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Bridging the Gaps: Examining the Impact of Technology-Based Active Learning in Workplace Safety Training Through a Systematic Literature Review

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Abstract: Theoretical background: Occupational safety training is crucial for reducing workplace risks, but traditional approaches often struggle to fully engage participants or guarantee effective knowledge retention. Over the past decade, interest in using technology-based active learning strategies has grown, with active learning focusing on practical approaches that actively engage workers in the learning process. Objective: The research aims to identify the active learning strategies currently employed in OS training and assess the benefits and challenges of these approaches. Method: A systematic literature review was conducted in line with the PRISMA guidelines. After a rigorous selection process based on inclusion and exclusion criteria, 24 eligible articles were identified from the Scopus, Web of Science, and PubMed databases. Results: Technology-based active learning strategies, especially serious games, enhance the comprehension of safety procedures. Simulating risk scenarios and providing immediate feedback facilitates knowledge transfer to real-world environments. However, limitations are evident, such as technical complexity, high implementation costs, and difficulties in acceptance by less experienced users. Conclusions: The study concludes by emphasizing the need for targeted research to overcome the identified challenges, such as improving simulation realism, reducing costs through collaborative partnerships, and addressing usability issues for different worker populations.

Keywords: occupational safety; active learning; serious games; systematic review

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1. Introduction

Over the past decade, there has been a significant increase in attention to occupational safety (OS), accompanied by a steady rise in legislation and regulations aimed at safeguarding occupational health and safety (OHS).

Occupational safety is commonly defined as an attribute of work systems that reflects the low probability of suffering immediate or delayed physical harm to people, property, or the environment during the performance of work activities [1–3]. The most commonly examined occupational safety indicator is the occurrence of accidents [4], defined as workplace events that cause physical harm to people. However, while accidents may indicate an absence of safety, the lack of accidents is not sufficient to infer the presence of safety [5]. This is because such accidents generally depend on many factors (e.g., unsafe behavior or latent organizational weaknesses) that often do not coincide in causing an accident [6]. For this reason, training suitable for preventing accidents and injuries and promoting safe behavior are of fundamental importance.

OS training presents challenges due to its multidisciplinary nature and difficulty in conveying its concepts dynamically and engagingly for trainees. This training generally includes teaching workers how to identify and manage hazards, follow safe work practices, correctly use personal protective equipment, and carry out emergency procedures and preventive measures. It also informs workers on locating further information regarding potential risks [7]. Training should not be regarded as purely bureaucratic, but there is a need to focus on active training that is not considered an administrative obligation. It must actively involve workers and provide them with the knowledge and skills needed to prevent occupational accidents. Training strategies must encourage workers to be active players in ensuring safety in the workplace [8].

One potential solution to these challenges is the implementation of active learning strategies. These strategies support the development of knowledge and various competencies from a perspective that differs from traditional methods. In the last decade, the interest in improving learning strategies from this methodology has grown significantly both in educational [9] and professional contexts [10–12].

Active learning is defined as an intentional process that involves knowledge acquisition through learners' active participation, in which they learn by solving real-world problems [13]. According to Felder [14], methodologies involving frequent action and reflection enhance the learning process [9].

The use of active learning methodologies in organizations is certainly not new. In fact, recognizing that the more engaged a learner is in the learning process, the more effective the learning becomes has led over time to a preference for these types of training. Examples of active learning at work include hands-on workshops, simulations of real-world scenarios, role-playing exercises, group problem-solving activities, and on-the-job training where employees apply new skills directly in their work environment. However, these methodologies have recently been enhanced through the integration of technology, which has transformed their application. An example of technology-based active training strategies is the use of serious games (SGs), which integrate game elements into non-game contexts to enhance motivation and engagement [9,15]. Their ability to make learning more dynamic and interactive has proven especially effective in boosting participant involvement [16]. The development and adoption of active learning strategies in occupational safety training are driven by several factors, including the increasing complexity of modern workplaces and the growing need for compliance with safety regulations. These strategies not only improve knowledge retention but also enhance the practical application of safety procedures [9,11]. The rapid growth of research in this area highlights the potential for these technologies to shape the future of occupational safety training, offering hands-on, interactive learning experiences [17].

Although these active learning tools may help create a realistic, engaging, and motivating context where workers can practice without the risk of injury or causing harm to themselves or others, they may also have limitations due to the complexity [18,19] some individuals face in becoming familiar with and adapting to new technologies. Low usability could make interacting efficiently with the game challenging, decreasing interest and the willingness to use it. Additionally, a poorly designed experience could lead to reduced satisfaction and motivation, negatively affecting user engagement and learning outcomes [19,20].

