ORIGINAL RESEARCH ARTICLE

Learning occupational safety through gamification: A randomized controlled field trial

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ABSTRACT

Background: Traditional health and safety training often fails to engage workers effectively. Gamification has emerged as a promising strategy to enhance motivation and learning outcomes. This study aimed to assess the effectiveness of a gamified training course in improving occupational health and safety knowledge.

Methods: A randomized controlled field trial was conducted with 77 participants. Participants were divided into two groups: an experimental group (EG) and a control group (CG). The intervention, titled "Let's play to 626!" consisted of a one-day course comprising a seminar and gaming session. The participants were assessed using an internally validated Q626 questionnaire at baseline (T0) and after the intervention (T1), with a knowledge score was computed ranged from 0 to15. Descriptive statistics, paired sample tests, and regression analyses were used to analyse the data.

Results: The internal reliability of the Q626 tool was moderate, with Cronbach's α of 0.723. The results indicated a significant improvement in Q626 scores for both the experimental group (EG) and the control group (CG) at T1 compared to T0 ($p<0.001$; meanEGT1=10.8, SD=1.9; meanCGT1=10.0, SD=2.7).

Discussion: The gamification session was associated with improved knowledge outcomes, comparable to those observed with traditional seminar-based training. Future studies should explore the long-term impact of gamified learning on occupational health and safety training.

Key words: randomized field trial, occupational health and safety, workers, workplace training, gamification

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Background

Ensuring occupational safety and health (OSH) is a fundamental aspect of modern business management. Conducting thorough risk assessments to identify potential workplace hazards is essential for implementing effective control measures aimed at preventing harm to employees. Training programs play a significant role "in improving current and future employee performance by improving their technical and professional competencies and enriching their specific knowledge, skills, abilities, and attitudes." To address these challenges, recent literature has explored innovative strategies to enhance OSH training, with gamification emerging as a promising approach (1). Numerous studies have emphasized the effectiveness of learning through play as a strategy for fostering engagement, inclusion, and comprehensive skill development, suggesting that play is synonymous with learning (2). Play "exemplifies one of the highest forms of experiential learning" (3), a principle that applies to adults as well (4). Moreover, research indicates that a playful mindset in adults correlates positively with various indicators of subjective and physical well-being (5,6). Gamification refers to "the use of game design elements in non-game contexts'" (7) to enhance user engagement, motivation and performance. In the context of training, gamified learning incorporates elements such as points, levels, badges, storytelling, or role-playing to simulate real-world challenges in a more engaging and interactive way. Studies have shown that gamified approaches can improve learning attitudes, behaviors and outcomes, making them particularly suitable for training in complex or high-risk environments such as occupational safety, including industrial settings and healthcare contexts (8–11). Despite the growing international interest in gamification for educational purposes, its application in workplace health and safety training remains limited, particularly in Italy. The consolidated Law on Health and Safety (Legislative Decree 81/08, commonly known as TUS in Italian) (12) serves as a key regulatory framework for defining health and safety standards. According to Italian legislation, all companies are required to provide risk-assessment training to their employees to avoid the risk of penalties. Employers are obligated to offer various mandatory training programs covering general and specific topics, including emergency management, with the costs covered by the employer. Workers engaged in professional activities within specific company locations must undergo mandatory training, consisting of general (four hours) and specific sessions (duration determined by risk factors). General training covers fundamental health and safety topics that are applicable to all types of businesses. Research has highlighted significant improvements in safety knowledge and test scores resulting from regular training courses utilizing diverse technologies and tools (10,11,13,14). However, in the Italian context, gamified training formats—such as role-playing and board games—are still rarely implemented in OSH education. Some evidence supports their use in health promotion programs targeting children and older adults (5–7,15–18), but their integration into worker training remains an innovative and underexplored area. This study aimed to perform a randomized controlled field trial to evaluate the efficacy of a gamified training program in enhancing workers' knowledge of occupational health and safety issues. Given the exploratory nature and limited sample size, this research should be considered a pilot study aimed at assessing feasibility and preliminary efficacy.

