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THE DIGISAFEMAN PROJECT: INNOVATING OCCUPATIONAL SAFETY TRAINING THROUGH GAMIFICATION IN MANUFACTURING

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List of Acronyms

ASL - Local Health Authorities

DfS - Design for Safety

ETTO - Efficiency–Thoroughness Trade-Off

EU-OSHA - European Agency for Safety and Health at Work

GT - Grounded Theory

GUI - Graphical User Interface

HCD - Human-Centered Design

HCI - Human-Computer Interaction

HFE - Human Factors and Ergonomics

IEA - International Ergonomics Association

ILO - International Labour Organization

INAIL - National Institute for Insurance against Accidents at Work

INL - National Labour Inspectorate

ISO - International Standard Organization

OSH - Occupational Safety and Health

PPE - personal protective equipment

RQ - research question

SC - subject categories

SMEs - Small and Medium-sized Enterprises

SWOT - Strengths, Weaknesses, Opportunities, and Threats

UI - user interface

UX - user experience

WAI - work as imagined

WCAG - Web Content Accessibility Guidelines

WHO - World Health Organization

PREFACE

This PhD research project aims to investigate the evolution of occupational safety training in the manufacturing sector, adopting a multidisciplinary approach that integrates the contributions of sociology, psychology, ergonomics, and interaction design. The increasing complexity of industrial workplaces, driven by technological innovation, automation, and digitalization, has changed the way employees carry out their work, how they interact with machinery, and the organizational and safety systems. At the same time, these transformations spread also to new opportunities to foster a culture of prevention and improve learning outcomes through innovative training methodologies.

The Human-Centered Design (HCD) method, which acknowledges the importance of human experience in the design of workplace systems, represents the theoretical framework of this project. By using participatory methods and iterative testing in an Italian manufacturing company, the HCD approach shows how technical, organizational, and human factors are connected in occupational safety.

The present thesis is structured to provide a comprehensive analysis of the state of occupational safety in manufacturing, beginning with a theoretical examination of safety as an evolving multidisciplinary field, tracing its historical roots and defining the current developments in safety culture, risk perception, and organizational practices. This part is followed by a detailed overview of occupational injuries in the manufacturing sector, highlighting statistical patterns, high-risk operational conditions, and the current role of safety training systems. Then, the HCD approach and the methodology adopted in this work are reported and the results for each HCD phase are presented.

Through mixed methods, including literature review, field observation, interviews, questionnaires, and usability testing, the project examines the context of use, identifies critical user requirements, and translates them into design specifications for the development of a prototype of a digital safety training tool. The final aim of this work is to contribute to the advancement of occupational safety research by showing how a multidisciplinary framework, rooted in HCD, can support the development of more engaging, intuitive and easy to use training solutions in high-risk industrial settings.

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CHAPTER 1 - Occupational Safety and Health: a multidisciplinary perspective

1.1. Occupational safety in the evolution of workers' tasks

In recent decades, the world of work has faced radical transformations. Market globalization, digitization, and growing job insecurity have changed employment structures, professional identities, and dynamics within organizations (Jetha et al., 2021; Lent, 2018). Within this evolving context, occupational safety represents a critical and multifaceted social phenomenon (Hollnagel, 2014; Yap & Choy, 2018). Safety in an occupational context is commonly defined as the absence of unexpected and adverse outcomes, such as accidents, injuries, or incidents. Specifically, the European Agency for Safety and Health at Work (EU-OSHA) states that occupational safety pertains to the identification and mitigation of hazards in the workplace that may cause injuries to employees. It is intrinsically linked to occupational health, which focuses on addressing potential health issues affecting workers. Both areas are integrated under the umbrella of occupational safety and health (OSH), defined as the discipline that deals with the prevention of work-related injuries and illnesses while also promoting the protection and enhancement of workers' health (EU-OSHA, 2022). Similarly, safety was defined as the freedom from unacceptable risk (ANSI/ASSE, 2011), where "unacceptable risk is indirectly defined as a risk for which the probability is too high" (Hollnagel, 2014, p. 37) and in the ISO/IEC Guide (2014), safety is defined as the "Freedom from risk which is not tolerable". Furthermore, the International Labour Organization (ILO) defines the safety and health in the workplace as "the discipline dealing with the prevention of work-related injuries and diseases, as well as the protection and promotion of the health of workers" (ILO, 2025), taking into consideration the social, mental, and physical well-being of workers. In this context, risk is also generally conceptualized as the combination of two main dimensions: the probability of occurrence and the severity of the consequences. Probability refers to the likelihood that a hazardous event may occur, while severity concerns the magnitude of its potential impact, such as injuries, fatalities, or other damages.

Therefore, risk is commonly understood as the interaction between these two components, both of which must be considered when analyzing occupational accidents and safety performance (CCOHS, 2025). To better understand modern approaches to occupational safety, it is essential to look back at the evolution of work organization and the relevance of workers' mental and physical status for overall system efficiency.

The relationship between work and safety historically traced back to the Industrial Revolution, which, alongside growing technological progress, gave rise to a range of new issues (ILO, 2019). As stated by Adam Smith (2002), the turning point was the increasing division of labor. Task specialization, together with the invention of machines designed to optimize each stage of the production process, facilitated productivity gains and enhanced individual efficiency (Negrelli, 2015). According to Adam Smith, Frederick Taylor believed that maximum prosperity could only be achieved through the highest possible productivity of both human labor and machinery. However, Taylor was the first who theorized a scientific organization of work. At the core of his methodology was the principle of the *"one best way"*, i.e., for each task there is a single and most efficient method of execution (Negrelli, 2015). Taylor's approach relied on the systematic examination of production procedures, emphasizing the simplification of labor, the standardization of movements and time, and the elimination of inefficiencies and unnecessary exertion, all aimed at maximizing worker performance and achieving the highest level of economic efficiency. Basically, each worker was considered a "perfectly adaptable machine". However, Smith acknowledged the negative consequences of this extreme division of labor, as it tends to limit workers' creativity and hinder their intellectual development. In terms of safety and health issue, although the division of labor increases industrial productivity, Smith also described the negative consequences of output-based remuneration systems for workers' well-being employed in that historical period: "Workmen… when they are liberally paid by the piece, are very apt to overwork themselves and to ruin their health and constitution in a few years" (Smith, 1776, p. 83, cited in Bender et al., 2012). Similarly, Karl Marx offered a critical perspective on this work process. Indeed, despite the division of labor offering economic advantages, it reduced the workers to perform a single, repetitive, and simplified operation throughout their working life. Thus, this fragmentation tends to create less skilled workers; less training is needed for each specific job and eliminates the requirements for both physical and mental flexibility (Marx, 1902). In terms of safety, Marx explained that workers' safety is sacrificed within the capitalist logic of production. When workers are injured because of lack of proper safety measures, it is a loss to the capitalist class as a whole and indeed to society as such, but this is unimportant to the individual capitalists. Since it costs money and reduces earnings, employers frequently disregard safety regulations and measures and tended to crowd hazardous machinery into small spaces (Marx, 2010a [1894] cited by Das, 2023).

Although safety was not a focus of his work, Taylor established a connection between lost personnel time and management policies and procedures. Safety was not viewed as a moral responsibility toward workers but as a practical issue connected to efficiency. The standardization of tasks and the reduction of unnecessary physical effort were intended to improve productivity, but they also had the indirect effect of reducing accidents and work interruptions (albeit at the cost of workers' mental health and well-being). This connection between safety and management represented an early step toward understanding that workplace safety depends on how work is organized (Goetsch, 2015). Subsequently, at the beginning of the 20th century, Henry Ford and his production model, commonly known as Fordism, represented the culmination of task fragmentation and mass production through the introduction of the assembly line to promote market growth and decrease production costs. While the economic success of Fordism is indisputable, its implementation has generated continued debates regarding its impact on workers' health and safety. In this context, human-centered dimensions such as job satisfaction, psychological well-being, and the long-term consequences of highly repetitive tasks were largely overlooked (Fordjour & Chan, 2020; O'Neill, 2017). Furthermore, many critical issues, such as prolonged working hours, the use of hazardous machinery and chemicals, unsafe working conditions, accidents in overcrowded factories, and industrial disasters (especially in the mining industry), were reported (ILO, 2019).

The Fourth Industrial Revolution has brought significant advances in key indicators of human well-being, including incomes, life expectancy, education, and health. The development and widespread adoption of new technologies, such as robotics and automation, have had a great impact on all aspects of work, profoundly changing how work is performed and workers' skills (European Agency, 2018; Ragazzi et al., 2023). These technologies also introduced new ergonomic risks associated with increasingly complex human–machine interfaces, as well as psychosocial challenges arising from human interaction with artificial intelligence and robotic systems. Alongside these technological transformations, OSH has gained growing interest among institutions, researchers, and policymakers.

More recently, through the Fifth Industrial Revolution, technological progress has continued, including metaverse, virtual reality, and holography, IoT systems, Big Data, and blockchain (Milea & Cioca, 2024). These technologies, emphasizing the collaboration between machines/robots and humans, led to positive consequences, since they can support workers in physically demanding and repetitive tasks (Braccini & Margherita, 2019). In contrast, they intensify workers' cognitive demands, as individuals' primary role shifts to supervising and controlling the new machinery (Nguyen et al., 2024). At the same time, the integration of such advanced technologies often needs a restructuring of organizational processes to achieve joint optimization of social and technical systems, ensuring that new technologies integrate effectively with human elements like roles, workflows, and decision-making (Carvalho et al., 2020). The main historical models of work organizations have notably contributed to increased productivity, yet often at the cost of workers' well-being. With the evolution of work systems, there has been a transition from traditional organizational models that significantly enhanced productivity, often at the expense of workers' well-being, towards a greater emphasis on physical demands alongside cognitive workload (Caiazzo et al., 2023; Gualtieri et al., 2022). Physical workload refers to the bodily effort required to complete a task, while cognitive workload involves the mental effort needed to perform tasks or maintain performance levels. In detail, the physical workload is frequently associated with postural and biomechanical overload, which is typically caused by manual material handling, repetitive movements, falls from height, and interaction with machinery or hazardous substances. Cognitive overload instead may be caused by continuous cognitive demand, multitasking, or time pressure that may reduce the workers' capacity to accurately perceive risks, leading to underestimation or oversight of critical safety cues. However, the labor market is not merely a space for the exchange of skills but also a social arena in which rights, protections, and working conditions are defined and negotiated (Klimczuk, 2017). Given this complexity, a systems approach that encompasses physical, cognitive, and organizational dimensions is essential for effectively addressing OSH. Such an approach acknowledges the interconnected nature of these levels, recognizing that workplace safety and well-being emerge from the interaction between individual capabilities, technological demands, and the broader socio-organizational context in which labor takes place.

1.2. The normative and sociological perspective

According to the ILO (2023), 395 million people suffer from non-fatal injuries, and almost 3 million people die each year due to work-related illnesses and accidents. As the social, economic, and health-related consequences of inadequate safety measures have become increasingly evident through the last decades, it has been progressively acknowledged that the absence of effective regulation incurs high costs not only for individuals but for society as a whole (Kapp, 2017).

Based on this, several international organizations, such as the International Labour Organization (ILO), the World Health Organization (WHO), and the European Agency for Safety and Health at Work (EU-OSHA), have established OSH as a priority of their policy frameworks. Indeed, the International Labour Organization (ILO) has established several conventions and recommendations, such as Convention No. 155 on Occupational Safety and Health (ILO, 1981) and Convention No. 187 on the Promotional Framework for Occupational Safety and Health (ILO, 2006). Specifically, the first convention establishes the general principles of national policies on OSH, requiring member states to adopt preventive measures and appropriate legislation; the second emphasizes the promotion of a national preventive safety culture, requiring continuous improvement through strategies, programs, and monitoring systems. Similarly, at the European level, the European Agency for Safety and Health at Work (EU-OSHA) has aimed since its establishment in 1994, to promote efficient standards of occupational safety and health across the European Union, ensuring that workers in all member states benefit from equal levels of protection (EU-OSHA, 2019). In EU countries, the Directive 89/391/EEC (European Union, 2008) represents the cornerstone of OSH legislation. It obliges employers to evaluate risks, implement preventive measures, and provide workers with adequate information and training. The directive also reinforces the principle of shared responsibility by requiring active workers' participation in safety management. Member States adopt these regulations and are also free to adopt even stricter rules into their national law for the protection of workers. For instance, in Italy, measures aimed at protecting health and safety at work are provided by the Legislative Decree No. 81 of 2008 (Ministero del Lavoro e delle Politiche Sociali, 2008a), which will be introduced and further discussed in paragraph 3.3.1.

The need for such regulations is reinforced by persistently high rates of occupational accidents and work-related diseases worldwide, which continue to impose significant human, social, and economic burdens (ILO, 2023; Takala et al., 2024). As mentioned in paragraph 1.1, industrialization marked a turning point, introducing a wave of unprecedented challenges that were already being documented: potentially hazardous conditions, excessively long working hours, the use of dangerous machinery and substances, exploitation of child labor to meet growing market demand, and disasters in mining and manufacturing industries (Crane-Kramer & Buckberry, 2023; Dimanov, 2024; Rosner & Makowitz, 2020). These issues gradually led workplace safety to become a central topic in socio-political debates internationally, reinforcing the need for normative and public intervention in the occupational sector to regulate the market and mitigate the individual and social costs arising from inadequate OSH management (Antonelli et al., 2023; Ragazzi et al., 2023). However, OSH goes beyond mere compliance with technical standards or legal obligations, and it should be understood as a complex social phenomenon shaped by values, power relations, and both organizational and territorial dynamics (Colombo et al., 2019). Thus, in addition to regulatory and institutional efforts, economic literature (Cao et al., 2025; Cohn & Wardlaw, 2013; Kolev & Randall, 2024) has identified four key categories of factors that shape the occurrence of workplace accidents:

- Individual factors, related to workers' personal characteristics and work experience, including psychological aspects such as risk perception, motivation, attention, and fatigue.

- Work-related and environmental factors, including work organization (e.g., shifts, hours, overload, pace), physical environment conditions (e.g., noise, lighting, ventilation, ergonomics), the presence or absence of safety management systems, as well as organizational climate, internal communication, and employee participation.
- Technological factors, related to the degree of automation, machinery maintenance, use of personal protective equipment (PPE), and the overall level of technological advancement and innovation available within the workplace.
- Economic factors, including financial incentives, competitive pressures, and market dynamics. Paradoxically, companies may reduce their investment in safety, especially when rules are weak or when firms face strong international competition. Thus, to contain costs, companies might avoid investing in prevention measures, putting workers at greater risk.

Location also plays a crucial role, as well as the company size. Areas with precarious employment, weak union representation, or fragile legality due to widespread criminal networks and high levels of violent crime tend to record a higher-than-expected number of accidents, and occupational risks are amplified (Shahidi et al., 2024). By contrast, cooperative environments and strong institutional frameworks contribute to their reduction (Marrocco & Castaldo, 2023). This suggests a substantial connection among weak institutional frameworks, a deficient legal culture, and increased workplace risk. In addition, regions with larger average-sized companies tend to provide more advantageous conditions, as they are less impacted by the typical challenges faced by small businesses: resource scarcity (particularly technological), informal management practices, limited organizational awareness, and a predominant focus on production needs due to competitive pressures from value chains (ILO, 2018).