Different types of active learning training through technology have been implemented recently; however, their effectiveness still needs to be clarified and the advantages or disadvantages of using these strategies need to be clarified. Indeed, the integration of new technologies into OS training poses challenges, such as the need for users to adapt to new platforms, which can be particularly difficult for those less familiar with digital tools. Issues like low usability, high costs, or technological malfunctions can undermine the training experience, potentially reducing the effectiveness of the learning process.

Understanding the real effectiveness of active learning methodologies is crucial for researchers and professionals in the field of OS. At the same time, recognizing the specific limitations associated with their use allows us to develop and implement targeted strategies to address these challenges, thereby enhancing the overall effectiveness of training programs. Based on these premises, the purpose of this study is to explore the advantages and disadvantages of technology-enhanced active learning in the field of OS, structured around two research questions.

1. What are the most common technology-based active training strategies implemented in the field of OS?
2. What are the inherent advantages and disadvantages of the technology-based active training approach in the context of OS?

The present study will be able to fill the gap in the literature by analyzing the effectiveness, advantages, and disadvantages of technology-enhanced active learning strategies in occupational safety training.

2. Methods

A systematic literature review methodology was employed to address the research questions. This approach allows for the investigation of the concepts and data already published in the literature on a specific field, answering predefined questions and assessing the authenticity of the information sought [21]. The methodological procedure was conducted based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (PRISMA) [22]. Initially, the databases identified for article searches were Scopus, Web Of Science, and PubMed. Subsequently, keywords and Boolean operators were defined to combine them for the search string construction. The identified keywords are as follows: "Safety" OR "Health and Safety" OR "Occupational Safety" OR "Workplace Safety" OR "Safety at work" AND "Serious game" OR "Gamification" OR "Immersive Learning" OR "Active Learning".

After extracting the articles, they were analyzed based on specific inclusion and exclusion criteria (see Section 3.1). Subsequently, those deemed suitable for inclusion were evaluated for their methodological quality using the mixed methods appraisal tool (MMAT) [23]. The first two screening questions on the MMAT must be answered correctly to move on to the quality assessment. These questions evaluate the suitability of the data gathered concerning the study's goals and the clarity of the research question or questions. The researcher then has to decide which category, according to the study's research design, is best for each study. The five fundamental quality criteria included in each category for assessing studies are the appropriateness of the sampling approach, the population's representativeness, the suitability of the measurements, the response rate, and the suitability of the statistical analyses. To perform the assessment, the latest version of the MMAT recommends selecting one of three response options (yes, no, and cannot tell) for each quality criterion identified for the specific design category [23]. According to the recommendations [23], the first two authors independently conducted the assessment, and any discrepancies were resolved through discussion with the third author.

3. Results

3.1. Research Results

The search and selection of publications followed several steps.

Firstly, the following inclusion criteria were applied: Empirical studies published in English or Italian and studies related to the OHS field. This led to an initial selection of relevant studies. Secondly, duplicates were removed.

The subsequent analysis phase followed four main steps, summarized in Figure 1. In the first phase (Identification), all studies (n = 1361) were gathered from the databases mentioned above using search strings, and the combinations of keywords were uploaded to the specifically created screening platform, Rayyan.