Methods

This study was conducted in accordance with the CONSORT statement (19), taking into account the pragmatic field setting of the trial. This project was conducted from September 2023 to June 2024. The study was registered on the Clinicaltrials.gov on September 28th, 2023 with the identifier number NCT06060379 and it was titled "Let's Play to 626!". The protocol was published in 2024 (20). A convenience sample of workers was recruited for this study, with participants randomly assigned to either the experimental group (EG) or the control group (CG). All invited participants were employed as technical-administrative staff within the university sector (Sapienza and Mercatorum Universities) or in the office-based sector (one company), ensuring a homogeneous organizational background across the sample. The random allocation

of participants to the experimental and control groups was carried out to ensure comparability between the groups and minimize the risk of selection bias. Participants were randomized at the beginning of each training session based on their presence at the meeting. A simple randomization procedure was applied using a pre-generated sequence of random numbers classified as even or odd, which determined allocation to the experimental or control group in a 1:1 ratio. The allocation sequence was generated by the research team prior to the sessions, and group assignment was performed by the investigators at the start of each session. Due to the pragmatic field setting of the study, no formal allocation concealment was implemented. Workers aged between 18-65 years were included in this study. Written informed consent was obtained after fully explaining the study. The intervention, named "Let's play to 626!" ("Giochiamo a 626!") is structured as a one-day course lasting 4 hours. It was conducted in person and divided into two sessions: a seminar and gaming session. According to Italian Legislative Decree 81/2008 (12), the seminar (1.5 hours) consisted of a slide presentation on occupational health and safety. It provides a concise overview of the evolution of occupational health and safety legislation in Italy, highlighting the definitions, obligations, and responsibilities outlined in the current legislation, for each role within a company (company owner "datore di lavoro DL", safety executive "Dirigente DG", Operator in charge "preposto OP", Prevention and Protection Service Manager "Responsabile Salute Prevenzione e Protezione RSPP", security officer "Preposto", inspector "Ufficiale dell'Organo di Vigilanza UOV", Occupational health physician "medico competente MC", workers' safety representative "Rappresentante dei Lavoratori per la Sicurezza RLS" and a simple worker). Additionally, the course explored risk assessment as a crucial tool for planning preventive and protective measures in the workplace, covering its definition, key components, and various stages. Three games were included in the second session: gamification session (approximately 2 hours). The decision to incorporate just three games is based on scientific considerations arising from previous studies that utilized gamification to support training courses focused on primary prevention themes, including fighting tobacco and alcohol consumption, diet and nutrition, physical activity promotion, and immunization (16,21–23). Through interactive, gamified experiences, employees can practice applying safety measures in scenarios that closely mimic real-world situations, fostering both awareness and proactive risk mitigation skills. 1. Role-Playing Game (RPG): One such game is a role-playing game (RPG). RPGs serve as pedagogical tools in various educational and professional contexts and foster the development of diverse skills and abilities. Scientific research supports the benefits of RPGs, including enhancement of social skills, experiential learning, problem-solving abilities, decision-making skills, team building, practical application of knowledge, and competence development (24–27). 2. Board Game: The second game is a board game. Board games facilitate knowledge development, socialization, friendly competition, and working memory (16,28–33). They provide an interactive environment that encourages players to engage actively with each other. 3. Card Game: The third game is a card game designed to enhance executive function. Card games improve attention, concentration, cognitive flexibility, and mental organization (23,34,35). This game aims to strengthen players' ability to manage tasks, adapt to new information, and effectively organize their thoughts. The three games are named respectively: "626 Action!", "Reduce the premium!" and "Your hand on it!", explained in the following section.

626 Action! (626 si Gira!)

It is a role-playing game where each player assumes the roles of various actors and actresses involved in workplace health and safety. Players engage in finding solutions to scenarios presented by 'story cards' actively participating based on the responsibilities and duties assigned to each character. This is a role-playing game where each player selects a "character card" to assume one of the various roles involved in workplace health and safety (e.g. DL, DG, RSPP, inspector, workers' safety representative, etc.). Through conversation and dialectical exchange, players create an imagined space where fictitious events unfold, introduced by a narrative card. The "character card" outlines the rules of the role-playing game, reminding players how, when, and to what extent each "player" can influence

the imagined space. The objective of the game was to find a solution to the scenario presented by the "narrative card" through active participation, adhering to the responsibilities and duties of each role. First, a story card is drawn, listing the characters/actors involved and the topic to be discussed. The number of actors ranged from a minimum of three to a maximum of eight. One player takes on the role of the "mediator" and guides the game using the "solution sheet" on the back of the "story card" This player can also assign roles to the participants and distribute the "character cards" along with their corresponding "character sheets" (Figure 1).