For instance, in Italy, small and medium-sized enterprises (SMEs) tend to have a higher rate of accidents with more serious consequences due to limited economic, human, and technological resources. This phenomenon, known as the “size effect”, can be attributed to various factors: limited investment in preventive measures, poor knowledge of regulatory requirements, low awareness of the economic benefits of safety, managerial and training deficiencies, short-term economic pressure and intense competition, inadequate enforcement of regulations, and lack of structured prevention services (Marrocco & Castaldo, 2023). A number of studies have highlighted relevant territorial disparities in the distribution of social capital (defined as the network of relationships, norms, and trust that facilitate coordination and cooperation for mutual benefit, Putnam, 1993, p. 35), also across Italian provinces and regions. Unsurprisingly, these discrepancies are strongly associated with territorial patterns of workplace accident risks and injuries observed. In detail, it should be noted that while the South has a comparable number of companies to the Center, it generally has fewer employees (Antonelli et al., 2023). The highest accident rates are recorded in the North-East and the Islands, followed by the South, the Center, and the North-West. In Southern Italy, however, the greater severity of workplace accidents can be attributed to the fragility of the labor market, characterized by a high incidence of irregular and undeclared work, which also leads to under-reporting (Antonelli et al., 2023).

In conclusion, occupational safety represents a multidimensional challenge that requires an integrated approach, one that considers economic, social, and territorial dynamics. Only through targeted policies, structural investments, and a shared culture of prevention is it possible to significantly reduce risks and promote safer and more inclusive working environments.

1.3. The psychological and ergonomics perspective[1]

Considering the number of accidents that occur in all occupational sectors despite the existence of prevention and sanctioning policies and safety measures, it becomes relevant to understand the other factors that contribute to such events, looking more closely at why failures occur, why systems break down, and why individuals are

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[1] This paragraph is partially based on the following published contributions:

Vigoroso, L., *Caffaro, F., Tronci, M., & Fargnoli, M. (2025). Ergonomics and design for safety: A scoping review and bibliometric analysis in the industrial engineering literature. Safety Science, 185, 106799. https://doi.org/10.1016/j.ssci.2025.106799*

Sguaizer, F.,* ***Vigoroso, L.*,*** *Micheletti Cremasco, M., & Caffaro, F. (2025). Perceived Working Conditions and Intention to Adopt Digital Safety Training in High-Risk Productive Sectors: An Exploratory Study in Manufacturing and Agriculture in Northwest Italy. Safety, 11(2), 51. https://doi.org/10.3390/safety11020051* injured, to develop more effective and resilient safety measures (Hollnagel, 2014). Work psychology literature identifies several variables that can increase the risk of accidents among workers. These variables include both individual characteristics (e.g., unsafe behaviors, experience, training, and risk perception) and organizational dimensions (e.g., work pressure, safety culture, and task design). Specifically, the adoption of unsafe behaviors in the context of safety management in high-risk sectors has received significant attention in the literature (Cooper et al., 1994; Cox et al., 2004), as approximately 80-90% of all workplace accidents and incidents appear to be attributable to workers' unsafe behaviors (Cox et al., 2004; Hosseinian & Torghabeh, 2012). Thus, to maximize the effectiveness of safety interventions, it is fundamental to address both behavior and behavioral change (Davis et al., 2015).

Previous studies have shown that most workplace accidents result from a failure to comply with safety rules and regulations, or from the improper use or discomfort associated with Personal Protective Equipment (PPE) (Al-Bayati et al., 2023; Sehsah et al., 2020; Zerguine et al., 2017). These behaviors are often indicative of broader systemic deficiencies and hazardous work environments (Mosher et al., 2014), including a lack of management support (Al-Bayati et al., 2023), time pressure to meet deadlines or negative peer pressure (Ghasemi et al., 2017; Gheorghiu et al., 2015; Palali & van Ours, 2017), unstable employment status (temporary and seasonal employment), challenging environmental conditions (Spector et al., 2019), or lack of safety training (Izudi et al., 2017).

Also, the history of previous accidents may influence unsafe worker behaviors, although studies across different occupational sectors have reported conflicting findings regarding this relationship. Indeed, a group of studies in the industrial and road safety fields (Gonçalves et al., 2008; Ngueutsa & Kouabenan, 2017) reported that those who experienced an accident and survived tend to have a lower risk perception and poorer safety behavior, often attributing the cause of such accidents to external factors and not to their unsafe actions. In contrast, some other studies (Kouabenan, 2009; Payani & Law, 2020) found a positive association between previous involvement in road accidents and an increase in risk perception, resulting in safer traffic behaviors.

Considering all the abovementioned factors, it appears that workers are part of a dynamic and continuously evolving work system, in which they must interact with various social and technical components. Therefore, it becomes important to adopt a systemic approach to investigate all these interactions and detect any possible deficiencies to design effective injury prevention strategies. A fundamental contribution in this sense is provided by ergonomics, defined by the International Ergonomics Association (IEA, 2000) as "the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance" (IEA, web page). From an ergonomic perspective, Hollnagel's conceptualization of safety emphasizes the interplay between the technical components of the system and the human factors (Hollnagel, 2014). His approach is grounded in two core assumptions, labelled as Safety-I and Safety-II. In Safety-I, it is assumed that safety is achieved by eliminating errors and malfunctions. Safety management, according to the Safety-I assumption, is primarily oriented toward the prevention of adverse events through the implementation of different types of barriers (e.g., physical devices, passwords, locks, signs, alarms, and warnings, including rules and restrictions). Thus, Safety-I focuses on what has gone wrong or what could potentially go wrong, seeking to control it primarily through restrictions and compliance measures. In this regard, near misses (i.e., unplanned events that do not result in any injury, illness, or damage only because of a fortunate break in the chain of events, National Safety Council, 2014) in the workplace represent a valuable learning opportunity, working as early warning signals even before any harm occurs. Several authors highlighted that several near misses frequently precede more serious events in the future (Haas & Yorio, 2019; Heinrich, 1931; Yorio & Moore, 2017). Thus, recording and analyzing these events enable organizations to identify latent hazards and implement preventive strategies to correct what is wrong at the workplace, thereby reducing the likelihood of future incidents (Aigbokhai et al., 2025; Ceesay et al., 2019). In addition, evidence showed that when near misses are not adequately assessed or discussed, they may foster riskier behavior due to lower perceived risk or reinforce the belief that the initial risk was overestimated (Haas et al., 2020; Tinsley et al., 2012). This underestimation increases risk tolerance, which in turn is linked to unsafe decisions and a greater likelihood of occupational injuries (Haas et al., 2020; Lehmann et al., 2006).

However, since work activities require workers' flexibility and variability, the adoption of protective safety measures may easily conflict with organizations' productivity. Preventive measures are usually designed and implemented based on *anticipated* operating conditions. Yet, these conditions often diverge from complex, dynamic, and time-pressured circumstances that characterize real work practices. Safety-II offers a different way to manage this conflict. In line with the Efficiency–Thoroughness Trade-Off (ETTO) principle, Safety-II views human adaptation not as a violation, but as a necessary condition for success in performance (Hollnagel, 2014). Indeed, Safety-II assumes that systems work correctly, and people can adapt their performance to the actual work conditions. Workers can demonstrate flexibility and can anticipate and correct potential problems before they develop into more serious concerns. Thus, within Safety-II, people are seen as a key source of resilience, able to react to unexpected events and to bring flexibility and creativity when situations become risky. The limitation of the Safety-I is therefore reinforced by the inevitable gap between "work as imagined" (WAI, i.e., how work should be done) and "work as done" (WAD, i.e., how work is actually performed to adjust to local conditions) and the continuous comparison between human performance and machines. Hence, being aware of these discrepancies between WAI and WAD is key to the design of a safe and human-centered work environment.

A relevant phenomenon to be considered is *habituation*, defined as the process by which habit "diminishes the conscious attention with which our acts are performed" (William James, in Hollnagel, 2014, p. 39), which can be interpreted from both Safety-I and Safety-II perspective. From the Safety-I point of view, habituation has a negative effect because expert workers can have a lower risk perception due to overconfidence and fatalism. As a consequence, low-risk perception significantly hinders the adoption of safety behaviors, such as the use of PPE (Arezes & Miguel, 2008) and active participation in safety management practices (Ghasemi et al., 2017). Expert workers may commit errors due to routine and familiarity and therefore require corrective interventions. In contrast, from a Safety-II perspective, habituation can be considered positively and as a resource for resilience, enabling workers to manage their cognitive workload and sustain performance under different conditions (Hollnagel & Braithwaite, 2019). For instance, some studies reported that novice workers lack sufficient experience with a specific task or with the correct use of equipment, which makes them more exposed to occupational risks (Hanvold et al., 2019). This lack of routine behaviors may, however, push them to keep informed about safety procedures and make them more careful about the procedures that need to be followed.

The principles of Safety-II have become central to the field of Resilience Engineering (Hollnagel, 2014; Patriarca et al., 2018), highlighting the need to design work environments that support human performance variability (Work-as-Done) rather than attempting to eliminate it through rigid procedures (Disconzi & Saurin, 2024). From this perspective, the focus shifts toward designing workstations and work systems that guide workers' behavior in ways that enhance both successful and safe performance, instead of relying on stopgap measures aimed at compensating for human performance failures or underlying design deficiencies in machinery.

1.4. Safety training and methods for increasing workers' engagement

Although laws and technical standards provide the normative framework, workers require proper training to increase personal knowledge needed to identify risks and adopt safe practices (Burke et al., 2006). Training not only ensures compliance with legal standards but also contributes to building a shared culture of prevention (Hutchinson et al., 2022), empowering workers at every level of the organization to play an active role in safeguarding health and safety. Previous research has also shown that effective safety training and effective risk communication are associated with lower accident rates (especially fatal injuries, Taylor, 2015) and improved workers' safety behavior and knowledge, as workers can learn to identify risks, avoid dangerous situations and behaviors, and comprehend the possible consequences (Lovreglio et al., 2020; Payani & Law, 2020; Ricci et al., 2016; Taylor, 2015). Moreover, other studies highlight that safety training enhances hazard perception among workers, increases reporting of near misses (Aigbokhai et al., 2025; Awolusi & Marks, 2015; Gnoni et al., 2022), and fosters safer decision-making under pressure in demanding working conditions (Weinstock & Slatin, 2012).

To deliver health and safety training, several methods are used that can be more or less engaging (Burke et al., 2006). Safety training is traditionally provided through lectures and classroom activities in which trainers use displays, pamphlets, and posters to integrate their verbal explanation (Park & Kim, 2013; Vigoroso et al., 2020). Despite being the least engaging training method (Burke et al., 2006), it remains the most common approach, mainly due to its lower cost compared to more interactive alternatives (Kraiger & Aguinis, 2001). Indeed, more engaging training methods may consist of feedback interventions, computer-based instructions associated with hands-on demonstrations, and finally behavioral simulation (Burke et al., 2006) that allows greater knowledge acquisition and more transfer of knowledge to the work setting. At the same time, the more resources involved, the higher the costs that need to be sustained.

Digital innovations have introduced new safety training methods that make the learning process more dynamic and engaging. Digital games are making the learning experience more thrilling, captivating and interactive (Williams-Bell et al., 2014). Through simulation, a game can offer players a sufficient opportunity for practical learning. Following the principle of "learning by doing" (Goetsch, 1993), workers can discover what they have to accomplish and which behavior to avoid by experiencing it themselves (Mohd et al., 2019a, 2019b). Game-based interventions have the advantage of focusing players' attention on specific tasks. Several software programs and simulation tools that are referred to as "serious games" or "gamification tools" have been created (Fanfarová & Mariš, 2017; Leba et al., 2014) and have various definitions. In brief, serious games simulate real-world events and processes to solve a problem, but they are more similar to classic video games; while gamification is a more recent technique that refers to applying game aspects and elements to a non-traditionally ludic setting (Deterding, 2011; Groh, 2012; see paragraph 1.5). Thus, providing rewards and incentives in forms of points, badges, and virtual goods, players are pushed and motivated to find effective problem-solving strategies (Isabelle, 2020), facilitating the transmission of information (Dwinggo Samala et al., 2023) and reinforcing the memorization of specific knowledge (Hesse et al., 2019).

Previous studies showed that serious game as learning technique has been successfully applied in different business fields (Williams-Bell et al., 2014) and in sectors where technologies and mobile applications are used, such as occupational health settings including medicine, surgery and rehabilitation (Deutsch, 2009), sports (e.g., baseball, Fink et al., 2009), automotive (Diewald et al., 2015), firefighting (Lovreglio et al., 2020), construction (Gao et al., 2019) and mining (Liang et al., 2019).

However, the application of some of these innovative training methods can be more expensive and demand significant investment in terms of time (Childs et al., 2005). For instance, although virtual reality (VR) has demonstrated considerable potential to engage workers by creating a strong sense of physical presence within a simulated game environment, this technology has its limitations: possible adverse physiological effects, such as disorientation, headaches, nausea, and motion sickness, are common among users (Chen & Wu, 2023). Moreover, the relevant costs and investments required for implementation still represent a significant barrier to its widespread adoption (Rangelova & Andre, 2018), and its accessibility cannot be guaranteed for all potential users.

In contrast to VR technologies, previous studies have highlighted how smartphones and mobile applications are even more flexible tools and are the primary means by which people interact with the web and digital interfaces (Deloitte, 2017). Mobile devices are widely used by individuals from different backgrounds, for multiple purposes, and integrated into several sectors, including education, entertainment, healthcare, communication services, and military systems (Sears & Jacko, 2009). Mobile devices can offer training solutions that are easy to use, quick to learn, cost-effective (Dwinggo Samala et al., 2023; Zhang & Xie, 2012) and accessible anytime and anywhere. Furthermore, they can offer real-time updates through push alerts and reminders (Mehdipour & Zerehkafi, 2013) and a variety of digital content, including texts (e.g., blog articles, wikis), audios, videos, graphics (posters), and games, that have the potential to reach various target audiences, enhancing their learning outcome (Zhu & Andersen, 2022). Therefore, the literature suggests that mobile applications represent the most feasible and effective option for increasing workers' engagement and improving safety knowledge, especially in industrial settings where cost, accessibility, and training time are critical constraints.

1.5. Gamification and its adoption in workplace environments

A game is commonly defined as a structured activity involving rules, play, and engagement, often with a goal or challenge. Huizinga (2002) described play as an activity intrinsic to human culture, and it is a voluntary activity that exists within a "magic circle," characterized by its own rules and intrinsic enjoyment. Also, Roger Caillois (1958) categorized games from highly structured (ludus) to free-form (paidia), identifying four key characteristics: competition (agon), chance (alea), mimicry (mimicry), and vertigo (ilinx). Caillois further argued that play is more than simple entertainment, as it reflects social values and dynamics, offering both order through rules and competition and escape through simulation. Thus, both these authors emphasize that games are immersive, and rule-bound experiences that foster engagement and challenge.

Game design is a discipline that shares several areas of interest with the discipline of interaction design, particularly regarding user engagement, feedback systems, and usability (Järvinen, 2009, see paragraph 1.6 of the present study), with the aim of creating efficient and intuitive interfaces. The term “interaction design” (Norman, 2013) is commonly used to describe a variety of design activities aimed at creating different types of products, including artistic artifacts, websites, desktop applications, GPS systems, and more (Fallman, 2008; Goodman et al., 2011; Huang, 2009) to support people in their everyday and professional lives, or to improve existing systems (Huang, 2009; Sears & Jacko, 2009; Sharp et al., 2007), taking the users’ perspective into account. To collect information and consider the users’ perspective, designers should adopt a Human-Centered Design (HCD) approach, defined as “an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, and usability knowledge and techniques” (ISO 9241-210 p.VI, see paragraph 3.1). The active involvement of users in all design phases ensures that the resulting products are useful, satisfying, and not frustrating. The interaction design process consists of four main activities, similar to the HCD approach: establishing requirements, designing alternatives, prototyping, and evaluating (Preece et al., 2015). Specifically, the possibility to design different alternatives and examine different design solutions makes it easier to move forward and make decisions throughout the design process (Figure 1).