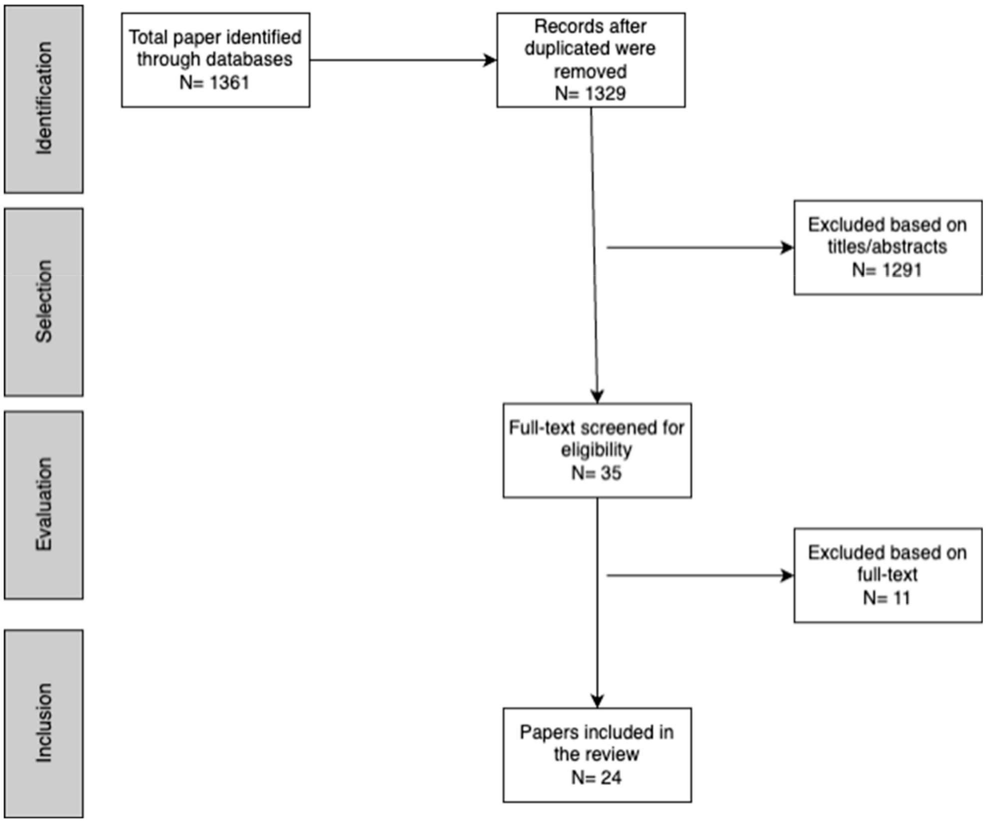

Figure 1. PRISMA flowchart.

After removing duplicates (n = 32), the remaining articles (n = 1329) were selected and evaluated for relevance to the selection criteria by reading their titles and abstracts. The inclusion criteria require that articles explicitly address the application of technology-based active learning methodologies for workplace safety training; present empirical studies (qualitative, quantitative, or mixed methods) analyzing the pros and cons, benefits, or challenges of using active learning for safety; and focus on relevant occupational contexts such as construction, the chemical industry, energy, and healthcare, where safety training is critical, while excluding articles centered on non-occupational contexts.

Of these, 1291 were excluded in the Screening phase as they were deemed unsuitable.

Subsequently, in the Eligibility phase, the full texts of the remaining articles (n = 35) were read, and those not meeting the criteria mentioned above were excluded (n = 11). The main reason for exclusion was linked to the presence of studies dealing with the topic of non-occupational safety training, such as road safety or urban evacuation procedures in case of natural disasters.

As shown in Table 1, all the selected papers satisfied at least three out of the five quality criteria outlined by the mixed methods appraisal tool (MMAT) [23] and were, therefore, deemed suitable for inclusion in this systematic review.

Table 1. Mixed methods appraisal tool (MMAT), version 2018.

	Screening Questions		Qualitative Studies					Quantitative Descriptive Studies				
	S1.	S2.	1.1	1.2	1.3	1.4	1.5	4.1	4.2	4.3	4.4	4.5
Proctor et al., 2007 [24]	Y	Y						Y	Y	Y	-	Y
Liang et al., 2019 [25]	Y	Y						Y	N	Y	-	Y
Ahn et al., 2020 [26]	Y	Y						Y	Y	Y	-	Y
Lanzotti et al., 2020 [27]	Y	Y						Y	Y	Y	-	Y
Lee et al., 2020 [28]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	Y
Kazar et al., 2021 [29]	Y	Y						Y	Y	Y	-	Y
Lovreglio et al., 2021 [30]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	Y
Paszkivick et al., 2021 [31]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	Y
Rahouti et al., 2021 [32]	Y	Y						Y	Y	Y	-	Y
Bernal et al., 2022 [33]	Y	Y						Y	Y	Y	-	Y
Dobrucali et al., 2022 [19]	Y	Y						Y	Y	Y	-	Y
Jacobsen et al., 2022 [34]	Y	Y						Y	Y	Y	-	Y
Kazar et al., 2022 [35]	Y	Y						Y	Y	Y	-	Y
Mystakidis et al., 2022 [36]	Y	Y						Y	Y	Y	-	Y
Wolf et al., 2022 [37]	Y	Y						Y	Y	Y	-	Y
Abotaleb et al., 2023 [38]	Y	Y	Y	Y	Y	Y	Y					
Boel et al., 2023 [20]	Y	Y						Y	Y	Y	-	Y
Chan et al., 2023 [18]	Y	Y						Y	Y	Y	-	Y
Gürer et al., 2023 [39]	Y	Y						Y	Y	Y	-	Y
Gurbuz et al., 2023 [40]	Y	Y	Y	Y	Y	Y	Y					
Rey et al., 2023 [41]	Y	Y						Y	Y	Y	-	Y
Ristor et al., 2023 [42]	Y	Y						Y	Y	Y	-	Y
Rivera et al., 2023 [43]	Y	Y	Y	Y	Y	Y	Y					
Tzioutzios et al., 2023 [44]	Y	Y	Y	Y	Y	Y	Y					