Once the characters are assigned, players have a few minutes to review and familiarize themselves with their characters' traits and responsibilities, and then… Action! The chosen story is then enacted. Each player portrays their character according to the "character card" and can consult the corresponding "character sheet" at any time for details on their character's traits and responsibilities. Players who are not directly involved can choose to assist a character or mediator. The game can proceed in various ways because there are no fixed rules. The mediator, through questions directed at different actors based on the story, should stimulate the narrative with the following questions:

- identifying needs
- defining the problem
- brainstorming possible solutions
- evaluate the solutions (if multiple solutions exist, players review the list and explain which ones they find acceptable)
- deciding on a solution (involving the relevant parties who must agree and acknowledge the efforts made to find a solution; it is also permissible to have later reflections from other characters).
- checking the solution by reviewing the story card and reflecting on different proposed solutions.

The game encourages active participation and problem-solving within the framework of each character's defined responsibilities.

Figure 1. The three games during their execution.

Reduce the premium! (Riduci il premio!)

This is a board game similar to monopoly, where each player represents a company, indicated by a pawn. Initially, each player receives an insurance premium represented by 15 colored bricks (Figure 1, 2nd photo). The game begins with all players rolling a die, and the player with the highest number takes the first turn, with the play proceeding clockwise. All players start from the "Start" square and move around the board based on the number rolled on the die. The board

consists of 30 squares; each associated with a different question or action that can either reduce or increase a company's insurance premium. When a player lands on a "Character" square, an opposing player asks them a question from the "True/False" True/False' deck. The player had 30 seconds to answer. If the player answered correctly, one brick was removed; if the answer was incorrect, one brick was added. When a player lands on a "Credits" square, the player to their left asks them a question from the "Credits Questions" list. These questions were related to a specific campaign and included three to five possible answers, with only one correct option. The player had 30 seconds to respond. A correct answer allows the player to remove one brick, whereas an incorrect answer results in gaining one brick. "Action" squares require the player to draw a card from either the "Pro" or "Against" deck. These cards describe the appropriate or inappropriate behaviors adopted by the company. Depending on the scenario, these actions can either reduce or increase the company's insurance premium, referring to INAIL (Italian National Institute for Insurance against Accidents at Work) insurance costs borne by the employer. INAIL offers premium reductions through a discount called "oscillation for prevention" for companies that implement measures to enhance prevention and improve health and safety conditions in the workplace beyond the legal requirements.

The winner is the first player to eliminate all of their bricks or, after a predetermined time, the player with the fewest bricks remains.

Your hand on it! (Mettici la mano!)

The rules of this game are based on the traditional Italian card game "Tappo". The objective was to answer character-related questions correctly and collect the most cards. Depending on the number of players, the dealer selects sufficient decks for each character to match the number of participants, ensuring that there are four cards of the same character with different colored backgrounds.

After shuffling the deck, the dealer handles four cards for each player and places the remaining deck in the center of the table. The game begins with the dealer's signal, at which point all players simultaneously pass one card to the player on their left while receiving a card from the player on their right (Figure 1, 3rd photo).

The first player to gather four identical cards (for example, four RLS cards) must shout "626!" and placed their hands in the center of the table. Subsequently, all other players had to quickly place their hands on top of their central hands. The player who places their hand first is then asked a question from the "True/False" deck by an opponent. They had 30sec to answer the following question:

- if they answer correctly: they win the "True/False" card;
- if they answered incorrectly, the card was awarded to the second-fastest player to place their hand in the center.

The game continues until a player collects the highest number of cards, or until a predetermined number of rounds is completed. The player with the most cards at the end of the game was declared the winner.Participants in the CG solely attended the "Seminar" on occupational safety and health without engaging in any games. The EG, on the other hand, participated in both the "Seminar" and the "gamification session" gamification sessions in groups of six individuals. All three games were tested by all workers in the EG (see Figure 1). A preliminary pilot session was conducted before the start of the randomized controlled field trial to assess feasibility and clarity of the training activities. Data collected during the pilot session were not included in the final analysis, as minor modifications were subsequently made to the game roles and to selected items of the Q626 questionnaire.