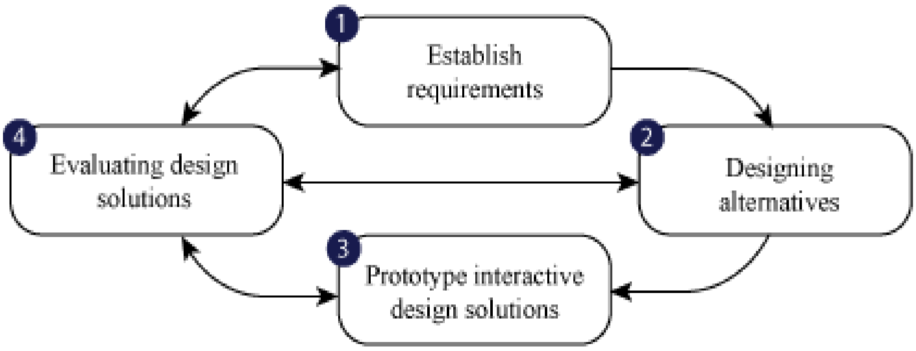

Figure 1. Interaction design phases (adapted from Preece et al., 2015).

Although the interaction design is formally considered a design discipline and primarily describes the interactions between humans and technological systems, it is inherently multidisciplinary, as it includes computer science, human-computer interaction (HCI), anthropology applied physics and electronics, cognitive psychology, behavioral science, semiotics and industrial design. It pays particular attention to the user interface (UI, i.e., the visual and interactive part of a product screen or web page and user experience interaction) and the user experience (UX, i.e., the overall user's experience and journey with such products or websites, from the first impression to the final interaction) (Chiappini & Rigamonti, 2010; Moggridge & Verplank, 2007). However, despite their similarities, game design and interaction design adopt different approaches to problem-solving: interaction design focuses on resolving usability challenges quickly and effectively, while game design deliberately incorporates challenges, puzzles, and obstacles that users must overcome within the game environment, emphasizing entertainment and enjoyment components.

These theoretical perspectives provide a useful framework for understanding why gamification can be effective: by transferring the dynamics of play (rules, challenge, immersion, and freedom of action) into non-game contexts, gamification activates the same psychological mechanisms identified as fundamental to the play experience. However, to be effective and widely adopted, game design must balance the use of a set of elements and rules, known as game mechanics (Bharathi et al., 2016;

Wang et al., 2016) which are the building blocks of gameplay, setting players' actions, as well as the flow of challenges, rewards, and progression. It should be noted that not all game mechanics are suitable for every type of user (Schmierbach et al., 2014), especially given the complex interplay of player preferences and user characteristics (Marchand & Hennig-Thurau, 2013). According to previous studies (Jent & Janneck, 2017; Koivisto & Hamari, 2014), users' age affects the perceived usability and ease of use of digital devices, playing a key role in technology and digital game adoption (Koivisto & Hamari, 2014). Similarly, not every type of game is equally appropriate for different learning contexts (Landers, 2014). Indeed, according to Zhonggen (2019), a game that is effective in one setting (employee training in industrial contexts or formal education) may yield limited or even negligible benefits in another, unless its structure and mechanics are carefully aligned with the requirements, constraints, and practices of that particular context.

According to Hamari et al. (2014), the most commonly used elements for gamified content include: points, leaderboards, and badges, followed by levels, story, clear goals, feedback, rewards, progress, and challenges. In addition, based on Markopoulos et al. (2015) four main genres could be considered particularly relevant, if they are carefully adapted into meaningful and useful learning content: puzzle games (including solving enigmas and that requires finding solutions to a problem, are simple and not require too complex graphics), adventure games (similar to puzzles but with a plot, where players are required to solve problems while progressing through a predefined storyline), simulation games (simulate the handling and controlling of real-world objects, although their design can be difficult and time-consuming to implement) and strategy games (the player must make strategic decisions to achieve the game goal).

The selection of specific game mechanics and genres, especially in the context of workplace safety training, is crucial, as different combinations can significantly influence the effectiveness of gamification initiatives. Successful adoption depends on aligning gamified solutions with organizational goals and the needs of employees, ensuring that the game experience is perceived as helpful rather than being perceived as superficial (Sanchez, 2022). To maintain the level of engagement, the level of difficulty should also be considered, since an appropriate level of difficulty enhances the sense of challenge, whereas an excessively high level may decrease motivation (Denisova et al., 2017).

Previous authors criticized the use of points, badges, and leaderboards because they were perceived as a superficial attempt to stimulate learning, and even as a manipulative practice, as they prioritize extrinsic rewards over the cultivation of intrinsic motivation (Armstrong & Landers, 2018; Bogost, 2011). However, much other evidence found that these elements positively influence learning outcomes and learners' participation compared to traditional learning systems (Dicheva et al., 2015). According to Armstrong and Landers (2018), although gamification can be used to enhance current training techniques and can effectively enhance workers' knowledge about safety procedures, gamification cannot completely replace them, especially in hazardous working sectors, where the complexity of certain operations requires hands-on experience, advanced technical skills, and direct supervision.

1.6. Design challenges of digital device interfaces

In paragraph 1.4, several digital solutions to improve training engagement and effectiveness have been introduced. To make the digital tools as intuitive and interactive as possible and avoid negative effects such as poor user-system interaction, information delivery failure, user stress, and rejection (Saputra & Kania, 2022), special attention has recently been paid to UX and UI (Norman, 2013). To ensure a meaningful and enjoyable UX, it is essential to consider both the information architecture and micro-interactions (Saffer, 2013). Specifically, information architecture refers to the organization of content and elements and can be considered the structural backbone of the product, whether physical or digital. A well-designed information architecture facilitates orientation and smooth navigation, allowing users to locate desired information or functions efficiently and intuitively. Efficient functions also depend on the design of interface elements and coherent design patterns that make functionalities perceptible and understandable. In doing so, interface elements clarify the link between their appearance and intended use, a link that Norman (1988) defined as affordance (e.g., underlined and bolded text on a webpage may indicate a hyperlink to another page, see Alexandre et al., 2024, and Nicholas et al., 2021); While the micro-interactions consist of small interactive moments that promote user engagement and enhance the overall coherence of the interface (Saffer, 2013). When well-designed, micro-interactions play a critical role in guiding user behavior, providing immediate feedback, and indicating whether the interaction with the object was successful or not. For example, when a user clicks a button, a pop-up may appear, or if a password meets security requirements, a green checkmark is displayed, or a red "X" appears when the password is incorrect.

Established design guidelines, such as Google's Material Design (https://m2.material.io/), Apple's Human Interface Guidelines (https://developer.apple.com/design/human-interface-guidelines/accessibility), and the Web Content Accessibility Guidelines (WCAG 2.0, https://www.w3.org/TR/WCAG22/) (Ahmad Faudzi et al., 2023), provide valuable criteria on layout, navigation, color, typography, iconography, and insights on development and usability of a toolbar. These guidelines are particularly useful as designing an effective mobile interface is challenging due to the limited screen size, which makes searching and typing difficult (Ahmad Faudzi et al. 2023). However, these standards may not provide comprehensive instructions on how to present specific content or how to make design elements discoverable (Ahmad Faudzi et al., 2023; Desideria & Bandung, 2020).

Despite the established guidelines, recent studies have shown that interface errors are still frequent. In Nicholas et al. (2021), operational malfunctions such as inoperable buttons are commonly reported, or forward arrows (placed at the bottom-right of the screen) were erroneously used to navigate the app instead of selecting the intended buttons, suggesting that their placement was inappropriate. Icon style, button design, and button size influence users' emotions, interaction quality, navigation guidance, and decision-making (Herlina, 2024; Tao et al., 2018; Yu et al., 2022). In Alexandre et al. (2024), underlined text placed under photos and text boxes with strong colors and icons were erroneously perceived as clickable, suggesting the need to adjust and replace text boxes to improve clarity and usability. The use of a larger font sizes and bullet points, rather than presenting information in paragraphs, is recommended (Nicholas et al., 2021). Finally, Gu (2016) proposed integration of an action bar and swipe-based navigation to replace traditional page-switching methods and recommended converting most content to a web-based format. She also suggested adding a global navigation menu for quick access to key functions, along with a built-in search feature to help users to better perform searches within the app interface.

Contrasting opinions emerged regarding navigation bar types. Prior research suggests that bottom bar menus are generally more efficient and elicit more positive user evaluations than hamburger menus (Tsiodoulos, 2016). Hidden navigation implemented with a hamburger icon has recently been considered as less discoverable (Pernice & Budiu, 2016; Tsiodoulos, 2016), and its use may add an extra step to the navigation process (Singleton, 2015). Additionally, categories listed in the hamburger menu should not duplicate those in the horizontal menu or on the home page, as this duplication can be unnecessarily confusing (Laubheimer, 2021). However, only a limited number of previous studies have compared these two interface features. For instance, Khadka (2021) found that choosing one type of navigation bar over another does not significantly affect user performance.

Other research emphasized the role of socio-demographic characteristics in interpreting visual affordances and using interface components. For instance, Mak and Nathan-Roberts (2017) found that children often struggle with vertical scrolling, tend to perceive horizontal scrolling more intuitively, and easily perceive glowing and 3D-style icons as touchable. Wong et al. (2019) pointed out that elderly people encounter distinct challenges when interacting with specific mobile phone features, including display, screen size, button size, colors, layout, and shortcuts. The same study highlighted that these features are particularly challenging for women as well. All these findings suggest that the development of effective interface design requires careful consideration of the socio-demographic characteristics of the intended user groups, rather than assuming that the same interaction patterns will be equally intuitive across all users.

Thus, the relationship between object and function should be as intuitive and automatic as possible because as apps become more feature-rich, the greater is the risk that navigation may become confusing, potentially hindering users from perceiving their added value during their first interactions (Nama, 2021). In addition, as Vukićević et al. (2021) observed, “there is no platform specialized for the purposes of the OSH education” (p.3) and research on design features of applications for professional sectors remains limited. In this context, previous studies highlighted the importance of adhering to visual conventions and the appearance of a visual interface for designing an easy-to-use system but also acknowledged that designing it is not an easy task (Jùnior et al., 2024). For instance, Deka et al (2016) investigated how UI layouts and design patterns changed over time in mining mobile apps. As a result, it was pointed out that “magnifying glasses” for search, “plus” signs for adding content, and textual elements such as “sign in” and “register” are the most frequently used icons and words. Then, to successfully lead common user flows, submit buttons are usually centered at the bottom of a screen, and the search symbol is placed in the top-right corner. In Kasap et al. (2019), the authors designed a mobile app to address a wide range of workplace hazards, such as electrical, fire, temperature, noise, pressure, chemical, ergonomic, and radiation risks. The study highlights key visual features, including hazard-specific information, an emergency call button connecting users to a safety engineer hotline, and a Personal Protective Equipment (PPE) guideline to emphasize the use of proper safety gear. The app interface and functionalities are illustrated through images to visually display how each feature is integrated and how they can be accessed by users. Thus, although in previous studies the overall appearance of apps was perceived as attractive, areas for further improvements were found (Alexandre et al., 2024; Kasap et al., 2019,2024; Pratama, 2024; Reychav & Wu, 2016), emphasizing the need to balance usability and aesthetics, particularly when developing mobile learning tools.

The usability concept is defined by ISO 9241-210 (2019) as “the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use” avoiding user frustration (Krug, 2006). Specifically, effectiveness assesses the quality of the output produced by users or their ability to complete tasks (i.e., completion rate and/or number of errors), efficiency concerns the amount of work produced in relation to the time, effort, and resources required, and satisfaction assesses the user’s perceptions and attitude towards the quality of interaction with a developed product (Morris & Turner, 2001). According to several authors, usability testing is a valid method to detect problems in system use and to assess the quality of a product (Desolda et al., 2023). However, despite its advantages, usability testing is often neglected, mainly because developers believe it is very resource-demanding (Desolda et al., 2023). Furthermore, when possible, the designs of interactive systems should be evaluated from both expert and user perspectives to obtain more feedback and establish whether requirements have been completely fulfilled (Bevan, 2009).

A relevant challenge to consider when developing a game is gender preferences for specific game genres and their different attitudes toward e-learning methodology (Alserri et al., 2018; Denden et al., 2021; Din & Gibson, 2019). Overall, men typically show higher engagement and a more positive mindset toward the adoption of digital games, whereas women are generally less motivated by playing games (Liu et al., 2024). In the leisure industry, where players "are free to express their personalities and emotions" (Codish & Ravid, 2017), it has already been proven that men prefer shooter, fighting, action, strategy, and competition games (Alserri et al., 2018; Lopez-Fernandez et al., 2021). In contrast, women usually prefer explorative, fantasy, educational, and puzzle games. Other studies have noted that both genders prefer adventure and role-playing games and enjoy funny games (Terlecki et al., 2011). However, only a few studies have considered gender differences in a gamification context (Codish & Ravid, 2017), highlighting that women appreciate badges more but are less motivated by games (Eickhoff et al., 2012; McDaniel et al., 2012; Pedro et al., 2015). According to Piquer Martinez et al. (2024), women are more motivated by social game elements and show a greater preference for mobile apps in terms of usability. In contrast, men are more motivated by game-like features and achievement game elements (Landers et al., 2019; Piquer Martinez et al., 2024). Although women and men expressed different preferences for different gamification techniques, they had an overall positive opinion of gamification (Larson, 2020). Based on these considerations, to ensure equal opportunities and to adequately address gender-related differences, the design process should first identify gamification elements effective for learners of both genders, then integrate additional features particularly valued by male learners and others that are more appreciated by female learners (Riddell, 2003). In summary, while mobile apps show strong potential for OSH education and safety management, their design remains complex. Therefore, improvements in usability and interface design are essential to enhance their effectiveness and real-world impact, and the implementation of rigorous testing procedures remains equally critical.

CHAPTER 2 – Manufacturing sector: Key Challenges and Study Context

2.1. Occupational injuries and statistics

The manufacturing sector encompasses a wide range of processes that transform raw materials, components, and semi-finished goods into finished products through physical, mechanical, or chemical operations, making them ready for market distribution (INAIL, 2023). Due to this breadth of activities, the manufacturing sector cannot be considered a homogeneous environment, as tasks, technologies, workforce composition, and risk exposure vary significantly across different industrial subsectors and organizational contexts. Precisely because of its extensive scope and diversity, this sector plays a key role in the economies of both developed and developing countries (Rigit et al., 2025). However, this same heterogeneity and complexity also contribute to a high incidence of occupational injuries and fatal accidents, both at the European and national levels.

Although comprehensive global data is difficult to obtain, several sources offer the basis for a general overview. According to Altunkaynak (2018) and Chang and Tsai (2014), in Turkey and Taiwan, more than half of all occupational accidents occurred in the manufacturing industry. In the United States, a total of 373,300 cases of non-fatal injuries and illnesses, and 341 fatal injuries were reported in 2020. Unfortunately, an increasing trend in fatal accidents was observed, with 336 and 351 fatal accidents reported in 2019 and 2023, respectively (NSC Injury Facts, 2023; U.S. Bureau of Labor Statistics, 2022). At the European level, manufacturing industry is also responsible for the most fatal and non-fatal accidents. Based on recent statistics (Eurostat, 2025a, 2025b), in 2022, this sector accounted for 15.2% of all fatal accidents (approximately 500 cases) and 18% of all non-fatal accidents (approximately 535,000 cases) across all economic activities. In detail, according to Eurostat (2025c), loss of control of machines, tools, transport and handling equipment is the main cause of both fatal and non-fatal accidents (33.21% and 22.37%, respectively), followed by slipping, stumbling and falling (14.2% and 16.45%, respectively). Surprisingly, similarly to the construction sector, working at heights remains a leading cause of severe and fatal accidents also in manufacturing (EU-OSHA, 2022).

