUAL INMERSIVA EN LA INDUSTRIA DEL ACERO

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ABSTRACT

In a competitive environment, technology such as virtual reality stands out as a fundamental pillar for the training of future engineers and becomes essential in production processes. The adoption of technologies in training and education is presented as an effective strategy to achieve positive results, so this research proposes the implementation of training through a practical case in the steel industry. This case illustrates the successful integration of immersive virtual reality to enhance worker training, recognized as essential to boost efficiency and the quality of transmitted information, as well as to mitigate occupational risks. The results of this study demonstrate the rapid transformation and digital adoption of new technologies, emerging as a strategic tool to keep workers updated and prepared for the changing challenges of the work environment.

Keywords:

Industry 4.0, training, immersive virtual reality, foundry.

RESUMEN

En un entorno competitivo, la tecnología, como la realidad virtual, se destaca como un pilar fundamental para la capacitación de futuros ingenieros y se vuelve esencial en procesos productivos. La adopción de tecnologías en la formación y enseñanza se presenta como una estrategia eficaz para lograr resultados positivos, por lo que en esta investigación se presenta una propuesta de implementación de formación bajo un caso práctico en el ámbito siderúrgico el cual ilustra la integración exitosa de la realidad virtual inmersiva para mejorar la capacitación de los trabajadores, reconocida como esencial para potenciar la eficiencia y calidad de la información transmitida, así como para mitigar riesgos laborales. Los resultados de este estudio muestran la rápida transformación y adopción digital de nuevas tecnologías que emerge como una herramienta estratégica para mantener a los trabajadores actualizados y preparados para los desafíos cambiantes del entorno laboral.

Palabras clave:

Industria 4.0, entrenamiento, realidad virtual inmersiva, fundición.

INTRODUCTION

Training constitutes a method by which it is feasible to enhance, consolidate and update the knowledge, skills and behaviors necessary for personnel to perform their duties more effectively and productively (Valencia et al., 2019). The absence of adequate training and preparation is a significant factor in occupational incidents, either due to the lack of implementation of established protocols and procedures, or the lack of knowledge or absence of controls in risk prevention, as well as the lack of continuous training, both technical and practical (Buitrago Cortés, 2023).

In a highly competitive environment where technology plays a key role in improving the skills of workers, the adoption of technologies such as virtual reality (VR) is positioned as a fundamental pillar for the training of future engineers. In the productive field, these technologies become increasingly essential for manufacturing processes (Cortés Caballero et al., 2020). According to Alvarez-Marin (2017), the use of virtual objects that replicate real environments significantly facilitates the achievement of objectives during the educational process. In the course of training, if an employee spends a period without activity or delays excessively in carrying out an action, it is possible that he or she is experiencing confusion, frustration or boredom (Véliz Vega et al., 2020). As a result, there is a likelihood that he or she will lose interest during the teaching process.

The implementation of VR programs together with a training plan for employees proves to be a highly effective strategy to achieve positive results in their learning process. This is due to the digital revolution that encompasses various sectors, including training and job coaching. The person immersed in a VR experience has the ability to explore the virtual environment and, when approaching interactive objects, prompts are superimposed describing possible actions. This approach makes simulation perceived as an effective tool for learning, fostering a higher level of interest and participation in the educational process (Hosseini et al., 2020).

In this context, training systems have evolved in response to the most prominent advances in artificial intelligence, resulting in a more effective approach to worker learning (Uribe Gómez et al., 2020). The convergence of virtual reality and training programs offers an immersive learning environment that adapts to the digital age in which we live. This approach not only allows workers to acquire knowledge in a deeper way, but also enhances their ability to apply that knowledge in practical situations. The incorporation of advanced technologies, such as artificial intelligence, helps to personalize the learning experience, adjusting it to the individual needs of each employee and thus optimizing the effectiveness of the training process.

In this scenario of rapid digital transformation, the adoption of VR as a training tool is presented as a strategic response to keep workers updated and prepared for the changing challenges of the work environment.

