EFFECTIVENESS OF INDUSTRIAL TRAINING USING VIRTUAL REALITY TO MITIGATE RISKS ASSOCIATED WITH THE WORK ENVIRONMENT: A LITERATURE REVIEW

André Martins Cordeiro [1,2], Fábia Cunha Ferreira Santos [1,2], Ingrid Winkler [2,3]

[1] Oswaldo Cruz Foundation - Fiocruz, Rio de Janeiro, Brazil.
[2] SENAI CIMATEC University Center, Salvador, Brazil;
[3] Head of the Institute for Science, Innovation and Technology in Industry 4.0 - INCITE Indústria 4.0
** Contact: andre.cordeiro@fiocruz.br*

Abstract: Effective training play a key role in promoting the safety of workers, equipment, products, and industrial facilities; thus, it's essential to evaluate its effectiveness. Virtual Reality (VR) has emerged as an enabling technology for industry 4.0 with potential to support training programs. By the means of a literature review, we investigated how VR can be applied in evaluating the effectiveness of industrial training programs before the worker is exposed to occupational hazards. The findings indicate potentialities and limitations of VR for industrial training, which are discussed, such as the need to consider individual factors of the organizational context and specifically related to the training environment. VR enables positive impact when dealing with risky behavior. However, the literature is scarce, and this indicates a theoretical gap.

Keywords: training evaluation; industrial training; virtual reality; immersive technologies; industry 4.0

EFETIVIDADE DO TREINAMENTO INDUSTRIAL USANDO REALIDADE VIRTUAL PARA MITIGAÇÃO DE RISCOS ASSOCIADOS AO AMBIENTE LABORAL: UMA REVISÃO DA LITERATURA

Resumo: Treinamento eficaz desempenha um papel central na promoção da segurança dos trabalhadores, equipamentos, produtos e instalações industriais. É essencial avaliar sua eficácia. A Realidade Virtual (RV) emergiu como uma tecnologia facilitadora para a indústria 4.0 com potencial para apoiar programas de treinamento. Por meio de uma revisão da literatura, investigamos como a RV pode ser aplicada na avaliação da eficácia do treinamento industrial antes da exposição ao risco. Os resultados indicam potencialidades e limitações da RV para o treinamento industrial que são discutidas, como a necessidade de considerar fatores individuais do contexto e especificamente relacionados com o ambiente. A RV permite um impacto positivo no comportamento de risco. A literatura é escassa, o que indica uma lacuna teórica.

Palavras-chave: avaliação de treinamento; treinamento industrial; realidade virtual; tecnologias imersivas; indústria 4.0

1. INTRODUCTION

As the pressures for innovation and global competition increase, so does the need for a competent workforce. This is especially true in sectors with high levels of investment, risk, regulation, competitiveness and innovation. Therefore, it is essential to look at training in organizations and its forms of evaluation to ensure the achievement of strategy objectives, especially due to the rapid changes in ways of working and workplace environments. In addition, intense technological advances impact companies, so that the survival of industries depends on workers' upskilling and reskilling processes [1-2].

In this perspective, the World Economic Forum suggested a series of Industry 4.0 trends that were consolidated during the pandemic, such as remote and hybrid work, online shopping with robotic delivery, tele-education, digital payments, telemedicine, improvements in the organization of production 4.0, 3D printing and robotics. Emerging technologies such as virtual reality (VR), augmented reality (AR) and artificial intelligence (AI) are enablers of Industry 4.0 and have potential applications in industrial training. VR, in particular, has been one of the most modern technologies of Industry 4.0 [3-5], and can be defined as a computer-generated environment that can be experienced and interacted with as if it were real [6].

There are opportunities for the development and application of emerging technologies in the industry, especially immersive technologies such as VR, in learning and development processes, both for the worker and for the organization. In addition, they also intensify the need for specialized and technical knowledge among the industrial workforce [1;7].

Effective training, especially training that teaches workers the tools and skills to identify and assess hazards on the job, is essential to worker safety. In addition, training is an important investment and identifying how this investment is generating a positive return is of great interest to organizations [1;7;8].

However, and recent studies have pointed to the need for standardized practices for new technologies applications for evaluating training processes, especially that go beyond just measuring usability before recommendations can be provided for training applications [9,10]. The concern is greater regarding risky occupations and activities that can potentially impact the environment and society in general.

Evaluation is a critical item, as inaccurate methods for evaluating training programs carry the risk of training workers having a mistaken understanding of their experiences, capabilities, and performance [1], jeopardizing the achievement of the desired results and increasing the risk for the organization.