The abovementioned statistics should be interpreted by considering both risk probability and impact. While incidence rates provide insight into the likelihood of accidents, the overall impact is also shaped by the size of the workforce and the variety of activities involved. In terms of probability, manufacturing reports lower non-fatal accident incidence rates (1,687 per 100,000 employed people) compared to sectors such as construction (2,899) and transportation (2,366). From a severity perspective, most accidents in EU manufacturing in 2023 resulted in shorter recovery periods, with 88.3% of cases leading to work incapacity of less than three months. More severe accidents were proportionally more frequent in sectors such as mining and quarrying, where 20.9% of cases involved incapacity lasting three months or more (Eurostat, 2025a, 2025b). However, due to the large size of its workforce, the manufacturing sector still accounts for a substantial share of total occupational accidents.

Specifically, the use of metalworking equipment carries several relevant risks including noise, vibration, moving parts, cuts, burns, electric shock, and contact injuries such as amputations or crush injuries. Among metalworking equipment, lathes and grinding machines are considered particularly hazardous, while drilling and milling machines are considered safer compared to other machines (Józwik & Pietras, 2013). This is consistent with earlier research showing that thousands of lathe operators are injured each year (ILO, 2011; Józwik & Pietras, 2013; U.S. Centers for Disease Control and Prevention [CDC], 2024). In addition, injuries related to lathe operation account for a higher percentage of machine-related incidents in the manufacturing sector, primarily due to the high-speed rotation of machine components (Dado et al., 2018). Furthermore, machinery with sharp edges, such as presses, remains a leading cause of amputations, accounting for 60% of such injuries (Tuktur, 2017). U.S. statistics also confirm the severity of the issue: between 2018 and 2022, 3,677 workers in the United States. died from contact with machinery or equipment, and in 2022, machinery-related fatalities represented 12.6% of all work-related deaths.

When examining the injured body part, European statistics (Eurostat, 2025a, 2025b) show that upper-extremity injuries accounted for 52.1% of cases, lower-extremity injuries represented 24.9%, and back injuries accounted for 7.5%. Less frequent, though still significant, outcomes of non-fatal workplace incidents included amputations or the loss of body parts, which represented 0.9% of cases in the manufacturing sector. Beyond the occurrence of accidents and injuries, empirical evidence has shown that occupational risks are perceived differently across worker categories in manufacturing industries. For instance, Pérez Floriano and Pacheco (2018) found that production operators, who are directly exposed to machinery, repetitive tasks, and environmental stressors, tend to report higher levels of perceived risk compared to their supervisors, managers, and indirect personnel (technicians). This difference has been attributed to their differences in levels of exposure and proximity to occupational hazards, as well as direct experience of risk during routine operational activities. Supervisors and managers, who are more strongly associated with productivity targets, coordination activities, and organizational control, may underestimate certain operational and ergonomic risks. Mearns and Flin (1995) previously identified similar differences, finding that supervisors and managers report slightly higher feelings of safety and perceive less pressure to prioritize production over safety compared to workers. This outcome is interesting because it suggests that either management is not sharing this mindset with their employees or that other perceived factors are influencing employees' behaviors.

To prevent accidents, reduce risks, and protect workers' health, international, national, and regional laws regulate occupational safety in manufacturing. Since injuries and accidents are frequently associated with machinery, repetitive tasks, noise, heat, chemicals, and manual handling, regulations include both preventive and corrective measures to control hazards. Additionally, the Machinery Directive 2006/42/EC (EU-OSHA, 2006; European Union, 2006) establishes a regulatory framework for the design, manufacture, and marketing of machinery, requiring manufacturers to comply with essential health and safety requirements and to ensure conformity through certification procedures and technical documentation. Furthermore, safety training is a crucial pillar of workplace safety in the manufacturing industry, where exposure to machinery, hazardous substances, repetitive operations, and environmental stressors demands constant awareness and continuous updating of skills and competencies.

2.2. The role of Design for Safety and ergonomics[2]

Understanding occupational accidents, particularly their timing, causes, and affected body parts, is fundamental for creating effective safety strategies, especially in high-risk sectors such as manufacturing. Despite regulatory efforts, accident rates remain high, notably in SMEs, often due to technical failures, poor design, and insufficient ergonomic considerations during machinery and equipment use (Barbosa et al. 2019).

In this context, the concept of Design for Safety (DfS) has emerged as a pivotal approach (Gullo & Dixon, 2018; Sheldon, 2004). DfS is defined as the application of engineering and management principles and techniques to minimize the risk of occupational injuries, illnesses or death (Gullo & Dixon, 2018). In the industrial context, DfS is related to the "Design for X" approach, i.e., the use of a set of methods and guidelines aimed at improving the X property of a technical system during its design and development stages (Bauer & Meerkamm, 2007; Meerkamm, 1994). DfS promotes safe human-machine interaction through a multidisciplinary, human-centered strategy grounded in Human Factors and Ergonomics (HFE), which focuses on optimizing the interaction among several factors, including anthropometric, biomechanical, and physiological aspects, factors related to information and control tasks, factors related to human–machine interaction, and environmental factors.

In such a context, despite the growing interest in HFE among engineers, practical guidelines for integrating ergonomics into equipment design are still limited. Technological advancements are reshaping worker-equipment interactions, further emphasizing the need for ergonomic design. Research in safety ergonomics is expanding but still lacks quantitative trend analysis. Gaps remain in connecting ergonomics with design integration, highlighting the need for bibliometric studies to guide future research (Donthu et al., 2021). Few previous studies have provided a systematic review of empirical evidence addressing the link between human factors and quality risk factors related to the entire design of the operational process (Kolus et

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[2] This paragraph is based on the following published contribution:

Vigoroso, L., *Caffaro, F., Tronci, M., & Fargnoli, M. (2025). Ergonomics and design for safety: A scoping review and bibliometric analysis in the industrial engineering literature. Safety Science, 185, 106799. https://doi.org/10.1016/j.ssci.2025.106799* al., 2018), and the relationship between fatigue and productivity (Yung et al. 2020), even though design features were not specifically investigated. The latter issue was analyzed by Fargnoli (2021) to bring forward the DfS approaches to tackling HFE concerns and consequently provide a unified design framework. However, this analysis is more oriented toward analyzing design tools rather than research hotspots. Moreover, all the latter reviews lack a bibliometric analysis, i.e., a quantitative analysis of the metrics of the literature employing statistical tools, which is capable of grasping potential future trends and research directions (Donthu et al., 2021). More recently, a scoping and bibliometric analysis was conducted aiming to understand how HFE issues are integrated into the DfS research in the industrial manufacturing work environment (Fargnoli, 2021; Vigoroso et al., 2025). According to Vigoroso et al. (2025), five main research themes were identified and developed in previous studies on DfS and HFE in manufacturing:

- Assistive or smart solutions interfaces (AS) are design approaches that improve operator interaction with Industry 4.0/5.0 technologies. They include wearables and RFID for monitoring operator presence (Dhalmahapatra et al. 2022), movement in hazardous areas, and PPE use, automated electrical monitoring systems to reduce operational risks (Floyd & Valdes, 2020; Patrucco et al. 2010), information models for human–robot collaboration that lower cognitive load and enhance situational awareness (David et al., 2023), and autonomous mechanical design tools that help identify hazards during operation and maintenance (Tedonchio et al. 2022).
- Frameworks and methods (FM) refer to design methodologies and tools aimed at improving safety and ergonomics through the application of risk assessment procedures and legislative and normative requirements in design activities and redesigning workstations within manufacturing environments (Caputo et al. 2013; Leite-Pacheco et al. 2022; Pačaiová et al. 2021; Perrin et al. 2012). In addition, several studies emphasize improving human–machine interaction in terms of usability, comfort, and error prevention, including task-based and human reliability–oriented evaluation methods to support safer work activity and workstation design (Rausand & Utne, 2009; Jeang et al., 2018; Muramatsu & Kato, 2019).

- Safety ergonomics knowledge (SK) refers to the need to explicitly address HFE factors in manufacturing design, as many designers lack an HFE background (e.g., in Gauthier et al. 2021). To support this, AI tools such as text mining, natural language processing, and machine learning can be used, for example, to translate LOTO procedure data into structured information (Delpla et al. 2023) and to enable tools that enhance operators' safety commitment and reduce errors (Fraile et al. 2023; Gonzalez-Cortes et al. 2022). In addition, specific frameworks integrate HFE expertise into the design process to optimize Industry 4.0 solutions, while the use of information from end-users and equipment manufacturers improves usability, intuitive interaction, and cognitive support in operational settings (Gauthier et al. 2021; Pinto et al. 2013; van Duijne et al. 2007).
- Workplace design (WD) refers to the conflict between productivity-oriented solutions and those improving safety, comfort, and human–machine interfaces (Azadeh et al. 2015; Houssin & Coulibaly, 2011; Žitňák et al. 2023), emphasizing the need to address human-related barriers and involve HFE specialists. Their main contributions are HFE-based DfS solutions, especially task and workstation simulations to prevent human–automation conflicts and to optimize working postures through integrated ergonomic assessment methods (Zubar & Alamoudi, 2019; Bolton et al., 2021; Houssin & Coulibaly, 2011) such as Rapid Entire Body Assessment (REBA), Ovako Working Posture Assessment System (OWAS), and Rapid Upper Limb Assessment (RULA).

Taken together, these themes provide a structured overview of how HFE has been incorporated into DfS research and how research on HFE-based DfS is evolving in response to technological advances, addressing new challenges and enabling more practical solutions. Evidence of this evolution is also reflected in the bibliometric analysis, which shows an increasing occurrence of keywords related to Industry 4.0 and human-centered decision-making in recent years (Lasi et al., 2014; Vigoroso et al., 2025, see Figure 2 and Figure 3). This increasing interest can be driven by the changes that occurred at the normative level, indeed the shift towards Industry 4.0 and 5.0 technical solutions has fostered the need to better manage the human-machinery interaction. At the same time, there is a growing recognition of the need to integrate insights from psychology, social sciences, neuroscience, and decision sciences into engineering research and practice (Bernabei & Costantino, 2024).

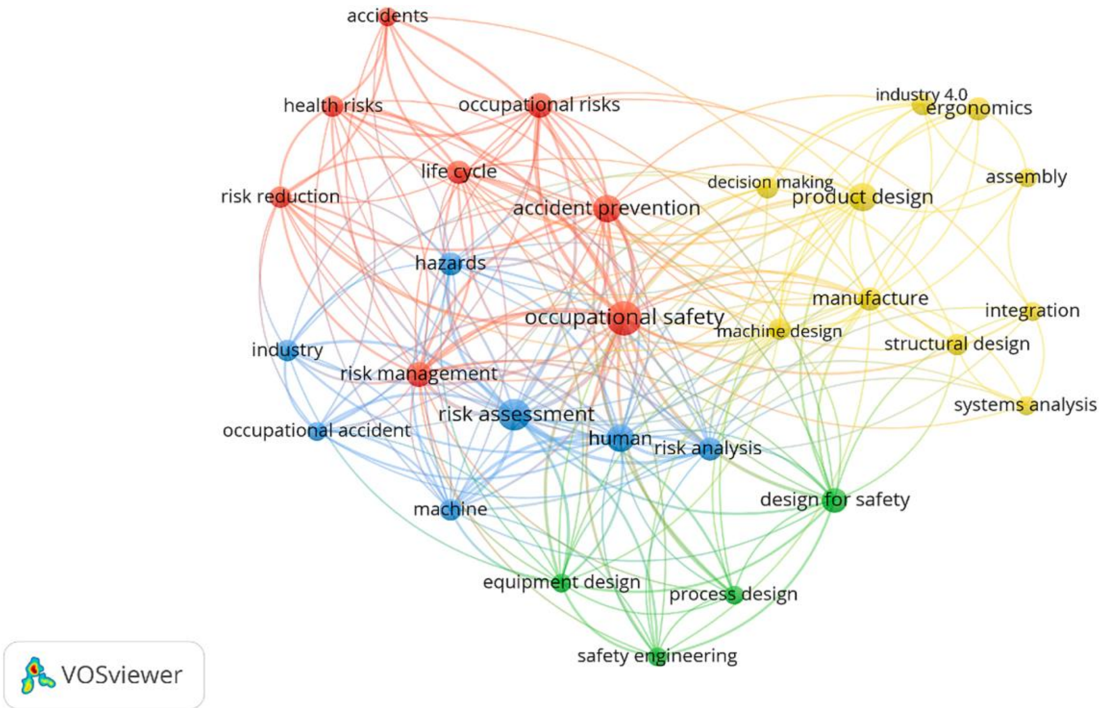

Figure 2. Index keywords network visualization (from Vigoroso et al., 2025).

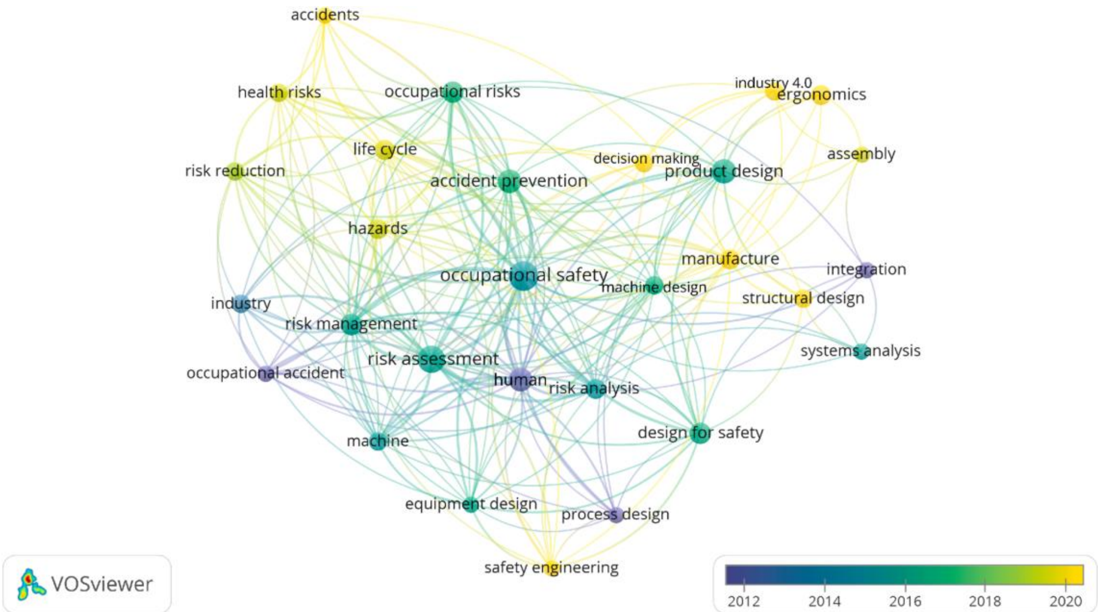

Figure 3. Co-occurrences index keywords, overlay visualization (from Vigoroso et al., 2025).

These trends are consistent with a recent bibliometric study conducted on industrial automation (Vigoroso et al., 2025), in which the importance of distinguishing between *adaptive* approaches (where the system makes decisions autonomously) and *adaptable* approaches (where control remains with the operator) was highlighted, as both approaches can offer significant advantages for DfS, enhancing operational safety and users' situational awareness.