With the aim of exposing the integration of VR in a training process, this study examines, through a case study, a proposal aimed at improving the training of workers in a productive sector through the implementation of VR-based technology. This approach is specifically applied in a company in the steel industry. It is recognized that employee training in this type of industry constitutes an essential and mandatory procedure to enhance the efficiency and quality of information transmitted through educational methods. In addition, it seeks to mitigate possible occupational hazards to which workers may be exposed.

VR, through tools such as simulators, provides complex information that requires the development of specific skills (Ávila-Tomás et al., 2020). In this context, Rouhiainen (2018), points out that the implementation of this technology is leading to a novel, innovative, artificial and didactic teaching method, supported by emerging technologies that benefit business operators. This creates a safer environment for people's physical integrity by avoiding exposures to unexpected risks due to lack of knowledge. In addition, it facilitates the active integration of the operator in the operational processes through VR, improving the focus on their development and learning.

Regarding research addressing VR as a training tool, Dyck et al. (2022), discuss how VR training provides industrial workers with the opportunity to acquire skills and perform complex tasks in a safe and controlled virtual environment. Furthermore, these authors mention that virtual technologies are becoming increasingly important in the manufacturing industry, especially in employee education and production work, as cognitive assistance systems can improve efficiency.

In the study conducted by Zemicheal & Houjun (2020), it is mentioned that VR is a technology that allows a user to interact with a computer-simulated environment, either real or imaginary. It is used in education and training to provide students with a realistic experience and save costs associated with human injury and equipment failure. In addition, it is highlighted that the effectiveness of educational training processes can be improved by introducing new training methods and technologies such as virtual reality. This is especially relevant to the curriculum of the high-speed machining technology program in the metal-mechanical industry.

Particularly, according to Radhakrishnan et al. (2021), several types of virtual reality are identified that vary in the level of immersion they offer to the user:

1. Non-immersive Virtual Reality: In this modality, the user can visualize the virtual environment through a desktop computer and explore it through the use of keyboard and mouse. This desktop virtual reality approach is more practical and accessible as it dispenses with expensive devices. Examples are Internet-based applications and video games that allow real-time interaction with other people in three-dimensional environments.
2. Immersive Virtual Reality: This type of virtual reality completely immerses the user and challenges his or her abilities through the use of various interaction devices, such as sensors, gloves, virtual reality visors and headsets. A prime example is video games that recreate unpredictable virtual worlds, allowing the user to feel an integral part of the virtual environment through sensory stimuli. Interaction in this type of virtual reality surpasses non-immersive reality, providing the possibility of transforming the virtual world and performing tasks that would be impractical in the real world.
3. In the industrial environment, according to Ramstorfer et al. (2022), VR is implemented as a series of games based on available 3D CAD data and a considerable amount of 360° images via a simulator for use. The Development and application of VR in the enterprise faces several challenges, in which da Costa & Porto (2011), point out the following:

- Capabilities to use or operate certain technology, adaptive capabilities.
- Lack of commitment from the operator to take its development seriously.
- Failure to show the exact image in the VR to the real thing on productive floor.
- Limitations of activities in different scenarios to be performed.
- High cost of VR program development.
- Equipment rental costs with supplier.
- Time and costs of staff training.

Other authors, such as Radhakrishnan et al. (2021), provide a systematic review on the use of immersive virtual reality (IVR) for industrial skills training, highlighting its potential benefits and limitations. Regarding the potential benefits of IVR for industrial skills training, they include:

1. Improved safety: IVR allows workers to practice and learn complex tasks in a safe and controlled virtual environment, reducing the risk of accidents and injuries.
2. Realistic simulations: VR provides realistic and immersive simulations that closely resemble real-world industrial environments, allowing workers to gain hands-on experience and develop skills without the need for physical equipment or machinery.
3. Increased engagement and motivation: The immersive nature of VR training can improve worker engagement and motivation by creating an interactive learning experience.
4. Cost-effective training: VR training can be a cost-effective alternative to traditional methods, eliminating the need for physical equipment, materials and travel expenses.
5. Skills transfer and retention: Studies have shown that immersive VR training can improve skills transfer and retention, allowing workers to apply what they learn in the virtual environment to real-world situations.
6. Customization and adaptability: VR training can be tailored to the specific needs of different industries and job roles, enabling customized and adaptive training programs (Radhakrishnan et al., 2021).