Measurement

All participants were requested to complete a questionnaire (Q626) consisting of two sections: the first section covered demographic and professional details (age, gender, professional activity, safety or safety rules in their own company: Y/N), while the second section focused on knowledge of occupational health and safety: 15 multiple-choice questions with four possible answers, only one of which is correct. The

questions in the Q626 were developed based on the content of the powerpoint presentation of the seminar, as well as the issues presented in the games. These questions are related to health and safety issues derived from the Italian Decree 81/2008 (12), and were developed by a panel of three experts on Occupational medicine and Workplace health and safety. In the supplementary material, the questionnaire is available in both English and Italian. For each correct answer, 1 point was calculated. The final score Q626 was calculated as the sum of the correct answers and ranged from 0 to 15 to assess the level of knowledge. The Q626 questionnaire was administered at two time points: T0 (before the start of the training activities) and T1 (post-intervention). At T1, participants in the control group completed the questionnaire immediately after the seminar, whereas participants in the experimental group completed it after both the seminar and the gamification session. The T1 assessment was designed to capture immediate post-intervention knowledge recall rather than long-term learning or retention. The primary outcome of the study was the Q626 knowledge score at T1.

Reliability analysis

The outcome "Q626 score" was adopted to assess the reliability and internal validity of the questionnaire.

A sample size of 60 workers was determined for the reliability analysis determined based on a widely accepted rule of thumb of four participants per questionnaire item, as recommended by Nunnally (36), Streiner and Norman (37) and Bujang and Baharum (38). This heuristic ensures stable and reliable estimates of internal consistency (Cronbach's alpha, α). Separately, an a priori power analysis was conducted to calculate the sample size required for the intervention study. Using Cronbach's α, internal consistency was interpreted as follows: ≥ 0.90: excellent (very high reliability); 0.80 – 0.89: good (high reliability); 0.70 – 0.79: acceptable (moderate reliability); 0.60 – 0.69: questionable (low reliability); 0.50 – 0.59: poor (very low reliability); < 0.50: unacceptable (no reliability) (39). The stability of Q626 was estimated by considering 25% of the sample workers (N=15) (38), to whom the questionnaires were administered twice with a five-day interval. The "Q626 scores" obtained in the two administrations of the questionnaire were compared using Spearman's correlation and the Wilcoxon signed-rank test for paired samples. For this study, the sample size of 78 participants was estimated, approximately 38-39 per group (EG and CG) was estimated through an a priori power analysis based on a significant level of 0.05, with (5% significance), a power of 80%, a baseline percentage of correct responses at T0 set at 50%, and an expected 30% improvement post-intervention (80% correct responses). Descriptive statistical analysis was conducted using the mean and standard deviation (SD), median, and interquartile range (IQR) values for quantitative variables, as well as frequencies and percentages for categorical variables. The effectiveness score, termed the "Q626 score"" (ranging from 0 to 15), was compared before and after the intervention (T0 and T1) and between the two groups (EG and CG) to estimate the effectiveness of the seminar alone versus the seminar combined with game sessions. The comparison was tested using the parametric Student's t-test for paired samples for normally distributed variables, or the Wilcoxon signed-rank test for two paired samples for variables not normally distributed. Additionally, the Student's t-test for independent samples in the case of normal distributions or the Mann-Whitney test was utilized to determine whether the EG group was different from the CG group. The normality of the distribution of the Q626 score was assessed using the Kolmogorov-Smirnov test. Levene's test was used to assess the possible presence of differences in variance between two independent groups. In addition to descriptive and univariate analyses, an analysis of covariance (ANCOVA) was performed to compare post-intervention knowledge scores between groups while adjusting for baseline knowledge. The Q626 score at T1 was used as the dependent variable, study group (experimental vs control) as the fixed factor, and baseline Q626 score (T0) as a covariate. Effect size was estimated using partial eta squared, and adjusted group differences were reported with 95% confidence intervals (CI95%). Statistical significance was set at $p < 0.05$. Analyses were conducted using GNU PSPP 2.0.

Ethical issues

The study was registered on ClinicalTrials.gov on September 28, 2023, under the identifier NCT06060379. Ethical approval was obtained from Universitas Mercatorum Ethical Committee on February 1, 2024 (Prot. 0617). The study will adhere to the principles outlined in the Helsinki Declaration of 1975, as revised in 2008 (40).

Results

Three intervention sessions were organized. The first session was conducted as a pilot phase prior to the start of the randomized controlled field trial. Participants involved in the pilot session were not included in the randomized sample and were excluded from the final analysis. The pilot phase was used to test feasibility, refine game roles, and improve the clarity of selected items of the Q626 questionnaire. After the pilot session, the intervention protocol and the questionnaire were finalized and applied consistently across all subsequent randomized sessions.

