

A Serious Game for Safety and Health Training in the Workplace

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Abstract

This paper describes the design process of a serious game for occupational safety training in waste treatment plants, which includes elements such as a scoring system, non-player characters, and simulations of the working environment to make it engaging and improve an inclusive educational approach.

CCS Concepts

• **Human-centered computing** → **Empirical studies in interaction design**.

Keywords

Serious game, Waste Management, Safety training, Human-Centered Design

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1 Introduction

The serious game is being developed in the frame of the SOHS Project ("Sustainable Occupational Health and Safety in Waste Treatment Plants: A Gamified Training Tool for Workers"), which aims to improve workplace safety in waste treatment plants. The main objectives of SOHS are to i) conduct a multidimensional assessment of occupational risks in two waste treatment plants in Italy,

ii) design and develop a prototype of a safety and health training tool for workers, based on realistic scenarios, and iii) evaluate the usability and user experience of the prototype with diverse worker groups in terms of age, gender, culture, and skills. The project brings together expertise ranging from anthropometry to environmental engineering, from industrial hygiene to Human-Computer Interaction (HCI), and involves two waste treatment plants.

The definition of suitable strategies for Municipal Solid Waste Management (MSWM) contributes to the achievement of the United Nations Sustainable Development Goals (SDGs). In particular, the establishment of integrated approaches strongly focused on recycling and resource recovery [3] has led to the opening of numerous waste sorting and recovery facilities, with an increase in the workforce in this field [7, 8] and an increase in the complexity of the MSWM systems [6]. Such complexity increases Occupational Safety and Health (OSH) risks in the working population and demands careful consideration. Workers at MSWM plants often belong to vulnerable groups, including migrants, people with low literacy levels, or persons who are psychologically or cognitively challenged [4]. These workers may find difficulties in understanding and retaining traditional safety training materials and participating in educational activities. Unlike conventional approaches to workplace safety training, serious games can provide a highly visual and direct interaction, reducing the cognitive and linguistic load on users by promoting user-centered education [2, 5, 9].

2 The Design Process

For the design process of the serious game, we involved 31 workers through observation, questionnaires, and interviews, and collected domain experts' feedback about training procedures, needs, and preferences [1]. By analyzing the work context, we identified three common operational scenarios among the two plants: *manual sorting performed at an inclined conveyor belt inside a shed*, where the worker removes non-conforming waste (e.g., plastic, paper) and place it in nearby bins, while the remaining material continues on a fixed-speed moving belt for further processing; *manual sorting carried out on a horizontally positioned conveyor belt inside a sorting*

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cabin, where the worker sorts waste based on quality and places it into collection boxes; *manual ground sorting in an open-air asphalt yard, sometimes under a canopy*, where the worker stands or bends to open separated waste bags, tipping out contents for manual sorting by type (e.g., hard plastics, cellophane) and placing them in separate piles. In all three scenarios, the workers wear appropriate Personal Protective Equipment (PPE), including safety shoes, reflective clothing, gloves, arm covers, and a respiratory mask.

The analysis of how workers perform their tasks led us to define four personas, two women and two men, of different ages, nationalities, and levels of experience, to represent the diversity of workers in waste sorting plants, which is essential for designing inclusive and effective work environments and digital tools. Elena (50, Italian) is the most experienced, with 12 years in manual sorting; Jelani (45, Senegalese) has 7 years of experience in ground-level sorting; Giovanni (43, Italian) has 6 years of experience and is the most tech-savvy; and Mandisa (26, Cameroonian) is the youngest and the most inexperienced (1 year of work in the field).

The types of risks related to this work context are biological and chemical (exposure to pathogens and chemicals, harmful gases, vapors, dust, radiation, inhaling toxic substances, and contact with poisonous substances), physical (awkward postures, repetitive movements, falls, collisions with machines, crashes with vehicles, slip risk, entrapment, and danger of being struck by falling objects), and psychosocial (stress, anxiety, depression, fatigue, monotony, and social isolation).

3 The Serious Game Design and Prototype

To inform the subsequent development phase that is currently carried out by a Company, we produced both a Game Design Document (GDD), for outlining the core mechanics, rules, objectives and player interactions, and a Narrative Design Document (NDD) that provides the narrative structure, characters, tone, and the integration of storytelling elements. Together, these documents serve as a reference for developers and facilitate the communication of the outcomes of our research to the stakeholders.