Additionally, Alpala et al. (2022), presents an analysis with the goal of improving collaboration and communication practices in 3D virtual worlds with VR and metaverse, specifically in the educational and production sectors in smart factories. Their focus is on improving collaboration and communication practices in 3D virtual worlds through the use of VR and metaverse technology in the educational and productive sectors of smart factories. They propose the development of an experimental framework that enables collaboration in virtual environments through VR-driven metaverses by replicating real-world features through digital twins and avatar models. This framework includes functional components, object-oriented configurations, advanced kernel, interfaces, and a multi-user online system. The study presents a practical application of the framework in a metaverse centered on the smart factory, showcasing relevant Industry 4.0 technologies. Usability metrics were used to evaluate the potential educational and commercial use of the framework, with satisfactory results. They conclude that a commercial software framework for VR games can accelerate the development of experiments in the metaverse, connecting users from different parts of the world in real time.

On the other hand, Camus et al. (2012), propose the use of a virtual environment to stimulate the safety rule negotiation process in industrial environments. These authors present the MELISSA model and methodology, which aim to identify the knowledge needed to represent safety rule application contexts and share it within the virtual environment design team. With the objective of identifying the implications of VR, Zemicheal & Houjun (2020), present a training system for advanced machining technology training.

Other research work related to training includes the proposal by Dyck et al. (2022), who present a technical solution for a virtual training environment that allows physically realistic simulation of mechanical assembly operations. Abbas et al. (2023), explore the growing importance of

VR in industrial training due to the complexity of the industrial world and the need for social distancing caused by the outbreak of COVID-19, while Cassola et al. (2021), present an immersive authoring tool for VR-based training that allows instructors to structure and define VR training courses, while trainees' actions are recorded and adjusted to the instructor's specifications.

The company specializing in steel casting, where this VR training project was carried out, has the safety and well-being of its employees as its main pillars. It is recognized that it is essential for workers to be trained in all operations that contribute to a safe and healthy work environment. Given that in any company or work organization there are roles with different levels of physical demands, which carry various risks to the operator's health, occupational risk prevention is positioned as a crucial element to be addressed by companies. In this specific case study, workers range in age from 18 to 50 years old, with variations in levels of knowledge and experience in the use of VR. The training focused on developing skills and abilities that are applicable in the daily operations of the company.

Particularly, the case study focuses on the "rolling shop cell" within the rolling macro-process. In this area, various activities are carried out with the purpose of supplying the necessary implements for the rolling processes (Figure 1). Operators were trained using traditional methods, including lectures and visual support in the work area.

Figure 1. Rolling process.

Based on the challenges identified during the process, information was gathered on what needed to be improved to increase the effectiveness of the activities. Some aspects to be improved were related to the long duration of the procedure and some complexity in some assembly activities, which generated boredom and distractions during training. This resulted in a considerable time of less understanding of the activities and information needed to carry out the daily tasks.

The workshop cell is made up of a work team composed of a total of 44 people, divided into sub-cells. In this structure, there are 28 people dedicated to assembly, 6 to maintenance, 1 to piling and 9 to machining. In the area called "lamination workshop", a mechanical process of assembling units is carried out. This process involves the use of specific implements and follows an assembly sequence, starting with the lower part and continuing with the upper part. Some of the equipment used includes blisters, rings, bearings, guides and cooling systems. Once all the assemblies are completed, 100% assembly is achieved, and the task of the Rolling Shop is concluded. This assembly, together with the Rolling Mill macro-process, contributes to give the preform to the structural beam, following quality guidelines, among others.