Note: (Y) yes, (N) no, and (−) cannot tell. If a response is not provided in the table, it means that the criterion is not applicable to that study. Screening questions: (S1) Are there clear research questions? (S2) Do the collected data allow us to address the research questions? Qualitative studies: (1.1.) Is the qualitative approach appropriate to answer the research question? (1.2.) Are the qualitative data collection methods adequate to address the research question? (1.3.) Are the findings adequately derived from the data? (1.4.) Is the interpretation of the results sufficiently substantiated by data? (1.5.) Is there coherence between qualitative data sources, collection, analysis, and interpretation? Quantitative descriptive studies: (4.1.) Is the sampling strategy relevant to addressing the research question? (4.2.) Is the sample representative of the target population? (4.3.) Are the measurements appropriate? (4.4.) Is the risk of nonresponse bias low? (4.5.) Is the statistical analysis appropriate to answer the research question?

3.2. Studies' Results

The present paragraph (and Table 2) presents the articles' characteristics, including the population involved, the context and country, and the type of active learning strategies used. Following this, in Sections 3.2.2 and 3.2.3 and Table 3, the strengths and weaknesses that emerged were identified.

3.2.1. Descriptive Results

Population: The analysis of the populations examined in the 24 studies included in this systematic literature review reveals that in most instances (n = 17), workers were involved. In two studies, both workers and students participated (n = 2). Additionally, in five cases (n = 5), the studies focused on university students, while in one case (n = 1), interns were included.

Occupational sector: Regarding the occupational sectors, most studies came from the construction sector (n = 11), followed by educational (n = 4), mining (n = 2), and chemical (n = 2). Other contexts represented included electrical substations (n = 1), aviation (n = 1), maritime navigation (n = 1), and healthcare (n = 1).

Methods: This systematic literature review identified three primary methods used to evaluate the effectiveness of training programs: post-training questionnaires (n = 22) to capture user perceptions and feedback on their active learning experience [18–20,24–35,45], pre- and post-training questionnaires (n = 8) to compare engagement and satisfaction levels before and after training [20,36–38], and interviews (n = 2) to gather detailed participant insights on training impacts [18,27].

Active learning: Most studies (n = 22) utilized serious games (SGs) as the primary strategy for active learning. Specifically, within the construction and mining sectors (n = 13), some SGs were based on Building Information Modeling (BIM) (n = 3), a design and project management methodology that integrates all the relevant data and information for construction projects. Additionally, SGs focused on guiding users in the correct selection and use of personal protective equipment (PPE) on construction sites (n = 4). These games enable players to interact with virtual PPE, learn about its proper application, and recognize the risks associated with neglecting safety gear. By immersing users in realistic scenarios, these SGs enhance PPE knowledge and reinforce adherence to safety protocols on the job. Fire safety and emergency response training (n = 3) is another critical area where SGs are applied, especially in preparing workers for fire-related incidents. In these games, players simulate emergency response actions—such as locating fire extinguishers, following evacuation routes, and practicing fire suppression techniques—offering a practical means for workers to develop the necessary skills to handle emergencies in high-risk construction environments. Furthermore, ergonomics and physical safety (n = 2) are addressed through SGs designed to teach safe lifting techniques and correct posture. These games use digital human models to simulate safe postures for common construction tasks, allowing trainees to practice the safe handling of heavy objects, which reduces the risk of injury. In one example, immersive simulations allow trainees to practice responding to hazardous scenarios and make critical safety decisions in a virtual job site. In another, virtual reality (VR) was integrated with simulation technology to enhance the realistic and interactive aspects of the training experience.

Table 2. Data extraction table about descriptive results.