A second relevant recurring theme raised in the recent review studies concerns the need for safety-related skills and knowledge to be shared not only among designers but also among workers and operators. Studies addressing this aspect have shown that although engineers are aware of these aspects, they hardly know how to put them into practice in design and development activities. In other words, a gap emerged between "work as imagined" (WAI) and "work as done" (WAD), i.e., the daily work situations and events.

Lastly, it should also acknowledge that the geographical distribution of research outputs in the OSH research field is highly concentrated in a limited number of countries (Finardi, 2023; Vigoroso et al., 2025): the United States ranks among the top producers of OSH research (Finardi, 2023), followed by a dominance of European countries, including Italy, the UK and Germany. However, an interesting divergence emerges in the domain of HFE-based DfS in manufacturing. Indeed, according to a recent bibliometric review (Vigoroso et al., 2025) the United States does not appear among the leading countries. This discrepancy may be explained by the strong and long-standing European tradition in ergonomics and HCD, which has historically emphasized the integration of human factors into engineering and manufacturing systems (Van Der Veer et al., 2025). As a result, European research appears to be more strongly oriented towards engineering-driven and manufacturing-specific applications of HFE within the Design for Safety framework.

2.3. Use of apps and gamification in the manufacturing industry

In hazardous occupational industries, gamification has already been applied in the construction industry (Gao et al., 2019), while its use in other hazardous sectors, such as agriculture (Godinot, 2018; Vigoroso et al., 2021) and manufacturing, remains limited, though interest in its application is increasing (Kasap et al., 2024; Keepers et al., 2022; Li & Liu, 2024). Focusing on games applied to manufacturing, Leite et al. (2023) in their review pointed out that many studies in this sector focused on production planning, execution, control, and the need to improve the workers' qualifications and skills, with only a limited number of studies related specifically to workers' training on the shop floor. Available studies have shown that mobile applications are a promising solution by enhancing real-time data capture, teamwork, communication, leadership and overall safety management, contributing to the sharing of safety knowledge and fostering a proactive safety culture (Datta et al., 2024; Tsourma et al., 2019; Zikos et al., 2019). In Datta et al. (2024), the purpose of the developed mobile app was to support safety management by streamlining inspections, reducing administrative burdens, eliminating manual data entry errors, and allowing immediate corrective actions, thereby improving overall safety performance. Managers can examine images to identify potential risk factors, discuss improvements, and take remedial actions to promote disaster prevention, enabling more efficient safety inspections. As a result, Datta et al. (2024) reported that 78% of respondents experienced significant improvement in safety audits and inspections, 72% observed improvements in data accuracy, and 67% mentioned a stronger communication and collaboration among stakeholders.

Zikos et al. (2019) created a collaborative platform to enhance social interaction among workers, save time, and support their knowledge sharing for problem-solving and greater satisfaction. A gamification system was integrated, allowing users to earn points when sharing information, uploading content, and sharing their experiences with co-workers. As a result, overall positive evaluations were received in terms of work experience and impact criteria. Similarly, Tsourma et al. (2019) developed a social media platform, where workers can upload, view, and share multimedia content, find documentation and guidelines, and exchange opinions with colleagues. As done by Zikos et al (2019), point-based gamification mechanics were applied to maintain user participation. Lithoxoidou et al. (2017) implemented gamification techniques (users can gain points, badges, or advance to higher levels in their personal profiles) in a *Questions & Answers* forum section of a Social Collaboration platform, to foster employees interaction and collaboration. Lithoxoidou et al. (2020) also proposed a team-based play mode within the gamified collaboration platform, aligning game activities with existing daily workflow tasks. The platform was used for three months, resulting in an overall enhancement of positive mood between colleagues, along with their satisfaction and engagement.

Liu et al. (2018) described how CNC machine operational jobs can be gamified through a job design framework: tasks emphasize skill variety (speed and accuracy in typical operations, enhanced through points, badges, and competition), autonomy (freedom in pace and task order, fostering motivation), and feedback (real-time performance awareness through rewards and visual indicators). Fortuna et al. (2024) explored mobile gamification as an innovative educational tool in machine workshops. The platform, available on Android devices, provides a virtual workspace with detailed models of equipment and specialized areas, where students use 3D avatars to navigate, identify risks, and practice emergency responses. Notifications reinforce safety behaviors (e.g., wearing helmets and gloves), while simulated scenarios and interactive posters support the understanding of OSH concepts, complementing traditional training methods in high-risk industrial environments.

In addition, according to European statistics (Eurostat, 2025c) and empirical studies (e.g., Khahro et al., 2024) it should be noted that, although manufacturing and construction differ in processes, organizational settings, and exposure to certain sector-specific hazards, falls from elevation, caught between incidents and falls at floor level' are the most common occupational accidents in both industries. Thus, research conducted in the construction sector, focused on preventing these risks can offer valuable transferable insights for manufacturing contexts. For instance, Tay et al. (2024) designed and developed a safety library repository, containing the common construction risks and design options based on expert recommendations and norms. It was created to support workers in completing their tasks independently. The authors, evaluating workers' performance pre- and post-course by means of quiz scores and questionnaire, found that digital training provided benefits equally, regardless of their prior work experience, improving workers' comprehension of OSH concepts and safety procedures when working at height. Greuter et al. (2012, 2013) proposed a fully graphical game, showing a construction site with animated workers and hazards, and where players must apply the correct safety controls, such as guard rails or harnesses, to protect workers operating on elevated platforms. A series of icon-buttons representing different safety controls (e.g., eliminate risk, PPE, fire extinguishers) is implemented to intervene against the hazard.

In terms of game elements, it is interesting that in all the mentioned studies, more than one game element was used. Although it is not possible to determine which game elements are "best" (Keepers et al., 2022), the most frequently implemented gamification components are goals and objectives, followed by points, credits, achievements, rewards, and feedback. Obviously, the presence of a mix of elements is justified, as gamification is a complex scenario that likely benefits from the simultaneous implementation of several game design components (Keepers et al., 2022; Leite et al., 2023).

According to the literature, the main benefits of gamification for manufacturing (consistent with evidence from other occupational areas) include improvements in motivation, productivity, efficiency, engagement, interest, focus, and enhancement of learning. Additional frequently reported benefits are greater enjoyment, flow, and social relatedness. Furthermore, to achieve these results, previous studies have already suggested some insights for implementing gamification in the manufacturing industry (Gilotta et al., 2018; Keepers et al., 2022; Leite et al., 2023; Stadnicka & Deif, 2019):

- Simplicity: a game should not be complex; it should avoid cognitive overload and ensure that participants have a clear understanding of the situation.
- Clear goal(s): the objectives of the game should be explicitly described, especially if they may appear challenging to realize.
- Motivated: employees should be encouraged to identify connections between the game elements and their own work environment.
- Core elements: include mechanisms that display progress and provide feedback.
- Challenge: incorporate meaningful challenges to keep engagement.
- Design approach: use a HCD approach to foster the development of innovative systems.

Although these six elements provide valuable indications, the literature still lacks a structured set of design guidelines that integrate them and support their consistent application in manufacturing contexts where the multiplicity of risks and activities demands a more systematic and coherent HCD approach.

2.4. Context and aim of the DigiSafeMan project

Based on the above-mentioned considerations, this project aims to design an innovative digital training tool specifically tailored to the manufacturing sector and its operational context, in cooperation with an Italian manufacturing firm, Olivero Impianti, which co-founded the project. The firm, with over a decade of experience and highly qualified personnel, offers comprehensive services in design, construction, automation and robotics, plant piping, integrated logistics, and intralogistics assembly and maintenance services for industrial plants and machinery, providing the manpower and all necessary spare parts to restore customer's machinery or systems to their proper working order. The assembly services can involve both single machines and entire systems at customers facilities, whether designed by firm's workers or supplied directly by the customer. As a company with consolidated expertise in industrial plants, its workers often operate in environments where they are daily exposed to risks, complex machinery, repetitive tasks, and potentially hazardous conditions.

The "*DigiSafeMan*" (DIGItal SAFEty training for MANufacturing) project, therefore, aims to create a training solution that integrates mobile learning technologies and gamification strategies to maximize workers' engagement, motivation, and knowledge retention. By means of interactive modules available on mobile devices, the tool is intended to strengthen employees' capacity to identify risks, implement safe practices, and comprehend more fully the potential consequences of unsafe behaviors. In addition, the initiative adopts the HCD approach, ensuring that the development process is guided by the actual needs, abilities, and expectations of workers. By focusing on usability, accessibility, and cognitive ergonomics, the tool will be designed to provide an intuitive and engaging training experience that facilitates active participation and sustained learning outcomes. Furthermore, the initiative aims to support both regulatory compliance and process optimization, fostering safer and more efficient workplace environments.

CHAPTER 3 – Materials and Results of the DigiSafeMan project

This chapter presents the HCD approach as the overarching framework guiding the development of the digital safety training tool, from the initial analysis of the industrial context to the iterative refinement of design solutions. Building on this framework, the chapter describes the mixed-methods research strategy used in the project, which combines quantitative and qualitative techniques to investigate workers' needs, training practices, and interaction with digital interfaces.

3.1. Methodological framework: the Human-centered design approach (HCD)

Human-Centered Design (HCD) (see paragraph 1.5), as defined by ISO 9241-210:2019, acknowledges the central role of human beings, their characteristics, needs, and how they interact with the environment and its components, throughout the entire design process. This approach is an iterative process, and it is structured around five interconnected phases, requiring the active involvement of end users from the earliest stages of system or product development. The key phases include (see Figure 4):

1) Plan the human-centered design process: define the overall design strategy, identify the activities to be performed and establish a comprehensive plan of action to guide the process.
2) Understand and specify the context of use: analyze the context to understand the physical, social, and organizational environments in which the product will be used.
3) Specify the user requirements: identify and describe users' needs and the specific problems they encounter, considering the organizational conditions under which these issues must be addressed.
4) Produce design solutions to meet user requirements: generate of design concepts that effectively address the identified user needs and problems effectively.
5) Evaluate the design against the requirements: evaluate the design solutions through iterative testing with real users. Feedback is collected and analyzed to

assess whether the design meets the defined requirements. If it does not, the process is repeated, thereby fostering continuous refinement and improvement.

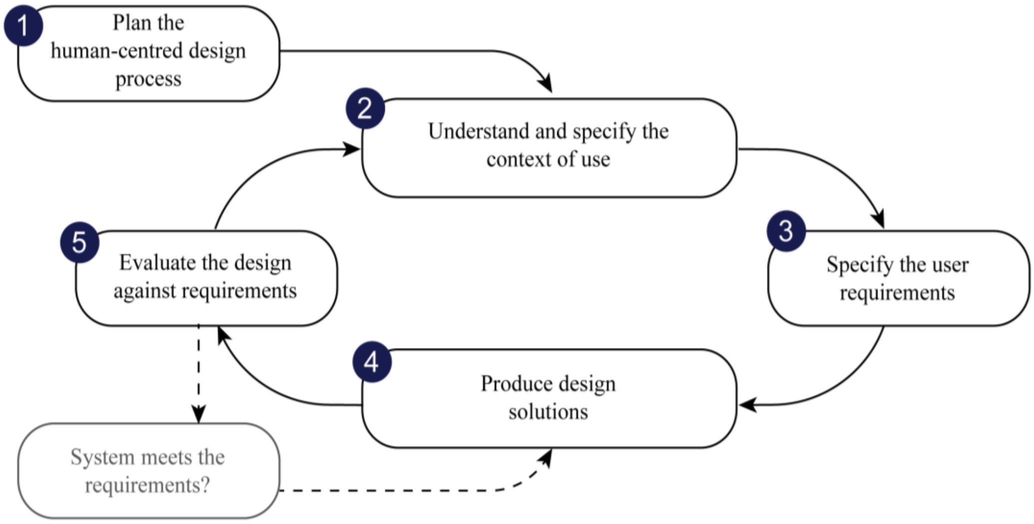

Figure 4. Representation of the HCD process, based on ISO 9241-210, 2019.

In the following sections, the methods and results for to each phase of the HCD process will be presented. Thus, each phase will be reported individually, outlining the methodological approach adopted, the materials and methods used, the participants involved, and the corresponding results. Each section will also present a brief introduction that outlines the key concepts and thematic areas previously introduced in Chapter 1 and the corresponding research questions (RQs). This structure aimed to provide a clear and systematic overview of how HCD principles were applied throughout the entire project. Discussions will be presented in Chapter 4.

For readers' clarity, Figure 5 represents the flowchart of the overall activities conducted, the participants involved, and the instruments used for data collection, qualitative (interviews and/or hands-on demonstration), quantitative (questionnaires), or both, according to the mixed-method approach (see paragraph 3.2.1), and what information was gathered throughout the whole process.

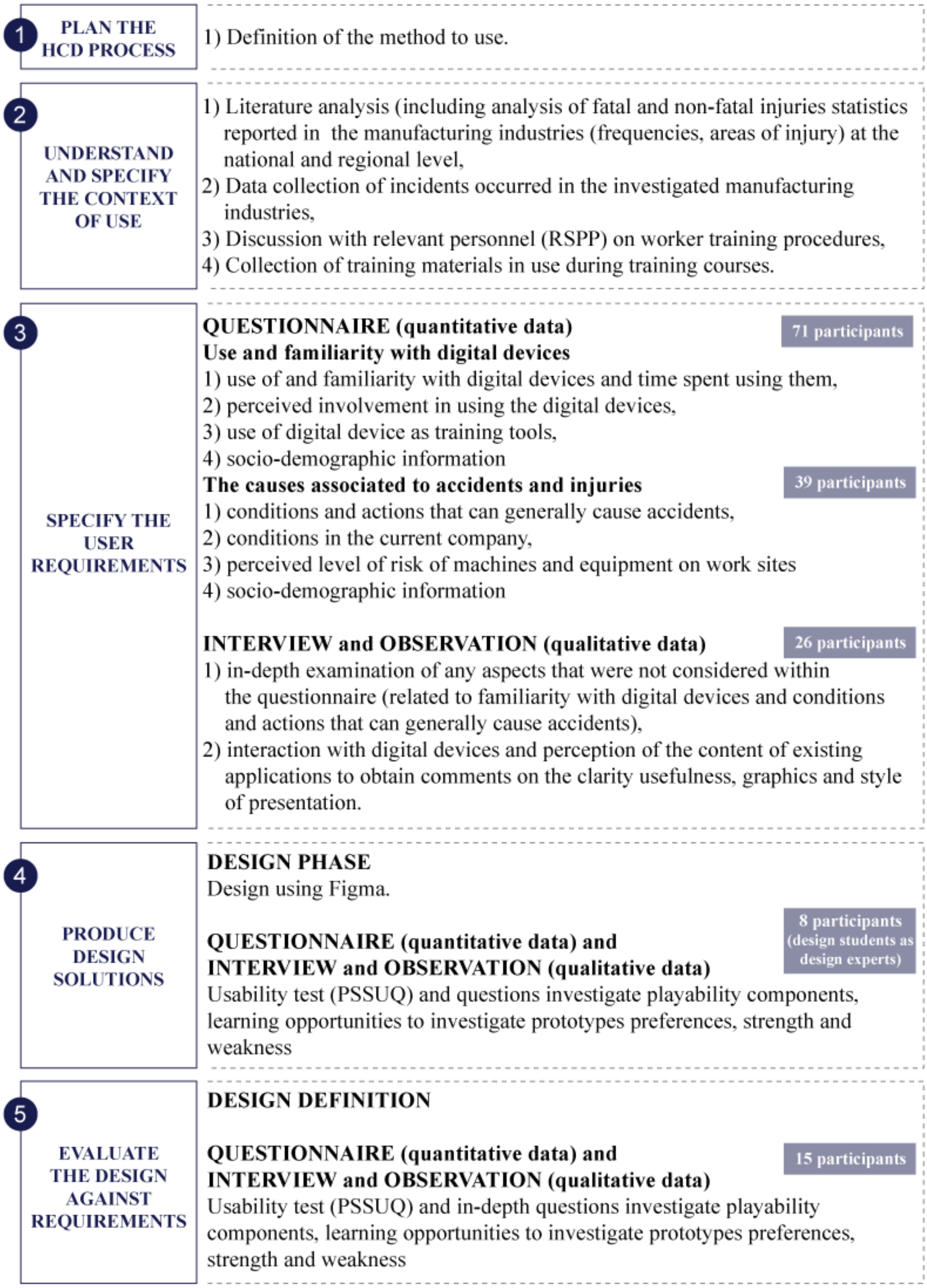

Figure 5. Flowchart representing the activities conducted.