The choice of this workshop cell to implement a training program based on intelligent design arises in response to the criticality of the daily activities and the level of safety risk faced by the operating personnel. At the company level, VR learning was considered as an alternative. This approach was developed in collaboration with an external supplier specialized in programming for the creation of IVR applications for training and coaching. This system is based on an expert system that is specifically configured to replicate human expertise in a particular context. The main technical characteristics selected for the technological tool used are described in Table 1.

Table 1. Technical characteristics.

Processor	Snapdragon XR2
Storage	128 GB
Sound	3D
Tracking	Internal cameras

In the case of the software its features allow the execution of the program in .apk to be installed in the glasses, said .apk has a size of 1.30 GB, which can be manipulated with the glasses and hand gestures without having to occupy the glasses controls.

Consequently, this VR system was focused on individuals and performance measurement using IVR. The goal of this tool was unambiguous interaction and learning, addressing weaknesses such as the concentration of the operators in their learning process. In this context, the worker's ability to explore the environment was developed and, when approaching an interactive object, indications were superimposed on the actions that can be carried out with that object. For the training process, the procedures shown in Figure 2 were carried out.

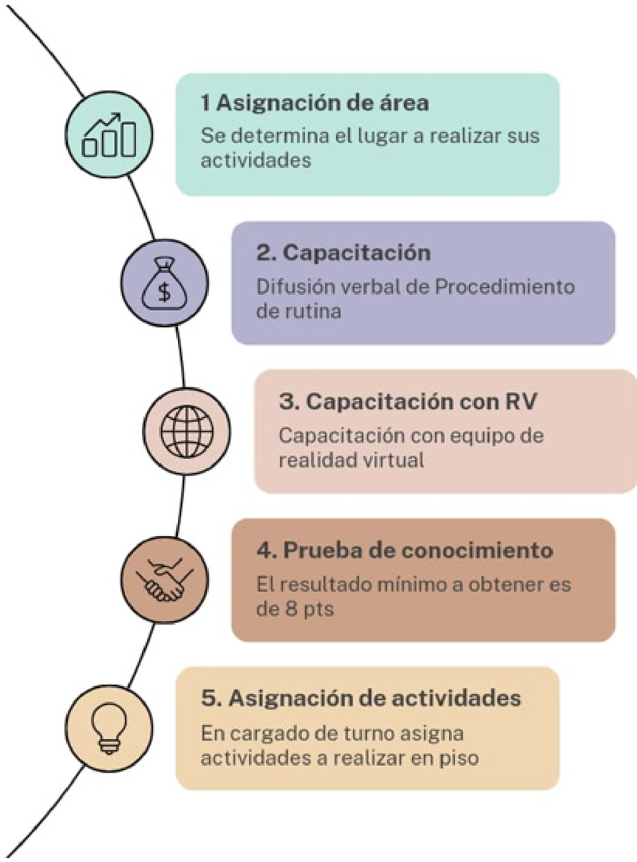


Figure 2. Training process

In relation to the parties involved in this training process, five stages were identified (Figure 3): 1) Project proposal (leader), 2) Approval (manager), 3) Development (provider), 4) Delivery and 5) Execution (trainers/work team).

Figure 3. Project development.

In the implementation of RVI for the training of operational personnel, we sought to measure and compare operational efficiency before and after its integration. In addition, extensive research was conducted to assess the acceptance and willingness of personnel towards these advanced training practices.

To facilitate familiarization with this intelligent system, the trainer played a crucial role in providing verbal support for the execution of tasks, allowing operators to more quickly understand how to perform specific activities. This interaction was fundamental to ensure an effective transition to the use of IVR in training.

The implementation process included the use of Meta-compatible VR software and virtual reality goggles to conduct the training activities. These devices, together with the interaction equipment provided by the supplier, sought to project an immersive experience beyond mere familiarization with the activities, offering realistic scenarios that reflect the work environment and allow the identification of possible risks.

During the development of the virtual reality program, prior training was conducted to address non-routine scenarios and detect possible errors, such as object manipulation problems, graphic errors and lack of clarity in the instructions. Adjustments were made in a second training with qualified personnel.