The application of immersive technologies in training can have a great impact on the development of skills associated with dangerous work processes, whether for workers, the environment and/or consumers. For example, a recent study showed that using VR in training led to a significant reduction in work-related injuries and mental workload, and more effective in terms of reported engagement. However, these studies also point to severe limitations in terms of assessing training effectiveness. There are not many systematic evaluations specifically for safety training in construction activities [9], that are essential to build and maintain industrial sites.

Considering the above context, this work aims to review how VR technologies can contribute to evaluating the effectiveness of industrial training before professionals are exposed to high-risk work processes.

2. METHODOLOGY

The study followed the methodological recommendations of the “Preferred Reporting Items for Systematic Reviews (PRISMA)”. The identification and selection of articles was carried out in August 2023 by two researchers, independently.

The following search descriptors and Booleans were used to search the title, abstract and keywords of documents of the type “articles”, “review” and “conference paper” published from 2018 to 2023, in English and Spanish, in Web of Science and Scopus:

> ((((("virtual reality" OR immersive OR metaverse) AND ("industrial training" OR "industrial learning" OR "workforce industrial training") AND ("assessment training" OR "training evaluation" OR “feedback on training result” OR “training impact”) AND organization))))

After applying the filters, excluding redundant and repeated articles that are not compatible with the work, 12 publications were considered eligible. It is noteworthy that 2 more studies were included outside the inclusion criteria because they contributed to the study and were cited in articles located using the string.

3. RESULTS AND DISCUSSION

3.1. Potentialities and limitations of VR for industrial training

Immersion in VR enables the experience of innovation, avoiding the risk of damaging expensive industrial equipment. It is possible to experience various failures, including emergency situations that do not occur in normal day-to-day operations, preventing losses, risks to health and the organization's assets while evaluating the behavior of the trainee. In the virtual environment, the instructor can adopt 3 presence strategies: controlling his own avatar (a situation like the traditional methods); visualization of the behavior in real time, guiding the trainee (by audio, for example); or a posteriori analysis of the trainee's experience through data collected by devices [11-13].

Furthermore, immersive technologies are powerful tools for manufacturing training. Considering the phases and activities of factory operations, VR is very useful for training in the first phases, with emphasis on safety training activities, setting/guidance, sorting, picking, keeping, assembling, installation. Virtual reality applications for training in the most advanced phases of industrial processes make up an unexplored field in terms of research. In addition, the operation of robots and humans in close proximity has great risk and the use of VR to control robots and heavy machinery, in a test environment, allows the evaluation of equipment and operator performance simultaneously, without physical risks [2].

Additionally, in contrast to traditional industrial training methods, which depend on facilities and equipment for each area, the use of virtual reality enables multiple training and assessment applications, independent of physical facilities, reducing investment in facilities, economic losses, and possible damages to equipment, as well as the training being conducted without interrupting productive processes in progress to train and evaluate the workforce [11].

Another point worth mentioning is that, considering the advancement of Industry 4.0, the factory operator experiences mental overload due to carrying out daily activities, especially when dealing with manual labor activities combined with different computer systems and digital equipment. The adoption of VR enables a possible solution by offering a digital assistance system for real-time worker training, thus reducing human errors [5].

The great advantage of using these technologies is found in the literature in enabling the development of critical skills in an environment without physical risks that allows interaction with the environment in a natural way. In addition, VR enables the immediate transfer of behavioral skills in virtual environments to the real world [11]. An identified limitation is that immersive technology platforms for training are limited by available hardware and software [2]. The degree of realism and immersion depends, among other factors, on the advancement of these technologies combined with the company's level of investment.

Finally, some authors point out that the incorporation of immersive technologies in training is not intended to replace practical sessions with real equipment, being preferable to combine real and virtual experiences [11;13].

3.2. Comparison between traditional and VR-based training on transferring content to a risky environment

The literature points out that the participation of workers in training focused on safety in a risky environment does not guarantee that these programs will be effective in actually improving the safety of trainees, and problems may occur in the process of transferring the knowledge, skills and attitudes learned to the real work environment. exercise of work activities [14;15].

This is because nowadays this type of training program is often executed in a traditional way and not customized to the heterogeneous and specific needs of the participants, that is, standardized programs are adopted that lead users to not realize the importance of the course and the applicability to your professional context. Furthermore, methodologies with low physical and psychological similarity with the risky environment are commonly used, in such a way that the sensory information received is not enough to create the perception of actually being in that place [15;16].