The serious game is structured into five levels, with linear progression, where access to each subsequent level is granted only after the previous one has been completed. Once a level is unlocked, it can be played again. This allows the player to improve their skills, review their acquired knowledge of the field, and also enjoy the gaming experience. Each level is designed to test knowledge about various aspects of the work at the plants. The first two levels address general topics, such as the meaning of safety signs and the appropriate work attire and PPE. The remaining levels focus on specific tasks: waste sorting on the ground, waste sorting on a horizontal belt, and waste sorting on an inclined belt. More specifically, the first level is a quiz challenge with questions about workplace signage. In the second level, set in a locker room, the player has to decide which items to equip and which not in order to operate in the workplace safely. The final three levels follow a different structure, each consisting of two distinct phases. The first phase, called the *pre-level*, is a quiz challenge similar to those in the earlier stages. Its goal is to assess the player's knowledge of specific issues related to the task at hand. If the player achieves a sufficient

score, they can proceed to the second phase, which is a task simulation, where the player must interact with key events. The order of the last three levels was determined based on the results of the psychosocial research conducted with employees. These results revealed that the task perceived as the most unsafe is waste sorting on an inclined belt, followed by sorting on a horizontal belt, and finally sorting on the ground. Therefore, the levels are presented in an increasing order of perceived difficulty. The players can track their current progress and view the progress of others with whom they are associated.

During each level, the player must make decisions, each of which results in a score, positive or negative, depending on the choice made. In some scenarios, there are multiple correct options, but only one represents the real optimum. In these cases, multiple answers yield a positive score, but the number of points awarded varies. At the end of each level or *pre-level*, the system checks the player's score and communicates the result. If it is a *pre-level* score, the possible outcomes are either sufficient or insufficient. A sufficient result allows the player to advance to the second phase, while an insufficient score requires them to repeat the quiz. If the score refers to the entire level, the outcomes can be: very high score, sufficient, or insufficient. The first two outcomes grant access to the next level, but award different trophies: a sufficient score earns the standard trophy, while a very high score earns the standard trophy and also a special one. An insufficient score means the player must repeat the level to progress. Players may also replay levels to improve their score. In this way, the system encourages continuous learning, gradually guiding players toward perfect performance and a thorough understanding of workplace rules.

During the game, the users encounter and interact with four Non-Playable Characters (NPCs), each inspired by one of the personas created during the user research phase. The NPCs serve multiple purposes: they add a narrative component that helps immerse the player in the game, interact with the player by explaining the tasks, functionalities, and interface components, and encourage the player to stay focused and pay attention to the instructions.

At the end of the design process, a complete interactive prototype has been created with Figma. However, the graphical elements are trivial and are not meant to be the ones that will appear in the final serious game; they only play a descriptive role in supporting the communication and handover between us and the external development team. Figure 1a shows a quiz screen that is presented to the users at various moments throughout the game. The background reflects the setting of the level, while the foreground displays the question, a relevant image, and two possible answers. By selecting one of the options, the system informs the player of the outcome of their choice. If the selected answer is incorrect, the system allows the player to either read an explanation of the mistake or proceed to the next question. In the screen depicted in Figure 1b, the simulated task is related to the sorting activity that leads the worker to dispose of the waste into the appropriate containers. In the top-left corner, an avatar simulates the posture chosen by the player. Just below the avatar, the *fatigue bar* is displayed: it represents an indicator of the avatar's remaining energy, which decreases at varying rates depending on the posture used throughout the gameplay. When the figure bar reaches a low level, an NPC appears on the screen and asks the user to change the posture. The player is presented

with different options, and depending on their choice, they will obtain a different score.



(a) The player is asked to choose the correct PPE to wear when dealing with a cutter.

(b) The player is guided in changing posture while performing simulated tasks to avoid injuries.

Figure 1: Two screens of the serious game prototype.

Once the serious game is developed, user tests involving workers in the two waste management plants will be organized to evaluate usability, user experience, and game effectiveness in safety and health training.

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