The trainer, by linking the vision of the virtual reality goggles to a computer, was able to provide effective visual guidance and answer doubts, significantly improving the learning experience. At the end of the training, valuable feedback was provided to strengthen highlighted areas and improve those that needed attention.

In addition, during immersive virtual reality training, the trainer monitors the operator's engagement and interest, and at the end, a diagnostic review is conducted to assess the achievement of the training objectives. Any changes in the process were reflected in the routine procedures and constant communication is maintained with the supplier to update both the procedures and the virtual reality.

A Routine Procedure (PE) is an instruction guide that describes all the relevant steps and activities of a process, where it is standardized and evaluated through different items such as safety, operation, quality, environment, among others, then follows a flow for the approval and dissemination of the same with the people who will be responsible for carrying out the process through this standard. The structure of a Routine Procedure is divided by items such as: activity, description, special care and criteria.

- Activity: Name of the activity to be carried out (e.g.: change of oil seals, plate identification, lubrication tests, among others).
- Description: Detailed description of how and with what to perform the activity.

- Special care: The specific place or action to be taken according to what is written in the description of the activity is written (for example: do not apply excess grease, the measurement should not exceed 5 mm).
- Criteria: Certain items (safety, quality, operation, environment, legal aspects) are placed in specific, where the activity receives a greater impact if the action not performed in the Special Care section (for example: Safety: take into account the care with hands, Operation: avoid leaving the equipment more than 5mm apart because it can cause a jam).

In detail, the implementation of the training with RVI comprised the following stages:

1. Definition of Training Objectives: The specific objectives to be achieved with the training were clearly identified, providing the basis for measuring operational efficiency before and after the implementation of artificial intelligence in the training of operational personnel. In addition, the worker's acceptance and willingness to adopt training practices with artificial intelligence was evaluated.
2. Audience and Needs Analysis: This was conducted with the purpose of understanding the audience and their learning needs, ensuring that the training was tailored to the skill and experience levels of the workers. The trainer played a crucial role in helping to execute tasks verbally, facilitating quick understanding of the activities.
3. IVR Platform Selection: The appropriate platform was chosen according to the company's needs, defining devices such as VR headsets, motion controllers and other accessories. Software compatible with Meta and Virtual Reality Glasses was chosen, allowing the execution of activities through VR.
4. Immersive Content Development: VR content was created or acquired, including simulations and interactive scenarios to provide an immersive and realistic experience. The program was designed to train new operators, using real scenarios to familiarize them with the activities and environment, identifying possible risks.
5. Integration of Educational Elements: We ensured that the content was aligned with the training objectives, incorporating educational elements, evaluations and feedback to maximize the pedagogical impact. Evaluations were conducted to compare previous and current teaching methods, and an exit survey was conducted to measure acceptance and adaptation to intelligent systems.
6. Hardware and Software Setup: Software was pre-installed on the VR goggles, with easy access and sensors to allow for hand interaction, provided META's branded interaction material was met.
7. Development of Test Sessions: Non-routine scenarios were faced during development, performing pre-training to detect errors in the program. Adjustments were made and a second training was conducted to validate the changes with qualified personnel.
8. Training Sessions: The trainer linked the vision of the glasses to a computer to provide guidance and answer doubts during training.
9. Feedback: The trainer provided feedback to staff at the end of the training, reinforcing salient issues and pointing out areas for improvement.
10. Performance Evaluation: During the VR training, the trainer evaluated the operator's commitment and interest, providing a diagnostic test at the end to measure compliance with the objectives.
11. Maintenance and Updates: Changes were made to the Routine Procedure and contact was maintained with the vendor to update the VR in response to process modifications, ensuring both documents were updated.

For its implementation, new workers were trained in the area by reading the routine procedure and a learning evaluation, as well as training with VR to guide their learning in a more sophisticated and didactic way, followed by a learning evaluation.

For the training proposal, a Meta Quest 2 equipment was considered (Figure 4), which includes its own processor, memory for storage, VR viewer, microphone, speaker, manual controls, batteries and wireless internet connection.

Figure 4. Meta Quest 2.