Regarding this aspect, VR has been punctuated in the literature as a set of technologies that have strong physical and psychological fidelity. That is, capable of immersively transposing trainees to a scenario with a high level of realism by recreating complex representations of the work environment that would be markedly difficult, expensive or dangerous to reproduce in the real world. There is also evidence that the use of VR tends to generate greater applicability of knowledge in the workplace, as it enables situational training, and is therefore essential in the training of technical personnel in the execution of activities and functions that require experimental practice and that bring risk to the safety of trainees, equipment and products. In addition, training simulations that use these technologies in conjunction with a generative learning strategy, which enables trainees to reflect on the content and materials used after the meeting, are more positive in terms of knowledge transfer [11,13,15] .

3.3. Traditional assessment models and new needs for effectiveness analysis derived from the application of emerging technologies in industrial training

The traditional 4-level model of KirkPatrick for assessment measures reaction, learning, behavior and results of a training program [17]. To assess the reaction to the training, it is sufficient that feedback is given after the event or that an anonymous questionnaire is distributed. To assess immediate learning, it is sufficient to apply a written or practical test. That is, the two initial levels measure results obtained in the short term and have more simplified analysis mechanisms. However, the great challenge of training evaluations concerns long-term effectiveness evaluations, related to behavior change and results analysis. This is because participants can react positively to the training and apply the knowledge gained in measurement through tests or activities. However, this does not mean that there will be behavioral change and transfer of knowledge to day-to-day work with practical results for the organization in the long term [1;17]. This model has withstood the test of time, being considered practical and widely used, both as a basis for research and for application in organizations [12].

Traditional effectiveness assessments tend to be restricted to the analysis of issues related to infrastructure, materials, or specific items at the time of the assessment. Therefore, this information would hardly help to feedback and contribute to the improvement of the program as a whole, as it would lack elements to indicate actions to improve the process itself [18].

Furthermore, when it comes to simulation-based learning, traditional methods are not capable of detecting or measuring trainees' reactions, emotions and experiences during a simulation. That is, as technology advances, providing increasingly impactful technological alternatives, approaches to training and assessment methods must be modified to enable the adoption of new learning environments [1].

3.4. Layers for evaluating the effectiveness of training programs focused on safety at work in VR

In general, the factors related to the training environment that are usually analyzed in security training effectiveness evaluations are those related to the course design, methodology and technologies used. However, the literature points out that there are individual factors and those of the organizational context that must be understood since they interfere in the application of the knowledge acquired after training and that, therefore, must be considered. The individual ones relate to the participant's characteristics (such as age; length of experience; profession; learning style; previous knowledge; intrinsic motivation; motivation for transferring knowledge to the work environment, and self-efficacy, which would be the person's perception about their ability to learn or practice actions). The factors linked to the organizational context are those related to the work environment where it will be applied after learning (such as type of professional activity or project; leadership; social support; safety-related communication; safety climate; incentives, and norms for the adoption of safe behaviors and organizational culture) [14,16].

The literature suggests the following variables to evaluate the results of a training focused on safety at work that uses VR technology in its format: pleasure obtained in learning; participant's intrinsic motivation; self-efficacy, external cognitive load; level of reflection generated by the training; learning perceived by trainees; Developed safety attitudes and behavioral change that translates into intention to change [15].

With regard specifically to the evaluation of learning related to aspects inherent to the training environment in VR, Jesus et al [18] proposes that in conventional training, the evaluation of the effectiveness of a training is in the ability of the trainee to reproduce that content, based on an expectation of training capacity. In the model suggested by the researchers in VR, the evaluation takes place dynamically, in the interaction of the participants with objects and learning scenarios, that is, with the simulated virtual environment. This evaluation is based on the data that are generated from this interaction, with a decrease in the time dedicated to training and less need for new training. The model by Jesus et al [18] converges with the research by Ben-Hador et al [19], regarding the importance of training programs being marked by the promotion of interactive experiences for trainees and less theoretical ones to have greater effectiveness in program evaluations and, consequently, greater long-term return on learning acquired.

4. CONCLUSION

The present work aimed to review how VR technologies can support processes to evaluate the effectiveness of industrial training programs before professionals are exposed to high-risk work processes.

From the evidence collected, it is possible to infer that, despite the promising perspectives for the use of VR, the existing literature on the application of immersive technologies for training still has significant limitations, especially regarding the evaluation of these training programs. Also, there are few articles found that delve into the topic of evaluating training programs using immersive technologies. That is, in general, they limit themselves to positioning the assessment as a step in the training process carried out in VR.

Finally, within the scope of the present work, no articles were identified aimed at carrying out the evaluation of industrial training, specifically, isolated from the need to carry out the training itself in VR, which signals a probable lack of knowledge on the subject and an opportunity to future scientific research.

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