Reliability of the measurement tool

A total of 77 workers participated in the reliability analysis, with the overall Cronbach's alpha coefficient for the Q626 questionnaire reported at 0.723 across all 15 items, indicating moderate reliability (Table 1). This reliability measure suggests that the Q626 questionnaire is suitable for assessing knowledge in occupational health and safety.

Regarding stability, a sample of 15 workers was recruited and completed Q626 twice. These workers were not exposed to the intervention. The Q626 scores did not significantly differ between the two administrations ($p = 0.107$, Wilcoxon signed-rank test), and Spearman's correlation coefficient was 0.609 ($p = 0.007$).

Randomized controlled field trial

The period of recruitment was from December 2023 to April 2024. The study sample consisted of 77 workers invited to participate in training courses.

Table 1. Statistics of Cronbach's Alpha total and if item deleted.

Items of Q626 questionnaire	Cronbach's Alpha if Item Deleted
Item 1	0.697
Item 2	0.697
Item 3	0.693
Item 4	0.731
Item 5	0.688
Item 6	0.712
Item 7	0.724
Item 8	0.719
Item 9	0.709
Item 10	0.736
Item 11	0.737
Item 12	0.715
Item 13	0.689
Item 14	0.702
Item 15	0.670
Total	**0.723**

The mean age was 40.1 years (SD=13.1) and 40 workers (52%) were female. All workers came from the same type of organization, specifically technical-administrative staff in the university sector. Additionally, 66 (86%) participants did not play a role in workplace health and safety.

The participants in the gaming experimentation group (EG) totalled 44 (57%), while those attending only the seminar (CG) numbered 33 (43%) (Figure 2). No missing data were observed for the variables included in the analysis.

No significant differences were observed between the experimental and control groups at baseline with respect to age, sex, or occupational safety roles ($p>0.05$). Table 2 shows the comparison between the EG and CG at T0 and T1, and the difference before and after the intervention. The Q626 scores did not significantly differ between the two groups at T0 ($p=0.172$; meanEG= 8.6 SD= 2.7; meanCG=7.7 SD=3.2). This indicates that the two groups started from a comparable baseline in terms of knowledge levels, which supports the internal validity of the comparison. Both

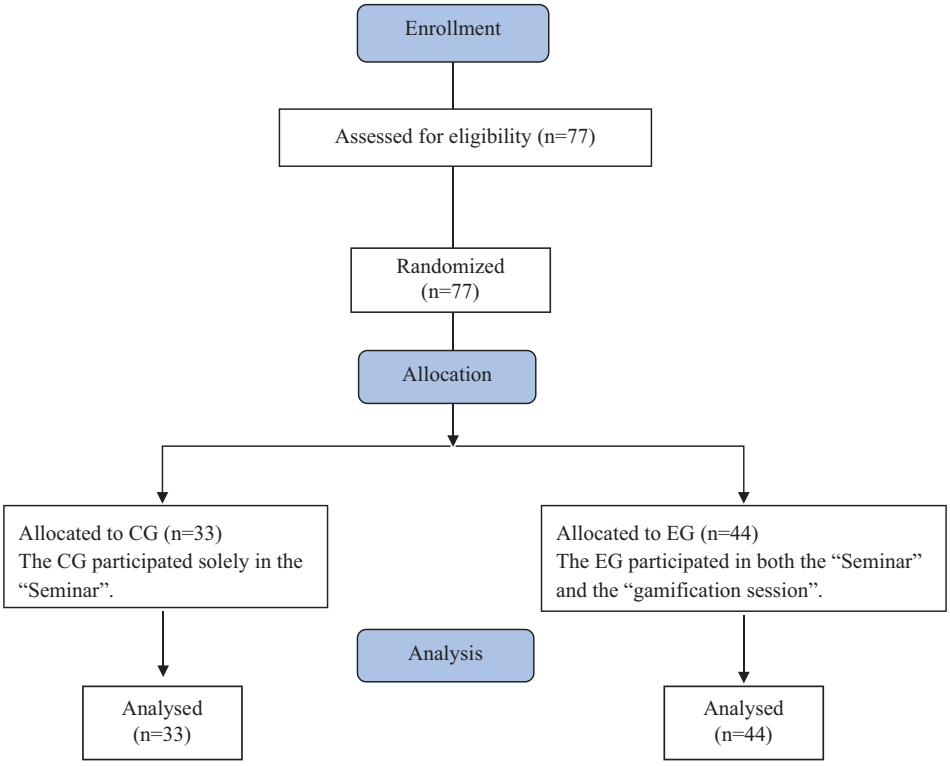

Figure 2. CONSORT flow diagram.