Source: Meta (2022).

During the training, the VR goggles, Meta Quest 2, were integrated with some hand gestures to perform the necessary activities in a more practical way as shown in Figure 5, these goggles have a "Guardian System" which helps to delimit the desired work area. The hand gestures will be easily identified, these gestures allow to grasp the necessary objects, as well as their manipulation.

Figure 5. Interaction and manipulation of objects.

The game consisted of 6 modules that covered all the steps of the EP with a total duration of approximately 5 hours. The duration varies according to each person's performance and familiarity with the program interaction. It automatically redirects you to specific points when indicated, but also allows you to move to different areas to perform desired activities. In case of leaving the delimitation of the guardian system, the image of the scenario disappears automatically, showing a red mesh with the actual view of the environment. To display the note or the next step, the left hand is raised, and to remove the instruction, the left hand is raised again. The transition to the next activity is automatic once the previous task is completed.

In order to capture the operators' attention and taking into account the importance of proper image perception in VR, simulated content was created that reflects an artificial reality similar to what the operator recognizes as real (Figure 6 and Figure 7).

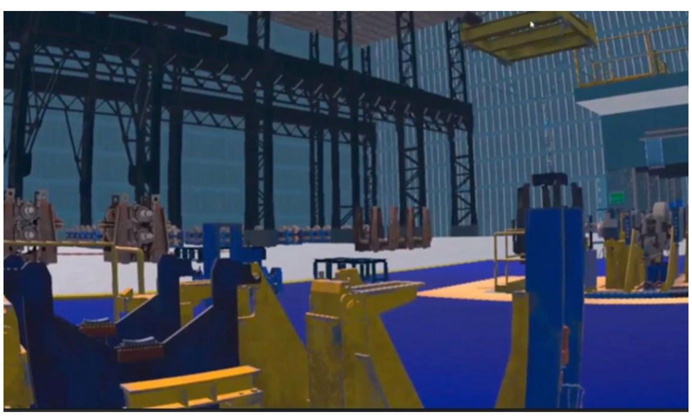


Figure 6. Real 3D Scenario.

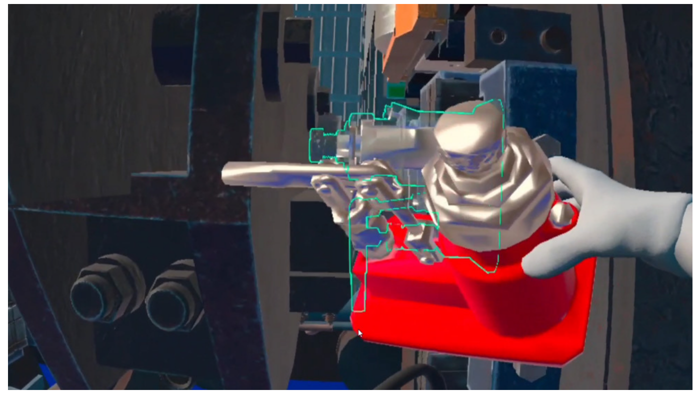


Figure 7. Handling of work tools.

During this training process, a conventional teaching method was used by reading and another by means of virtual reality to verify the performance acquired by each person, with both methods to determine the feasibility of VR in the training of personnel in the routine unit assembly procedure.

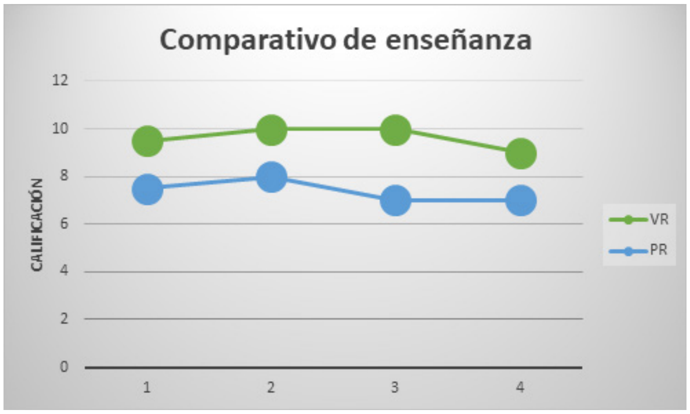
Evaluations were carried out where the operator tests his acquired knowledge with questions on familiarization of equipment, materials, some questions on critical issues such as identification of oil leaks, type of degreaser and lubricant to be used, torque required for screws, maximum and minimum measurements of some implements to ensure adjustments, and ways to tighten screws. Both evaluations have this structure; however, the training test with the use of virtual reality has an exit survey on their experience and satisfaction with the training using a simulator that allows for greater interaction with the process.