Context	Method	Training	N and Type of Work	Country	Author (Year)
Construction	Questionnaire	BIM and Serious Game	189 Construction workers	Korea	Ahn et al. (2020) [26]
Construction	Questionnaire	BIM and Serious Game	167 Construction workers	USA	Dobrucali et al. (2022) [19]
Construction	Questionnaire	Serious Game	150 Construction workers	Italy	Lanzotti et al. (2020) [27]
Construction	Questionnaire	Serious Game	90 University students	Singapore	Lee et al. (2020) [28]
Construction	Questionnaire	Serious Game	90 University students	Turkey	Kazar et al. (2021) [29]
Construction	Questionnaire	Serious Game	14 Construction workers	Denmark	Jacobsen et al. (2022) [34]
Construction	Questionnaire	Serious Game	50 Construction workers	Turkey	Kazar et al. (2022) [35]
Construction	Questionnaire	Serious Game	30 Construction trainees	Denmark	Wolf et al. (2022) [37]
Construction	Questionnaire	Serious Game	59 Students and safety experts	Egypt	Abotaleb et al. (2023) [38]
Construction	Questionnaire	Serious Game	20 Construction workers	Spain	Rivera et al. (2023) [43]
Construction	Questionnaire	Serious Game	109 Construction workers	Columbia	Rey et al. (2023) [41]

Table 2. *Cont.*

Context	Method	Training	N and Type of Work	Country	Author (Year)
Use of fire extinguishers	Questionnaire	Serious Game	45 Workers	New Zealand	Lovreglio et al. (2021) [30]
Use of fire extinguishers	Questionnaire	Serious Game	20 University students	Poland	Paszkivick et al. (2021) [31]
Use of fire extinguishers	Questionnaire	Serious Game	33 Workers	Greece	Mystakidis et al. (2022) [36]
Use of fire extinguishers	Questionnaire	Simulation and VR	36 University students	France	Ristor et al. (2023) [42]
Chemical	Questionnaire	Serious Game	37 Chemical workers	France	Chan et al. (2023) [18]
Chemical	Questionnaire	Serious Game	24 University students	Norway	Tzioutzios et al. (2023) [44]
Mining	Interview	Serious Game	20 Trainees in the mining sector	China	Liang et al. (2019) [25]
Mining	Focus Group	Serious Game	30 Mining workers	Turkey	Gürer et al. (2023) [39]
Aviation	Questionnaire	Simulation	45 Aviation workers	USA	Proctor et. al. (2007) [24]
Hospital	Questionnaire	Serious Game	45 Hospital workers	Belgium	Rahouti et al. (2021) [32]
Instruction	Questionnaire	Serious Game	8 Construction workers, 50 students	Netherlands	Boel et al. (2023) [20]
Maritime navigation	Questionnaire	Serious Game	10 Maritime workers	Turkey	Gurbuz et al. (2023) [40]
Electrical substation	Questionnaire	BIM e Serious Game	16 Workers in electrical substations	Columbia	Bernal et al. (2022) [33]

3.2.2. Strengths of Training Through Active Learning

Engagement and Active Learning

The results of the analysis indicate that one of the primary strengths observed in various studies is the increased engagement of workers during the training activity (n = 7) [19,27,35,38,39]. The studies demonstrated that workers are more attentive and focused during the learning process, leading to a greater understanding of safety concepts and procedures, as well as more effective application of safety practices in the workplace [19,27,35,38,39].

Additionally, two significant strengths observed were increased motivation to learn (n = 5) [18–20,38,39] and a heightened sense of self-efficacy among workers, defined as confidence in their ability to perform safety-related tasks (n = 3) [18,19,37]. The studies highlighted that the motivation derived from using SGs encourages workers to actively participate in training and apply what they have learned in the field [18–20,38,39]. Furthermore, an increase in self-efficacy perception leads to safer workplace behaviors and reduced incidents [18,19,37]. These positive elements contribute to promoting a safer work environment and preserving workers' health and safety.

Another significant observation from the analysis concerns the learning experience of the workers who participated in training through SGs. The workers expressed positive opinions on various aspects of the experience, including the sense of engagement, the quality of game design encompassing information organization and user interface, and the degree of interest and enjoyment during the learning experience. They also acknowledged SGs' usefulness and practical value for their learning (n = 2) [20,36]. These results suggest that SGs can effectively engage workers and enhance the acquisition of skills relevant to their professional field. Finally, our analysis also highlighted workers' positive responses regarding using virtual reality in training. Workers reported increased engagement, attention, and a sense of control during the learning process (n = 1) [18]. These realistic models have proven helpful in providing effective training on specific safety procedures and gathering more accurate feedback on workers' skills.