3.2. Phase 1 – Plan the human-centered design process

Under Phase 1, the project begins with a SWOT analysis to systematically identify strengths, weaknesses, opportunities, and threats related to current safety training practices and organizational conditions, clarifying priorities and constraints for the new digital tool (Figure 6). Next, the methodology to be used was defined. A mixed-methods design, which combined quantitative and qualitative techniques to capture both measurable patterns and contextual insights, was used, to address the technical, organizational, and human dimensions involved in developing an effective safety training tool.

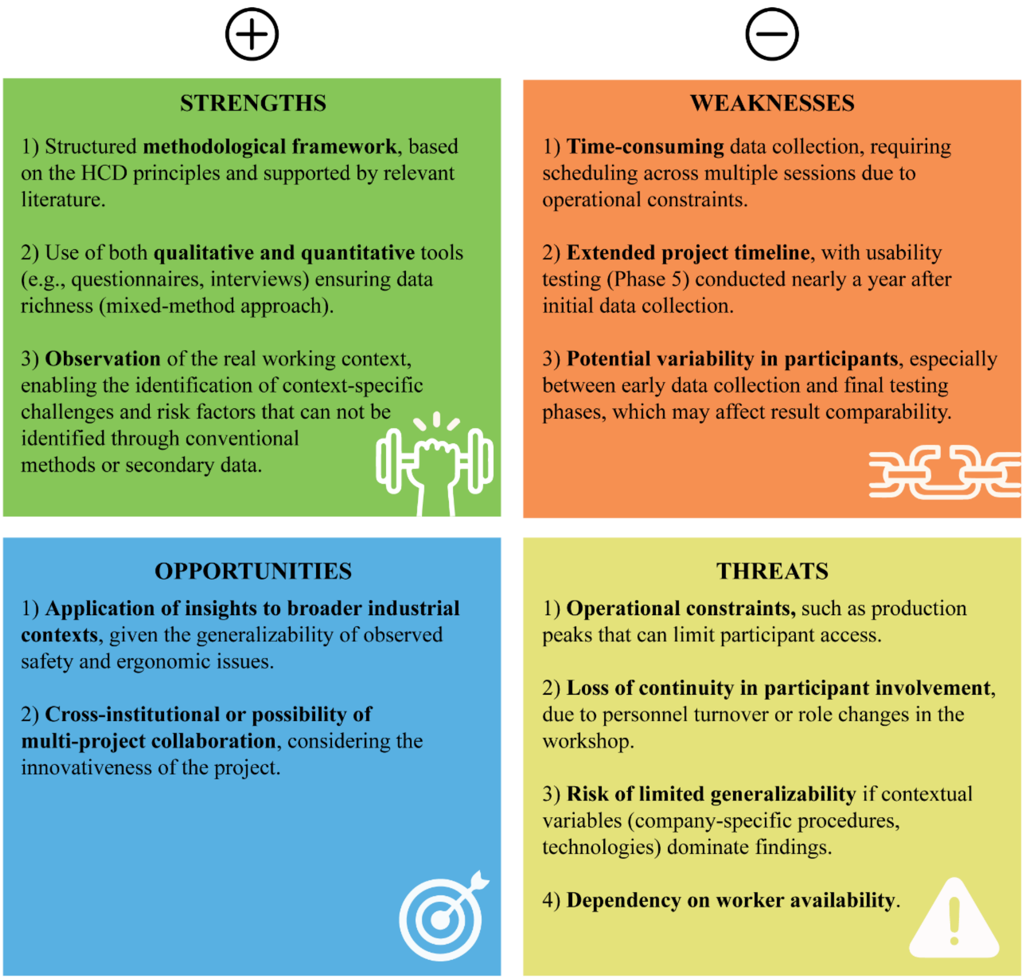

Figure 6. SWOT analysis based on the project's activities and considerations.

Based on these premises, the planning of on-site data collection activities required careful consideration of time constraints and participants' work schedules to minimize interference with ongoing operations. In particular, during Phase 3 of the HCD process, workers who agreed to participate in the project were asked to fill out a questionnaire and, subsequently, to take part in an interview. The data collection sessions were expected to last approximately 35-45 minutes each. Given the time required and the variability of work schedules, the possibility of splitting the administration of the instruments into two separate sessions was considered, acknowledging that the number of completed questionnaires and the availability of workers for subsequent interviews might vary significantly. To ensure that no key information was lost despite these fluctuations, we carefully analyzed data from questionnaires and interviews throughout the process, verifying that emerging topics were consistently captured and integrated. The same approach was used during the usability tests planned for Phase 5 of the HCD process (also estimated to last 35–45 minutes per session), which were conducted after the development of the digital tool. Considering the potential turnover within the workshop during this timeframe, particular attention was paid to maintaining coherence and completeness in the data, even when different workers were involved in later stages. Finally, since the study required human participation, the study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the University of Torino (protocol code 0250477 on 14 May 2024)[3]. Before participation, the researcher explained the aims of the study to all participants, informed them that all data would be collected and analyzed anonymously and that they were free to withdraw from the study at any time without consequences. Participation was entirely voluntary, and no incentives were offered. Oral informed consent was obtained before data collection, and participants were asked to generate an alphanumeric code when answering the questionnaire to ensure the anonymity of their responses.

[3] *Ethical approval for the study was requested and granted by the Ethics Committee of the University of Turin, as the project falls within a broader research framework led by the University, which includes other initiatives addressing similar topics. Given the methodological similarities, particularly regarding participant involvement, a joint ethics application was submitted on behalf of the related projects.*

3.2.1. The Mixed methods approach

For the aim of the present project, a mixed-methods research approach was employed (Creswell, 2003). The mixed methods research does not introduce new techniques but rather leverages the advantages of both quantitative and qualitative approaches. In quantitative research, face-to-face administration of questionnaires allows direct interaction between the interviewer and respondent. This interaction offers the advantage of fostering greater participant cooperation, reducing the incidence of missing responses (Cardano & Ortalda, 2017). However, it is also a resource-intensive method, as it requires more time to establish contact with respondents and to administer the questionnaire. In the case of self-administered questionnaire format, participants receive the questionnaire and completed it independently. This approach is adopted to minimize the researcher's influence on participants' responses and optimize data collection time. Immediate return further ensures control over the timing of administration and respondent identity, while still allowing participants to request clarification if needed during completion. Unfortunately, this approach also does not provide absolute assurance that respondents will answer all the questions included in the questionnaire (Caselli, 2005). In addition, such questionnaires are usually structured using Likert scales, given their ease of construction and comprehension. Furthermore, this approach may also facilitate the exploration of individuals' meanings, motivations, perceptions, and lived experiences (Cardano & Ortalda, 2017).

The qualitative method, instead, is the most widely used approach in psychosocial research. In structured or semi-structured interviews, the interviewer defines the objectives of the conversation, while the interviewee responds to the questions posed. Thus, the interview guide works similarly to a script: it provides a framework without rigidly determining the dialogue. Nevertheless, interviewees retain the possibility of diverging from the interviewer's prompts, thereby allowing them to respond according to their own needs and perspectives.

The Thinking Aloud protocol is useful for gathering qualitative data on thinking processes, particularly during hands-on tasks. Through the Thinking Aloud method, participants are asked to verbalize their thoughts and feelings and share any questions or concerns while interacting with the system. This enables the researcher to interpret faulty or successful interface elements and get insights (Barnum, 2020). This method is useful to capture both users' actions, thoughts, reactions, and emotional responses in real time, obtaining deeper insights into their experience and the reasons behind their decisions, rather than relying on assumptions (Barnum, 2020).

Through participants' observation, significant amounts of information are usually conveyed through gestures, which can be monitored to enrich the spoken data collected during interviews, and support a deeper understanding of users' actions and their mental processes (Yammiyavar et al., 2007, 2008). According to Mehrabian (1981), non-verbal cues in usability testing or user data collection sessions are particularly relevant as they may account for up to 55% of the overall impact of a message. However, in contrast to interview data collection, where recordings are transcribed, participant observation relies on systematic notes taken by the researcher during fieldwork or immediately afterward, especially when the data collection context or interview setting does not permit video recording. These notes are then the primary data source, and their production is a time-intensive process (Hurst, 2023). In particular, during the usability sessions, the researcher acted as a moderator, staying close to the participants to facilitate the Think Aloud protocol and serve as an attentive listener (Vasalou et al., 2004). This proximity allows the researcher to observe users' initial reactions and first impressions as they explore new systems, while also enabling discussion with participants during and between test tasks. The moderator's presence further supported user engagement, encouraged participants to complete all assignments, and provided immediate feedback on task performance when appropriate. In addition, moderators can manage specific circumstances that may arise during user testing, such as unexpected events or system crashes (Riihiaho, 2015).

For the present study, a sequential explanatory strategy was adopted (phase 3 of the HCD process). This strategy is characterized by the initial collection and analysis of quantitative data, followed by the collection and analysis of qualitative data (Figure 7). Thus, the qualitative data can be used to further explore quantitative results in more detail. The linear structure of this strategy is its main strengths, but its main weakness is the length of time required for in data collection, with the two separate phases (Creswell, 2003).

Figure 7. Mixed-methods research approach, sequential explanatory strategy (based on Creswell, 2003).

In addition, for the usability test (phases 4 and 5 of the HCD process), a concurrent triangulation strategy was adopted. This approach involves the simultaneous application of both quantitative (questionnaires) and qualitative (semi-structured interviews and observations) data collection and analysis techniques. Within this framework, both quantitative and qualitative data contribute equally contribution, with neither being prioritized over the other, except potentially during the interpretative discussion phase (Figure 8). Adopting a triangulation strategy, qualitative results can be used to validate quantitative results (and vice-versa), for instance, by comparing survey data with insights obtained from focus groups and/or interviews (Cardano & Ortalda, 2017).

For the present research, quantitative analyses were performed using IBM SPSS Statistical Package for Social Science v.29 (IBM Corp., Armonk, NY, USA).

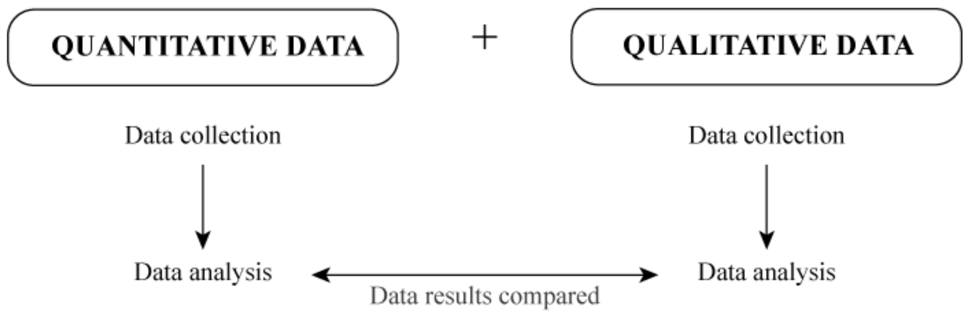

Figure 8. Mixed-methods research approach, concurrent triangulation strategy (based on Creswell, 2003).

3.3. Phase 2 – Understand and specify the context of use[4]

This phase focused on establishing a comprehensive understanding of the regulatory, organizational, and operational context. First, the Italian normative framework on occupational safety and health (OSH) is described, followed by an overview of accident trends in the Italian manufacturing sector, to contextualize the study within the broader national setting. The analysis then narrows to the case study of Olivero Impianti. In this phase, secondary data on workplace accidents at Olivero Impianti were examined through analysis of the Report on Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR). In addition, workers and trainers were observed during safety training courses conducted within the company over a three-month period. These observations aimed to understand how training activities are carried out in practice, identify existing dynamics in the delivery of safety training, and provide an overall perspective of the organizational context, which served as a foundation for the subsequent phases of the study.

3.3.1. OSH normative aspects in the Italian manufacturing sector

To promote efficient OSH, the European Union established several Directives (see paragraph 1.2). At the national level, in Italy, the Legislative Decree 81/2008 (Testo Unico sulla Salute e Sicurezza sul Lavoro, Ministero del Lavoro e delle Politiche Sociali, 2008a) establishes a comprehensive framework that requires employers to carry out detailed risk assessments, designate prevention and protection services, and ensure continuous worker training. According to the Italian Legislative Decree 81/08, safety training is mandatory in the workplace. Workers are required to complete 4 hours of general training covering the foundational principles of OSH, followed by

[4] This section is partially based on the following published contribution:

Vigoroso, L., *Alce, G., Boccadutri, L., Caffaro, F. (2025). Enhancing Workers' Safety in Manufacturing: A Human-Centered Approach in Interaction Design of Digital Training Tools. In: Jin, S., Kim, J.H., Kong, YK., Park, J., Yun, M.H. (eds) Proceedings of the 22nd Congress of the International Ergonomics Association, Volume 4. IEA 2024. Springer Series in Design and Innovation, vol 56. Springer, Singapore. https://doi.org/10.1007/978-981-95-0289-9_14* specific training based on the level of risk associated with the company's activities: 4 hours for low-risk sectors, 8 hours for medium-risk sectors, and 12 hours for high-risk sectors. For instance, since manufacturing is typically categorized as a medium- to high-risk sector, workers in this occupational field are generally required to complete 12 hours of specific training addressing sector-related hazards such as machinery use, chemical exposure, noise, and ergonomics (Ministero del Lavoro e delle Politiche Sociali, 2008b), for a total of 16 hours of safety training (general plus specific). In addition, safety training must be continuously reinforced through updating courses and targeted sessions whenever new machinery, technologies, or processes are introduced.

Another fundamental element of the Italian decree is the Risk Assessment Document ("Documento di Valutazione dei Rischi", DVR) through which the employers identify all potential hazards in the workplace, evaluate the level of risk associated with each, and define specific preventive and protective measures (Ministero del Lavoro e delle Politiche Sociali, n.a.). For the manufacturing sector, this document usually includes mechanical safeguards (e.g., machine guarding, lockout/tagout procedures), organizational measures (e.g., safety protocols, shift planning to reduce fatigue), personal protective equipment (PPE), and environmental controls to mitigate risks linked to noise, vibration, or inadequate thermal conditions. However, employers are not the only ones responsible for ensuring compliance with these duties. They are supported by a structured system of institutions, including the National Labour Inspectorate (INL) that oversees the compliance with the safety regulations, the National Institute for Insurance against Accidents at Work (INAIL) which supports occupational injury prevention, research, and compensation., while the Local Health Authorities (ASL) conduct inspections at the territorial level, focusing on workplace hygiene, risk assessment, and preventive measures.