The training for each operator had a total duration of approximately 8 hours, the first 2 hours were of conventional and self-taught training with detailed reading of the routine procedure, in addition to a 20-minute evaluation, once the training was completed with VR to reinforce the knowledge read through interaction with a duration of 5 hours and a 20-minute evaluation, the times in the VR were variable according to the adaptation that each operator had with virtual reality.

DEVELOPMENT

Throughout this project, the feasibility of VR training in various industrial settings was thoroughly investigated. Based on the average of the data collected from the evaluations (Figure 8) the results provide a complete picture of the benefits derived from the implementation of this innovative technology, evidencing higher average ratings with the use of virtual reality and demonstrating the feasibility of adopting this new form of technology.

VR training proved to be highly effective in improving the acquisition of skills and knowledge by allowing the creation of immersive environments and the reproduction of real-world situations, especially in the area of assembly of the workshop's Implements section. This technology quickly adapts to training scenarios according to the specific needs of the industry, providing a strategic advantage that leads to deeper and longer lasting learning, while improving the attention of participants with better results.



VR: Virtual Reality training; PR: Traditional training.

Figure 8. Results.

A positive effect on safety was observed, as the introduction of this VR simulator has had a beneficial impact on occupational safety. This is due to the realistic representation of the unit assembly process in the virtual scenario, which allows operators to practice safety procedures and activities in an authentic way. This practice reduces the risk of accidents and improves emergency preparedness.

To evaluate the efficiency of this training plan with RVI, comparative evaluations were carried out before and after implementation, addressing possible changes in the teaching method. In addition, a final survey (Figure 9) was conducted to evaluate the acceptance, ability and adaptation of the operators to this innovative form of training.

Figure 9. Final survey.

By interacting with the training program, operating personnel can easily and didactically identify their production process, providing them with a risk-free understanding prior to carrying out their activities on the production floor. The implementation of a VR program and a specific training plan for assembly personnel promises positive learning results.

CONCLUSIONS

The use of VR enriches learning content by providing interactivity, experimentation and collaboration. The comprehensive training and education tool simulates real-life situations in a three-dimensional environment, providing learning in a safe, efficient and controlled manner. The virtual reality application is designed for the specific needs of the implement shop, allowing the skills and knowledge acquired by personnel to be evaluated, ensuring that they are prepared to perform unit assembly activities safely and efficiently.

This training medium not only facilitates the gradual learning of operational processes, but also addresses the operation of attachments, tools, hydraulic robots, overhead cranes and other activities related to the unit assembly process. Working with new personnel translates into more accurate results, as the initial lack of knowledge is overcome with the interaction provided by the 3D virtual scenario. This virtual environment, similar to reality, guides learning and improves staff attention and interest, generating greater commitment to the process. The combination of these technological advances not only optimizes learning efficiency, but also contributes to the continuous development of skills, aligning with the changing demands of an ever-evolving society.

The integration of virtual reality in the training of arming personnel offers an effective and advanced solution to improve preparedness, safety and efficiency in the work environment.

Considering the achievements obtained through the successful integration of virtual reality in the training of assembly personnel, several areas of research and development are envisioned to continue improving and maximizing the benefits of this innovative methodology. Some of the future work that could be undertaken includes: content customization, integration of emerging technologies, continuous performance evaluation, expansion to other operational processes, development of additional content, as well as collaboration and communication in virtual environments.

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