Interactivity and Feedback

Technology-enhanced active learning strategies have proven more effective for safety training (n = 5) [25,30,31,33,34], particularly in knowledge acquisition (n = 1) [37] and procedural learning (n = 1) [20]. In particular, when SGs are designed to be challenging and fun, participants are more engaged and motivated to learn. These elements make the learning experience more engaging and effective, facilitating the absorption and retention of workplace safety information [25,30,31,33,34].

Additionally, SGs help maintain skills over time (n = 1) [28] and achieve learning objectives quickly (n = 1) [35]. This active learning methodology allows for a comprehensive job performance evaluation, considering all the relevant aspects (n = 1) [26]. Instead of evaluating performance based on a single element or event, this approach finds a full range of pertinent factors, providing a more accurate and in-depth view of an individual's capabilities and overall performance [26].

Workers report that SGs offer good usability, with positive feedback largely based on the feelings of immersion and flow experienced during interaction. Immersion refers to the sensation of being fully absorbed in the gaming experience. At the same time, flow is a mental state where a person is fully engaged in an activity, experiencing deep involvement and a pleasant loss of time and space perception [24].

3.2.3. Weakness of Training Through Active Learning

Technical Limitations

The analysis revealed several weaknesses related to technology-enhanced active learning strategies, including technical limitations and challenges. One major issue is the lack of realism (n = 10) [24,25,27,30–33,35,36,39]. This problem manifests through a simplified and sometimes distorted representation of real concepts, situations, and processes. Such a lack of realism significantly impairs the ability of active learning strategies, such as SGs, to provide an authentic and educational experience for workers. This discrepancy is attributed to various factors, such as the need to simplify complex concepts for a gaming audience and technical limitations in accurately replicating real environments and dynamics. Additionally, the game design often prioritizes entertainment over accuracy, further contributing to this disconnection from reality [24,25,27,30–33,35,36,39].

Moreover, the complexity of developing and designing the software used in these educational contexts presents a significant challenge. One of the primary obstacles to these modern educational approaches is the substantial financial investment required for their implementation (n = 3) [26,28,34]. This high financial commitment is a significant barrier for many educational institutions. Additionally, the intrinsic complexity of developing and designing the associated software necessitates specialized expertise in pedagogical and technological fields and dedicated resources. The lack of such expertise or resources can lead to delays or compromise the creation of high-quality digital resources, thereby limiting their effectiveness and adaptability to specific educational needs (n = 3) [19,28,34].

Ease of Use and Worker Acceptability

Technology-enhanced active learning strategies can present limitations due to the complexity some individuals encounter in familiarizing and adapting to modern technologies [18,20,29,37]. Many workers have not yet become familiar with the SGs used in safety training (n = 2) [18,20]. This phenomenon can be attributed to the rapid evolution of technology, which makes it difficult for some individuals to keep up with new trends and developments in educational gaming. Additionally, limited digital literacy, or the ability to effectively use and understand digital technologies and the information circulating within them, can make some individuals less inclined to use or adapt to complex technologies like SGs [18,20].

Other limitations associated with using these training methods include a perception of low usability (n = 3) [18,20,37], low acceptability (n = 3) [18,20,29], and complex ergonomics (n = 3) [18,20,29]. These factors can negatively influence workers' experiences, particularly with SGs, reducing their engagement and motivation. Low usability makes efficient interaction with the game challenging, decreasing interest and the willingness to use it [18,20,37]. Similarly, an unacceptable experience leads to dissatisfaction and reduced motivation to use the game [18,20,29]. Furthermore, complex ergonomic design causes physical discomfort, negatively affecting the experience and reducing user motivation [18,20,29]. Prolonged use of tools (such as headphones) during training sessions can have adverse effects on physical health, with some workers reporting ill feelings such as dizziness (n = 1) [18]. These factors undermine the overall effectiveness of SGs as learning and training tools.

Table 3. Data extraction table about strengths and weaknesses.