Table 2. Univariate analysis of the Q626 between CG and EG.

Q626 score			**Tot**		**CG**		**EG**		**p CG versus EG**
T0	**Median**	**(1st-3rd quartiles)**	9.0	(6.0-10.0)	8	(5.5-10.0)	9	(7.0-10.0)	0.172[a]
	Mean(SD) CI95%(low-upp)		8.2 (2.9)	(7.53-8.86)	7.7(3.2)	(6.55-8.79)	8.6 (2.7)	(7.77-9.41)	
T1	**Median**	**(1st-3rd quartiles)**	11.0	(9.0-12.0)	10	(8.0-12.0)	11.0	(9.0-12.0)	0.173[b]
	Mean(SD) CI95%(low-upp)		10.4 (2.3)	(9.92-10.94)	10.0(2.7)	(9.06-10.94)	10.8(1.9)	(10.18-11.32)	
P-value T0 versus T1			**<0.001**[c]		**<0.001**[c]		**<0.001**[c]		

a: p-value of t-student for independent samples equal variances assumed; b: p-value of t-student for independent samples equal variances not assumed; c: p-value of non-parametric Wilcoxon signed-rank test for two paired samples

EG and CG scores demonstrated significant improvement at the end of the intervention (T1) ($p<0.001$; $meanEG_{T1}=10.8$, $SDEG_{T1}=1.9$; $meanCG_{T1}=10.0$, SD=2.7). This overall improvement suggests that the educational content had a positive impact on participants' knowledge in both groups, regardless of the modality of delivery. No significant difference was observed between the two groups at T1 ($p=0.173$), indicating comparable post-interventions knowledge scores between the experimental and control groups. After adjustment for baseline knowledge (Q626 score at T0), the ANCOVA showed no statistically significant difference in post-intervention knowledge scores between the experimental and control groups