When considering the work sectors, the industrial sector represents one of the main drivers of the Italian economy (INAIL, 2025). Unfortunately, it also represents a leading sector in terms of the number of accidents. Based on recent INAIL statistics (INAIL, 2025), in 2023, a total of 93,346 occupational accidents were reported in this sector, of which 20% are reported in manufacturing industries. In addition, with 178 cases, it records the second-highest number of fatal accidents, following the construction sector, which reports a total of 220 fatalities. Going into the details of the specific categories within the manufacturing sector, in Italy the manufacturing of metal products reported the highest number of injuries and fatal accidents (21%), followed by the manufacture of machinery (about 14.2% and 10% of non-fatal and fatal injuries, respectively). The workers most affected by accidents are unskilled workers (5.6%), mechanists and assemblers (5.5%), while fatalities are highest among metal assemblers (5.4%). Overall, these data still confirm the risks of this sector in Italy. Although the machines involved were not explicitly mentioned (e.g., presses, lathes, drills, etc.), the considerable number of accidents suggests the need for targeted analyses. Furthermore, the understanding of the potentially dangerous nature of some machines is also demonstrated by the fact that the metalworking industries are more inclined to submit projects under the "innovative safe companies" calls (ISI, from the Italian acronym *Imprese Sicure Innovative)* (28.4% of projects). The machines most frequently requested for funding were computer numerical control (CNC) lathes, turning and milling centers (INAIL, 2025). Looking at the injured body part in manufacturing, the hand was the most injured, accounting for 41% of cases, followed by the ankle and foot (12%). Furthermore, the same data reported that the eyes, followed by hands, are the most injured body parts among workers who operate machinery. Regarding the nature of injuries, wounds, contusions, and dislocations together, they represent just over 74% of reported cases. More details are reported in Figure 9.

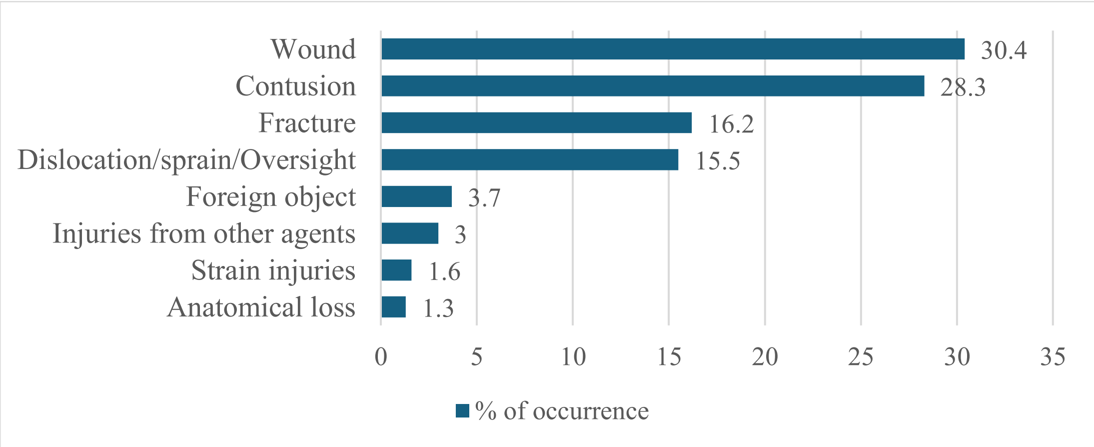

Figure 9. Nature of injuries in manufacturing industries (adapted from INAIL, 2025).

Furthermore, manufacturing injuries predominantly involve male workers (85%), with more than nine out of ten fatal cases. Whereas, regarding the time, around one-third of all accidents occur between 9:00 and 12:00 (INAIL, 2023).

3.3.2. Accidents and training in Olivero Impianti

The analysis of RIDDOR data indicated that between 1989 and 2023, a total of 163 accidents were recorded, including two fatalities, caused by falls while working on elevating platforms. Overall, the other incidents occurred predominantly in summer months, including July, August, and September (Figure 10), and involved twelve different body parts. Eyes (25%), hands (25%), and ankles (10.72%) were the most frequently injured body parts (Figure 11). While the causes of the incidents during work activities include slipping on parts or tools or being struck by objects, injuries related to grinding, followed by cuts, or foreign bodies in the eyes, and incidents occurring while coming down the ladders and slipping during work operations (Figure 12).

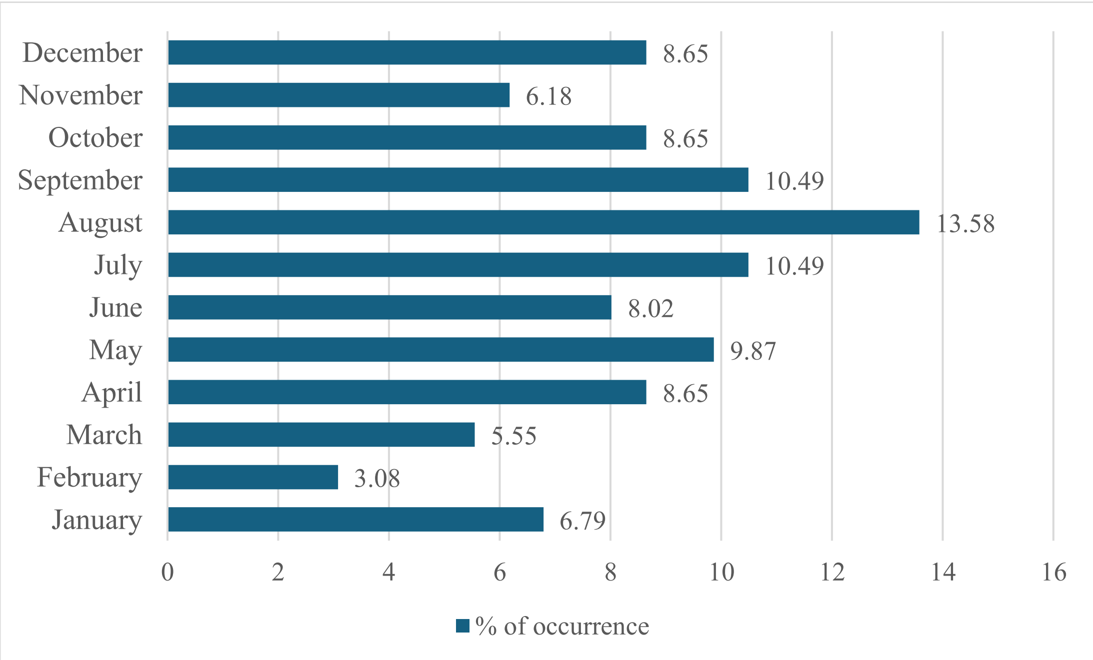

Figure 10. Months in which accidents occurred.

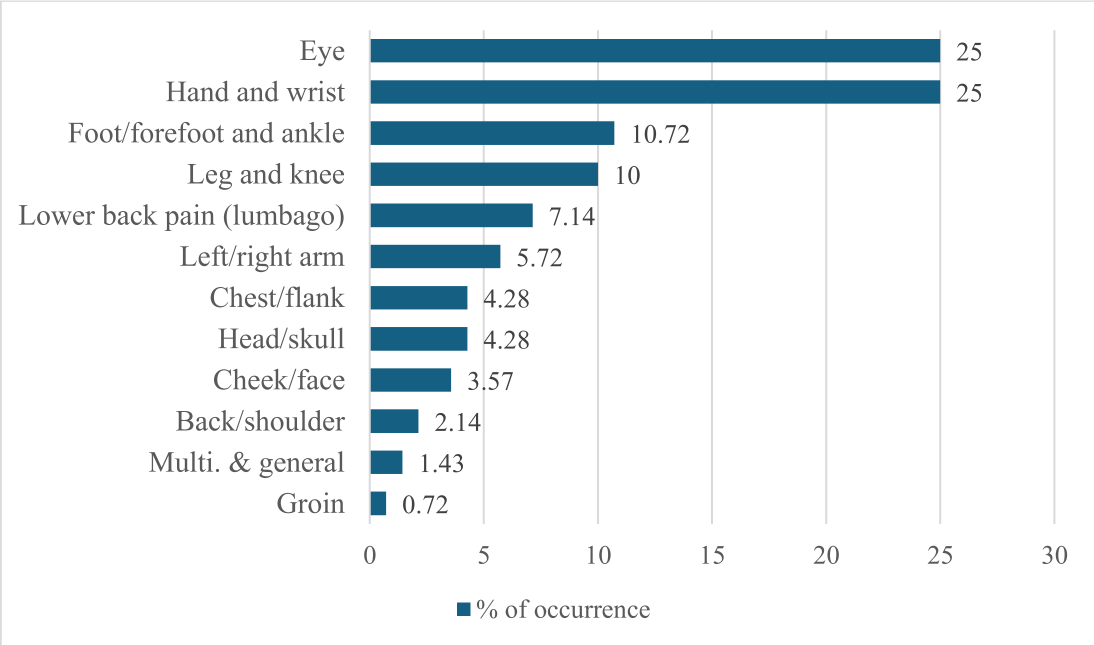

Figure 11. Injured body parts.

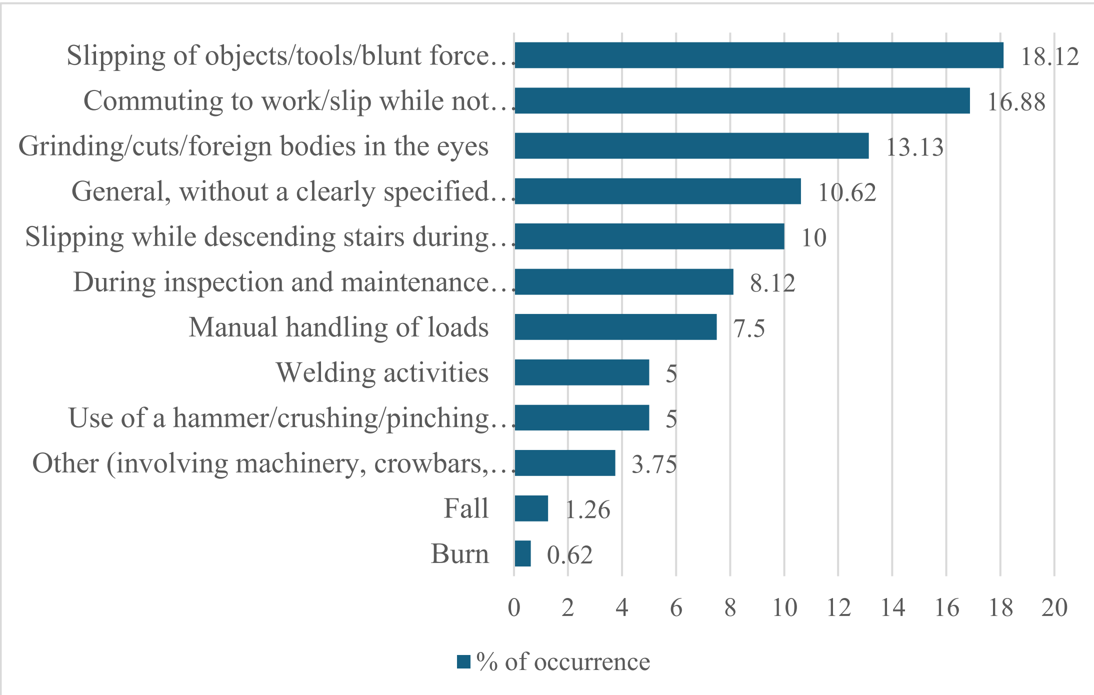

Figure 12. Causes of accidents.

While analyzing the data collected, which describes accidents, related cases and the period in which they occurred (Figure 10,11,12), it should be noted that these data are consistent with national and European statistics of injuries in the metalworking manufacturing sector (Eurostat 2025a, 2025b). In addition, the data related to fatal injuries is not completely unexpected, as both European statistics (Eurostat, 2025c) and national trends (Lineevita, 2023) indicate that falls from height are one of the primary causes of death in the manufacturing sector. In addition, an increase in incidents during the summer months can be attributable to different factors (Hollá & Kockar, 2025; Norton, 2019):

- The replacement of experienced personnel with less trained temporary or seasonal workers (Eurostat, 2025a).
- Extreme weather conditions that affect concentration and responsiveness (EU-OSHA, 2017).
- Production peaks before and after the summer shutdowns.

This seasonality in accident occurrence may also reflect broader dynamics influencing occupational health and safety. As Theorell (2022) notes, working conditions are shaped by a complex interplay of macro- and micro-level factors, including workforce ageing, precarious employment, economic fluctuations, and political change, alongside specific occupational risks such as noise exposure, shift work, work intensity, digitalization, and climate change. Such a multifaceted perspective reinforces the need for integrated prevention strategies that address both psychosocial and physical dimensions of workplace safety.

Moreover, it should be mentioned that safety is achieved through the combined use of multiple countermeasures; therefore, alongside the purchase of safer machinery, personal protective equipment must be made available, and their use must be consistent (Ragazzi & Sella, 2023). To ensure compliance with safety practices, it would be important for employers and supervisors to be constantly present on sites. However, in daily operations, it is practically impossible to monitor every situation, and employers are not considered responsible if workers fail to follow the rules, especially if they had the proper safety training and received all the necessary PPE (EU-OSHA, 2017; Sella et al., 2023). In addition, considering the multiple causes that can lead to an accident, recent guidelines highlighted that training programs should also address psychosocial hazards, including work-related stress, as raising awareness and providing coping strategies are essential for safeguarding both physical and mental well-being in the workplace (OSHA, 1970).

Regarding safety training, courses in Olivero Impianti were provided through lectures, in which slides were used to support the trainer's presentation. However, the trainer kept workers engaged by asking questions, fostering discussion, and prompting them to share real-life experiences related to workplace safety. When possible, a practical demonstration of the correct use of safety equipment was provided within the firm, allowing workers to observe and replicate procedures in a realistic setting. For instance, regarding fire safety, specific moments were dedicated to recognizing different types of fire extinguishers, understanding their appropriate use according to the class of fire, and learning how to correctly control the discharge of extinguishing material. These hands-on activities, conducted in a controlled and safe environment, allowed workers to gain confidence and familiarity with emergency equipment. Observing safety training lectures, it should be noted that incorporating training activities that actively involve workers during the lecture, such as questions, interactions, and short practical exercises, can effectively enhance workers' engagement and participation in group discussion (Burke et al., 2006).

3.4. Phase 3 – Specify the user requirements[5]

This phase focuses on identifying users' needs, expectations, constraints, and preferences related to occupational safety training and the adoption of digital tools in the manufacturing context. Particular attention is paid to the analysis of workers' risk perception and to the examination of accident and injury causes, since these factors directly influence safety behaviors, training effectiveness, and technology acceptance (Davis, 1989). To this end, empirical data were collected through questionnaires and interviews with workers, addressing safety-related experiences, perceived risk, past accident involvement, and familiarity with digital devices. The outcomes of this phase informed the definition of functional, usability, and content requirements, providing a foundation for the prototyped training tool developed in the subsequent phase.