Author (Year)	Strengths	Weaknesses
Proctor et al., 2007 [24]	More effective for training	Low fidelity to reality
Liang et al., 2019 [25]	More attractive and memorable experience More engaging More familiar with high-risk contexts	Discomfort
Ahn et al., 2020 [26]	Feasibility and applicability to context	Need to resources
Lanzotti et al., 2020 [27]	More realistic assessment Increased attention Provides better feedback	Inaccurate knowledge assessment
Lee et al., 2020 [28]	More effective for training	Low fidelity to reality
Kazar et al., 2021 [29]	Fun Possibility of maintaining knowledge for longer	Difficult software development High costs
Lovreglio et al., 2021 [30]	Improved risk perception Better performance	Low fidelity to reality
Paszkievick et al., 2021 [31]	Reduced safety training costs More efficient training	Low fidelity to reality
Rahouti et al., 2021 [32]	Increased effectiveness for knowledge acquisition and retention Increased self-efficacy	Low usability Low sense of presence
Bernal et al., 2022 [33]	Acceptable usability Good feeling of flow and immersion	Low fidelity to reality
Dobrucali et al., 2022 [19]	Better performance Greater involvement Increased motivation	Difficulties in technology adoption
Jacobsen et al., 2022 [34]	Optimal assessment of worker knowledge	High cost Requires technical knowledge and user acceptance
Kazar et al., 2022 [35]	Greater involvement Possibility of simulating high-risk activities	Low fidelity to reality
Mystakidis et al., 2022 [36]	Elements of challenge, fun and mastery	Low fidelity to reality
Wolf et al., 2022 [37]	Increased motivation Greater involvement	Does not provide immediate feedback
Abotaleb et al., 2023 [38]	Feasibility and applicability to context	Differences in learning styles
Boel et al., 2023 [20]	Increasing risk perception	Low usability Uncomfortable ergonomics

Table 3. *Cont.*

Author (Year)	Strengths	Weaknesses
Chan et al., 2023 [18]	Greater involvement Increased motivation Increased attention	Low usability Uncomfortable ergonomics Unfamiliarity with the method
Gürer et al., 2023 [39]	Greater involvement Increased motivation	Low fidelity to reality
Gurbuz et al., 2023 [40]	More effectiveness for training	Low fidelity to reality
Rey et al., 2023 [41]	Greater involvement Increased commitment Increased self-efficacy	Need of training
Ristor et al., 2023 [42]	Improved procedural learning Increased motivation	Any effect on conceptual learning
Rivera et al., 2023 [43]	More effective for training	Difficult software development High costs
Tzioutzios et al., 2023 [44]	Achievement of learning in a short time Greater involvement Increased feelings of trust	Low fidelity to reality

4. Discussion

This systematic literature review aimed to assess the effectiveness of technology-enhanced active learning strategies in occupational safety (OS) training, examining the types of strategies implemented and evaluating their benefits and drawbacks.

Regarding potential benefits, previous studies have shown that active strategies can transform the learning process from passive to active and participatory, facilitating better knowledge assimilation and practical skill transfer [45]. Additionally, they offer the possibility to simulate risk situations in a controlled environment without exposing workers to real dangers [18,25,27,41,42]. This research confirmed that the adoption of SGs as an educational tool significantly increases workers' engagement and interest during the learning process [19,27,35,38,39]. This increased engagement translates into a better understanding of safety concepts and procedures and a more practical application of safety practices in the workplace. Furthermore, active learning enhances motivation for knowledge and a higher perception of self-efficacy among workers, which are critical elements for promoting safe behaviors [18,19,37,39]. The interactive nature of active learning strategies allows for immediate and accurate feedback on the participants' actions, facilitating a better understanding of concepts and more lasting learning [25,30,31,33,34]. This interactive dynamic is essential for maintaining high interest and long-term training effectiveness and for familiarizing workers with complex environments and procedures without exposing them to real risks.

Despite the highlighted benefits, implementing active learning poses certain limitations and challenges. The systematic review identified significant limitations compared to the existing literature. Reduced fidelity to reality remains a considerable challenge [24,27,30–33,35,36,39]. This lack of adherence to reality can compromise the educational experience, reducing SGs' ability to provide an authentic learning environment for workers. Those involved in developing these training interventions should, therefore, increase their realism as much as possible. Improved realism can enhance the training experience and ensure that workers are better prepared to deal with real risks.