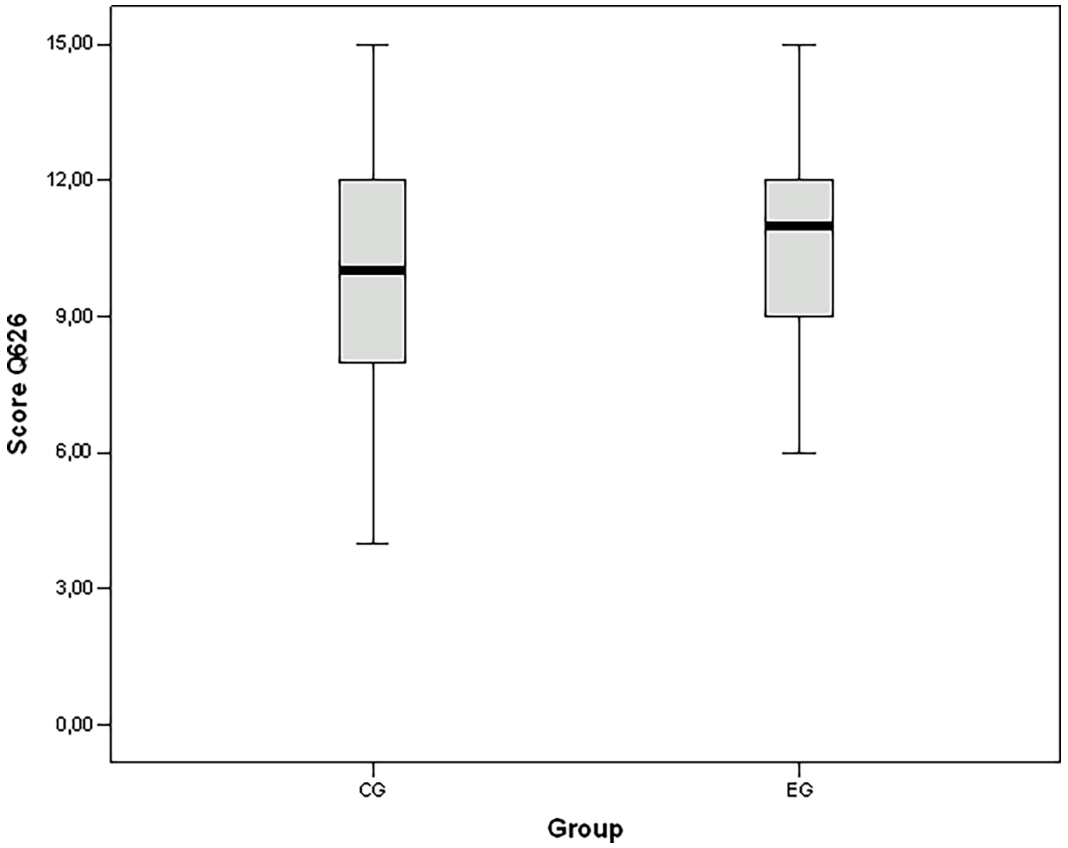

Figure 3. Box plot with whiskersof Score Q626 at T1 stratified by EG and CG.

(F(1,74) = 0.639, p = 0.427, partial η^2 = 0.009). The adjusted mean difference between groups was −0.35 points (CI95% −1.22 to 0.52). However, although a significant difference in variance was found (Levene's test applied to T1 scores: p=0.048; $SDEG_{T1}$=1.9; $SDCG_{T1}$=2.7). This greater variability in the CG may reflect a more heterogeneous learning outcome, possibly influenced by differences in individual engagement or prior familiarity with the topics. Figure 3 shows a box plot with whiskers of the Q626 score at T1 in the two intervention groups. The visualization further illustrates the narrowing of score distributions and the shift toward higher median values in both groups.

Discussion

This randomized controlled field trial found that both the traditional seminar and the gamified training session significantly improved participants' knowledge of occupational health and safety. Although the average knowledge scores did not differ significantly between groups, a lower variability in post-intervention scores was observed in the experimental group. This finding should be interpreted with caution, as variance-related outcomes were not pre-specified and were explored post hoc; therefore, they should be considered exploratory and hypothesis-generating rather than confirmatory. While the gamification session did not lead to higher mean knowledge scores, the lower dispersion observed in the experimental group may suggest a more uniform learning experience. However, this interpretation requires confirmation in larger studies specifically designed to assess variability as a primary or secondary outcome. The structured and interactive nature of the games—especially role-playing and board-based scenarios—likely fosters collaborative problem-solving and mutual reinforcement of

concepts, helping participants clarify uncertainties in real time. In contrast to traditional seminars, where learning is largely passive and unidirectional, gamification creates an inclusive environment that supports engagement across a diverse range of learners (1). These findings partially confirm our initial hypothesis. While we expected the gamified training to produce significantly higher knowledge scores compared to traditional seminar-based instruction, the data did not reveal a statistically significant difference in mean performance between groups. This is particularly relevant for occupational health and safety training, where minimum competency thresholds must often be achieved by all employees—not just some. Therefore, even without superiority in average score, the capacity of gamification to reduce variability may represent a valuable advantage for training effectiveness and equity. These findings align with previous research highlighting the benefits of gamified learning in occupational safety contexts, particularly studies using digital serious games and virtual reality to improve attention, motivation, and retention of knowledge (41–43). However, our study adds novel evidence by focusing on an analog board game format—a relatively unexplored yet accessible and cost-effective modality in the workplace training setting. This original contribution offers a viable alternative to digital approaches, especially in small enterprises or resource-limited contexts. The use of gamification in occupational health and safety training may represent a promising complementary approach to address challenges related to engagement and retention of information. By incorporating game design elements such as competition, collaboration, and interactivity, gamified learning environments could motivate participants to engage more actively with the material and apply their knowledge in workplaces. Although this study did not demonstrate a statistically significant advantage of the gamification over traditional seminar–based training (lecture with slides) in terms of knowledge scores, the narrower confidence interval and lower variance observed in the experimental group suggest more consistent learning outcomes. These results indicate a potential role for gamification in supporting occupational health and safety training, especially when combined with theoretical instruction, but further research is needed to confirm its added value and long-term impact. While our findings are in line with previous studies that show improved engagement through gamification (44,45), the limited literature on analog game-based interventions highlights the importance of exploring diverse formats. Unlike digital platforms that may pose technical or financial barriers, analog games promote interpersonal interaction and experiential learning in face-to-face group settings, which may foster social reinforcement and collective responsibility (46). Nevertheless, players do not seem to significantly increase their knowledge compared to those who attended the seminar, although both groups showed a significant improvement in their knowledge following the training intervention. This suggests that the theoretical component remains essential for knowledge acquisition, and gamification should be viewed as a complementary strategy that can support—but not entirely replace—traditional methods. The theoretical course has a more significant impact on the meaningfulness of knowledge, regardless of the game, but the two groups exhibited different variances, and the confidence interval of the mean for EG was narrower and shifted toward higher values (EG meanQ626 score CI95%: 10.18 to 11.32; CG meanQ626 score CI95%: 9.06 to 10.94). It can therefore be assumed that the knowledge score in the EG group, although higher, is not significantly better than in the CG group. However, there is less dispersion of scores within the EG group, which suggests a greater homogeneity in learning. This more consistent learning outcome in the experimental group may reflect the board game's ability to support peer discussion and clarification of doubts, potentially reinforcing learning equity among participants—a finding consistent with studies on board-game interventions in occupational health and safety education (47).

Limitations

Several limitations must be acknowledged. The relatively small sample size of 77 participants may limit the generalizability of the results. Although efforts were made to recruit workers from diverse backgrounds, the sample consists predominantly, but not exclusively, of university administrative and technical staff, all belonging to the clerical/office sector. This

limits the generalizability of the findings. However, workers may have varied professional backgrounds and experiences within this category, potentially introducing some degree of heterogeneity. The Q626 questionnaire exhibited moderate reliability (Cronbach's α=0.723) and may not comprehensively measure all aspects of occupational health and safety knowledge. The duration of the gamification session, limited to a one-day course, may have constrained the depth and breadth of the topics covered. Consequently, not all questions on the Q626 questionnaire may have been addressed during the gaming activities, potentially affecting the extent to which the intervention could influence participants' knowledge. Extending the duration of the intervention or integrating additional sessions could provide a more comprehensive coverage of occupational health and safety topics, thereby potentially yielding more significant improvements in knowledge scores. After the randomization process, there was an imbalance in the number of participants between the experimental group (EG) and the control group (CG), with 44 participants in the EG and 33 in the CG. Although the total sample size was deemed adequate, this discrepancy could introduce variability that affects the comparability of the two groups. Furthermore, the matching process was based only on participants' age and their previous roles in occupational health and safety. Age was also considered a proxy for work seniority, and both variables were deemed most relevant to the expected training outcomes. However, other potentially influential characteristics—such as gender—were not included and may have affected the results. Future studies should strive for equal group sizes and consider a broader set of matching criteria to minimize potential biases and ensure more accurate comparisons between intervention and control conditions. This study can be seen as a preliminary intervention to explore the topic. Our intention is to repeat the RCT with a bigger sample, where participants have similar organisational backgrounds and comparable characteristics. This study also did not assess long-term knowledge retention or behavioral changes in the workplace. Additionally, factors such as prior experience with gamification and baseline motivation were not controlled for, potentially affecting outcomes. Future research should address these limitations by including larger and more diverse samples, refining measurement tools, and exploring long-term impacts. A further limitation of this study concerns the timing of the post-intervention assessment. While participants in the control group completed the questionnaire immediately after the seminar, those in the experimental group completed it after both the seminar and the gamification session. This difference in timing may have influenced immediate recall, cognitive fatigue, or test performance and could have affected short-term knowledge scores. Therefore, the results should be interpreted as reflecting immediate post-training recall rather than stable learning outcomes.

Conclusion

This randomized controlled field trial showed that both traditional seminar-based training and gamified training significantly improved short-term knowledge of occupational health and safety education. No statistically significant differences in mean post-intervention knowledge scores were observed between groups, even after adjustment for baseline knowledge. However, a lower variability in post-intervention scores was observed in the gamification group, suggesting the potential for more homogeneous learning outcomes. This finding should be interpreted cautiously, as variability was explored post hoc and was not a pre-specified outcome. Overall, gamification appears to be a promising complementary approach to traditional occupational health and safety training. Future studies with larger samples, longer follow-up periods, and pre-defined outcomes are needed to confirm these findings and to assess knowledge retention, behavioral impact in workplace settings.

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Conflict of Interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article.

Consent to Participate: At the beginning of the training course, participants were asked to read and sign a form containing information about the study. Submission of the completed and signed form was taken as consent to participate in the study.

Consent for Publication: Study information stated that the information provided by the participants would be published, but that their identity would not be revealed at any stage.

Ethics Approval.: Research protocol was approved on February 1st, 2024 (Prot. 0617) by the Ethical Commission of "Universitas Mercatorum" of Rome, Italy.

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Declaration on the Use of AI:. AI-assisted tool was not used.

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