Consistent with the literature, the results show that adopting active learning strategies requires significant financial investments and specialized human resources for the development and maintenance of digital applications [19,26,28,34], representing an obstacle, especially for organizations with limited resources. To reduce the costs associated with the implementation of technology-based active learning strategies, partnerships could be developed with public agencies, academic institutions, or organizations interested in promoting OS. These actors could help fund the development of modular training programs applicable to various occupational sectors. In this way, at least some components of training modules could be shared across multiple industries, optimizing costs and making training accessible even to companies with limited resources. Such partnerships could also support companies, easing the economic burden and enabling them to benefit from advanced technological solutions for occupational safety.

This research reveals significant gaps in evidence regarding acceptability, its potential health effects, and its impact on conceptual learning. The analysis found that the complexity associated with using active learning strategies, such as SGs, can negatively affect usability and acceptance by workers, especially older ones [18,20,29,37]. Perceptions of low usability and acceptance can reduce the effectiveness of active learning, limiting user engagement and motivation. Additionally, these learning strategies can cause discomfort, resulting in a negative experience for workers. It must be acknowledged that prolonged headset use could pose a health risk, necessitating preventive or corrective measures to mitigate such undesired effects [18]. To address usability challenges, a user-centered approach grounded in User Experience (UX) design could be adopted, ensuring that users play a key role in the development and refinement of training platforms. This approach emphasizes creating intuitive and user-friendly systems that meet the diverse needs of workers. In addition, offering progressive training sessions could help users gradually build familiarity and confidence with the technology, reducing potential resistance.

5. Limitations

From a methodological perspective, the main limitation of this review is the exclusion of gray literature related to the topic. Including only peer-reviewed papers ensured a high quality of evidence and reported findings. However, this approach may have excluded potentially valuable studies, best practices from organizations, industry reports, or unpublished literature. Comparing these results with other works, such as doctoral theses or conference papers, could help avoid "publication bias". Additionally, including articles in languages other than English could further broaden the scope of the analysis. The number of articles included in this systematic literature review highlights the need for more empirical studies to deepen the understanding of the topic. In particular, further research is recommended in high-risk industries beyond construction and mining, such as the energy and chemical sectors. Expanding the focus to these additional occupational environments could help assess the generalizability and variability of technology-based active learning strategies across different industries.

6. Practical Implications and Potential for Improvement

Our results suggest that active learning can significantly enhance training effectiveness by increasing worker engagement, motivation, and self-efficacy. These elements are crucial for promoting active and lasting learning, where workers acquire theoretical knowledge and develop practical skills and safe behaviors. However, technical and usability limitations must be considered when designing and implementing active learning. For this reason, this study highlights several actionable strategies to enhance the implementation and effectiveness of technology-based active learning in OS training.

Firstly, the design and implementation of these platforms require significant financial investments and specialized expertise, including professionals in pedagogy, game design, and occupational safety. Creating realistic and engaging scenarios can also be challenging, especially for organizations with limited resources. The formation of strategic partnerships with public institutions, academic organizations, and stakeholders committed to reducing workplace accidents could significantly alleviate the financial burden on companies. These collaborations could fund the development of modular training programs that are adaptable across industries, making advanced safety training accessible even to resource-constrained organizations.

About the acceptability issue, integrating a user-centered approach, immediate feedback, and personalizing the learning experience could mitigate some of the identified limitations, improving the overall effectiveness of active learning strategies. Enhancing the realism of simulations can provide more immersive and authentic learning experiences, better preparing workers for real-world hazards. Additionally, immediate feedback allows workers to quickly understand and correct errors, while personalized learning experiences can tailor content to individual needs and skills, enhancing relevance and impact. Simulating realistic risk situations without exposing workers to dangers is another advantage, allowing them to prepare adequately for emergencies. To reduce health risks associated with prolonged VR or headset use, training protocols should include regular breaks and ergonomic measures. Future research should investigate the long-term health impacts of VR training to guide improvements to minimize discomfort and other adverse effects. Lastly, there is a need to measure long-term impacts through longitudinal studies that assess the effects of active learning strategies on reducing accidents and improving the effectiveness of safety procedures.

7. Conclusions

Despite its technical and usability challenges, technology-based active learning remains a valuable tool in enhancing workplace safety training, promoting safer environments, and protecting workers' health. For researchers, further exploration is needed to expand the application of active learning across industries and investigate its potential to improve worker behavior. Future studies should focus on refining integration methods, evaluating the long-term effectiveness of skills learned, and exploring ways to make these technologies accessible and user-friendly for a wider range of employees. For practitioners, adopting more intuitive systems and exploring scalable, cost-effective solutions could help overcome the current barriers and ensure that active learning tools are widely adopted in workplace safety training.

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