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[5] This section is partially based on the following published contributions:

Vigoroso, L. *(2024). Human-Centered Design e formazione digitale per la sicurezza sul lavoro nell'industria manifatturiera: un'analisi di contesto. In: Angelini, C., La Rocca, C. (a cura di), Romatre-Press (ed), Quaderni del Dipartimento di Scienze della Formazione, Scienze sociali, La serie del dottorato Tres. Vol. 3/2024 https://doi.org/10.13134/979-12-5977-419-4*

Vigoroso, L., *Caffaro, F. & Boccadutri, L. (2024). How Do Workers Perceive Job Risks and Technology? Insights for Designing Human-Centered Digital Safety Training Tools. In: XX Congresso Nazionale della Sezione di Psicologia per le Organizzazioni "Immaginazione organizzativa, ricerca e azione trasformativa. passato, presente e futuro delle pratiche di psicologia del lavoro e delle organizzazioni", Bergamo 4-6 settembre 2024, Book of Abstract. Disponibile al link: https://aipass.org/wp-content/uploads/2024/10/BOOK-OF-ABSTRACT_PO2024.pdf*

Vigoroso, L., *Alce, G., Boccadutri, L., Caffaro, F. (2025). Enhancing Workers' Safety in Manufacturing: A Human-Centered Approach in Interaction Design of Digital Training Tools. In: Jin, S., Kim, J.H., Kong, YK., Park, J., Yun, M.H. (eds) Proceedings of the 22nd Congress of the International Ergonomics Association, Volume 4. IEA 2024. Springer Series in Design and Innovation, vol 56. Springer, Singapore. https://doi.org/10.1007/978-981-95-0289-9_14*

Sguaizer, F.,* ***Vigoroso, L.*,*** *Micheletti Cremasco, M., & Caffaro, F. (2025). Perceived Working Conditions and Intention to Adopt Digital Safety Training in High-Risk Productive Sectors: An Exploratory Study in Manufacturing and Agriculture in Northwest Italy. Safety, 11(2), 51. https://doi.org/10.3390/safety11020051*

Three research questions were formulated for this phase, and they can be grouped into two main categories: the first concerns workplace injuries and sector-specific risks (RQ1, RQ2), while the second relates to the use of digital devices as tools to support training activities (RQ3):

- **RQ1:** What are the main causes of injuries and accidents? What are the typical unsafe behaviors adopted by workers, and to what extent do workers perceive the risks?
- **RQ2:** Which work environment variables are most strongly correlated with workers' perception of risk?
- **RQ3:** What visual elements are expected in a digital tool focused on OSH topics? How are digital devices perceived as tools for conveying OSH information?

In the HCD phase 3, a questionnaire and an interview were administered (see Figure 13). Through the interviews, the topics addressed in the questionnaires were further explored and a hands-on demonstration involved participants in the interaction with digital devices and testing of different existing apps and demo versions of gamified training tools. In the following sections, the materials and methods used will be described. Then, for readers' clarity, overall results related to *"the use and familiarity with digital devices"* are presented first, followed by the results related to *"the causes associated with accidents and injuries"*.

Figure 13. Number of workers who completed the questionnaires and who were involved in interviews. Due to the length of time required to complete the questionnaires, a larger number of responses was obtained for the questionnaire concerning familiarity with digital devices.

3.4.1. Materials and Methods

Instruments and procedures

Quantitative data. Participants were administered a paper-and-pencil questionnaire structured into two main sections: the first focused on familiarity with digital devices, and the second addressed perceived causes of workplace accidents and injuries. The entire questionnaire required 30-35 min to be filled out. First, a short form collected participants' socio-demographic information (i.e., gender, age, education, job role, years of experience in manufacturing work, and number of safety training attended in the last 5 years) (see Appendix A.1).

The first section of the questionnaire *("the use and familiarity with digital devices")* includes three sub-sections (see Appendix A.2). In details, the first one was related to general use and familiarity with digital devices, based on their own experience. Participants were asked to indicate:

- average amount of time they spend per day on various activities using electronic devices (6-point scale, 0 = never, 1 = a few minutes, 2 = less than 30 minutes, 3 = 30 minutes to 1 hour, 4 = 1 to 2 hours, and 5 = more than 2 hours) (8 items) (Salmon et al., 2017; Susilowati et al., 2022).
- motivation and purposes for using digital devices, i.e., for staying informed or for entertainment (4-point, from 1 = not at all, to 4 = strongly) (2 items) (Bourgonjon et al., 2010).
- level of experience with digital devices (1= novice, 2 = moderate, 3 = expert) (1 item) (Bourgonjon et al., 2010).
- average amount of time they spend per day on different devices (computer, smartphone, tablet, 4-point scale, 1 = less than 1 hour, 2 = between 1-1.5 hours, 3 = between 1.5-2 hours and, 4 = more than 2 hours) (3 items) (Dindar, 2018; Ventura et al., 2012).

The second sub-section asked participants about their level of agreement with 5 statements regarding their engagement when using digital devices (4-point, from 1 = not at all, to 4 = strongly agree) (O'Brien et al., 2018).

In the third sub-section, participants were first asked to indicate their perception about the use of digital devices as a supporting tool for safety training. In detail they were asked:

- Their level of interest in using digital tools to stay informed about OSH, if available on the market, (4-point, 1 = not at all interested, 4 = very interested) (1 item) (Bourgonjon et al., 2010).
- Their level of agreement with 4 statements regarding the benefits of using such devices to support safety training (e.g., making it faster, 4-point scale, from 1 = not at all, to 4 = very much) (Davis, 1989).
- the perceived importance of 5 different types of training support (e.g., manuals, video, gamified exercises) when delivered through digital platforms (4-point, from 1 = not important at all, to 4 = very important) (Oswald et al., 2014; Rizky & Anggraini, 2022).
- context in which they would most likely access the digital platform (at home, during working hours, or during work breaks (1 item, single choice).
- perceived interest of their colleagues in using digital platforms based on safety contents (4-point, from 1 = definitely not, to 4 = definitely yes) (1 item) (Hao et al., 2017).

The second section (*"causes associated with accidents and injuries"*) included two main sub-sections (see Appendix A.3). In the first section, participants were asked to rate their level of agreement on a 4-point scale (1 = not at all, 2 = a little, 3 = quite a lot, 4 = very much) with 7 general statements regarding the role of working conditions (WC) in leading to accidents in manufacturing (e.g., short timelines and tight deadlines, heavy working hours, mentally exhausting working conditions); 4 statements regarding the contribution of human behaviors and actions (HB) (e.g., failure to comply with work instructions, safety rules, failure to use the required personal protective equipment) (Choudhry & Fang, 2008; Nordlöf et al., 2015; Umugwaneza et al., 2019); 13 statements regarding their specific working conditions and their role in leading to accidents (e.g., my job is dangerous, my job requires great concentration and attention from me, my job is repetitive) (Choudhry & Fang, 2008; Hon et al., 2010).

In the second section, participants were asked to describe their interaction with machinery and perceived the level of risks. More specifically, they were asked:

- Whether they operate specific machines and equipment (yes/no question, following, Ministero del Lavoro, n.a.), the perceived level of risk (16 items, 4-point scale, 1 = negligible, 2 = low, 3 = medium, 4 = high) and which is (based on their opinion) the most hazardous (one answer only).
- Whether they have been involved in different types of accidents in the last 5 years (9 items, 3-point scale, 0 = never, 1 = once, 2 = more than once) (Caffaro et al., 2022) without having any physical injuries. Then, participants' answers were dichotomized (contrasting the 0 and the other responses) to check whether they had had at least one accident in the last 5 years or not.

Qualitative data. Semi-structured face-to-face individual interviews were administered with the aim of further exploring topics previously addressed in the questionnaire. The interview track consisted of open-ended questions and was developed based on current literature and related publications. Semi-structured interviews were administered and lasted approximately 40-50 minutes and were audio recorded. As mentioned in the previous paragraph, the interview was organized into two main thematic areas.

In the first part of the interview (see Appendix B.1), participants answered questions related to digital media habits, self-perceived digital competence, interest, preferences for digital content, and credibility towards digital media. Then, as part of a hands-on demonstration, participants were shown a selection of existing applications available on smartphones and inherent in occupational safety and were asked to interact with them. These were used to collect comments and perceptions regarding app features and evaluate if users can access relevant sections rapidly and find information efficiently (Nouman & Umer, 2019). Then, participants tested other selected demos of safety applications and safety games freely available online. No login was required at the time of the interview. The demo versions presented interactive features such as timed challenges, quizzes, puzzle games, and navigation through 2D or 3D environments. These were used to collect additional comments and perceptions regarding game features and game preferences. The Thinking Aloud technique (Lewis, 1982) was used to facilitate data collection on their cognitive processes while interacting with the demos.

In the second part of the interview (see Appendix B.2), questions were organized into three thematic areas: injury experience (Choudhry & Fang, 2008; Wong et al., 2020), safety climate (Nordlöf et al., 2015; Zhang, Lingard et al., 2015), and machinery and equipment-related risks (Bordas et al., 2001). In detail, workers were asked to describe common task-related risks and describe a recent injury or near miss. Questions explored contributing factors (e.g., lack of PPE, time pressure, stress) and whether these events affected their attitudes and behaviors toward PPE and safe practices. The second group of questions assessed perceptions of the organizational safety culture, including interactions between experienced employees and new hires, adherence to safety procedures among coworkers, and mutual monitoring of safe behaviors. Finally, workers were asked to identify machines or tools considered particularly hazardous, especially those associated with biomechanical overload, manual handling, pushing or pulling tasks, or repetitive upper-limb movements, and explain why.

Data analysis

Quantitative data. Descriptive statistics in terms of frequencies of all the investigated variables were computed. Regarding time spent per day using digital devices, the sum of the scores (7 items) was computed. Then, a series of exploratory factor analyses (EFA, with no rotation) on the scores reported for the five items related to the perceived engagement and the four items related to the perceived benefits, were performed. For items related to the perceived engagement, the Kaiser-Meyer-Olkin (MKO) measure of sampling adequacy was .654, indicating suitability for analysis and Bartlett's Test of Sphericity was significant X^2 (10) = 50.62, p < .000). The analysis identified two factors that together explain 65.14% of the variance. The first factor is related to positive engagement (POS) and the second is related to negative engagement (NEG). Similarly, for the items related to the perceived benefits one factor was identified (BEN), the Kaiser-Meyer-Olkin (MKO) measure of sampling adequacy was .740, indicating suitability for analysis and Bartlett's Test of Sphericity was significant

$X^2(6) = 109.19$, $p < .000$). The analysis explained 66.59% of the variance. Considering that workshop-based workers are more frequently exposed to high-risk situations compared to technicians and other occupational roles in the manufacturing sector (Pérez Floriano & Pacheco, 2018), independent-samples *t*-tests and chi-square tests were performed to detect differences between selected variables (i.e., time spent using digital devices and aggregated scores of perceived engagement and perceived benefits) and to examine differences in relation to the contexts in which digital tools may be used (i.e., at home, during working hours or during work break). In addition, the correlation analysis between selected variables and demographic information (age, education, years of working experience, and attended courses) was used to determine the strength and direction of associations with variables of interest.

Furthermore, for questions related to conditions and behaviors that can lead to accidents, the means ($1 < \mu < 4$) were used to distinguish between low and high user perception. Accordingly, a mean score of greater than 2.5 indicated a higher degree of perception, whereas a score of less than 2.5 indicated a lower degree of perception (Simha et al., 2017). Then, two exploratory factor analyses (EFA, with no rotation) on the scores reported for the seven items related to statements regarding working conditions (WC) and four items related to the contribution of human behaviors and actions in leading to accidents (HB), were also performed. The first EFA (WC) showed that the Kaiser-Meyer-Olkin (MKO) measure of sampling adequacy was .811, indicating suitability for analysis. Bartlett's Test of Sphericity was significant (X^2 (21) = 124.79, p < .000). The analysis effectively identified one factor that explained 61.70% of the variance; while for the second EFA (HB), the Kaiser-Meyer-Olkin (MKO) measure of sampling adequacy was .833. Bartlett's Test of Sphericity was significant (X^2 (10) = 131.69, p < .000), explaining the 74.15% of the variance. As previously done, a series of Mann-Whitney tests were performed to identify possible differences in risk perception based on worker categories (technicians vs workshop operators) and prior accident experience.

For further analysis, to determine the minimum number of participants required for the statistical correlation tests, a power analysis using G*power software (v. 3.1.9.7) (Faul et al., 2007) was performed to calculate a priori sample size. Based on this analysis, to uncover a medium effect size (0.5; Cohen, 1988) with a power of 0.90

and an α level of 0.05, a total sample of 34 participants would be required. Thus, a Spearman correlation analysis was performed, but considering the limited sample size, selected variables were chosen, analyzed, and commented on.

In conclusion, the socio-demographic characteristics of participants who filled out the entire questionnaire and who completed only the part related to the *"causes associated to accidents and injuries"* were compared using a series of Mann-Whitney tests. The analyses showed no significant differences between the two groups in terms of age, education, and years of experience (U = 1297.50, p = .586, U = 1138.00, p = .138 and U = 1170, p = .262, respectively). Additionally, a chi-square test confirmed that there were no significant differences in the distribution of participants by category (i.e., technicians vs. workshop operators, p = .072).

Qualitative data. Regarding data from interviews, qualitative content analysis was used to analyze the empirical material derived from written, oral, and visual sources. To ensure a systematic and transparent analytical process, the analysis was conducted at a manifest level. This means that the analysis was focused on "what the informants actually say, stays very close to the text, uses the words themselves, and describes the visible and obvious in the text" (Bengtsson, 2016, p. 10). For the analysis, each interview was recorded, transcribed verbatim and responses were categorized into recurring content themes (Bengtsson, 2016). Miro visualization software (https://www.miro.com) was used to organize the data into categories and represent them in a more visual diagram. A key advantage of the analysis of qualitative data is the ability to gain a deeper understanding of the context and limitations of existing similar tools and to identify the behaviors and mental models of potential users (Cooper et al., 2014).

3.4.2. Results

Participants

Questionnaire. Seventy-one male workers filled out the questionnaire section related to *"use and familiarity with digital devices"* (see Figure 13). Their mean age was 35.11 years (SD = 10.86, range: 18 - 60 years) with a mean working experience of 12.76

years (SD = 10.16, range: 1 - 43 years). Regarding their job role within the company, 49.3% were technicians, 29.6% were assemblers/maintainers, and 21.1% specialized as machine operators. Regarding education, 24% of them had completed junior high school, 69% had a high school diploma, and 7% had a university degree. Regarding the training courses attended, participants reported an average of M = 2.90 (SD = 1.91).

Of the 71 participants, 39 filled out also the second section of the questionnaire related to *"causes associated to accidents and injuries"*. The drop out of the participants was due to work schedules which did not allow them to complete both questionnaires (see paragraph 3.2). Their mean age was 36.38 years (SD = 11.58, range: 18 - 57 years) with a mean working experience of 15.11 years (SD = 11.16, range: 1 - 43 years). Regarding their job role, 27% were technicians, 43.2% were assemblers/maintainers, and 29.7% specialized as machine operators. Regarding education, 35.8% of them had completed junior high school, 57.9% had a high school diploma, and 5.3% had a university degree. In addition, the average attended training courses in the last 5 years was 3.23 (SD = 1.67).

Interview. Twenty-six of the initial 71 participants agreed to be interviewed. The mean age of the participants was 32.8 years (SD = 9.74, range: 18 - 57 years) and a mean working experience of 12.6 years (SD = 10.79, range: 1 - 31 years). Regarding the job role within the company, 34.6% were technicians, 34.6% were assemblers/maintainers, and 30.7% specialized as machine operators. Regarding their level of education, 23.1% of them had completed junior high school, 73.1% had a high school diploma, and 3.8% had a university degree. Regarding the training courses attended, participants reported an average of M = 2.52 (SD = 1.96).

Use and familiarity with digital devices

Based on the descriptive analysis of the quantitative data, workers reported using digital devices for an average of no more than one hour per day (considering all the activities listed in the questionnaire: reading, using messaging apps, writing emails, browsing the internet, listening to music, accessing social media, and gaming) (Figure 14). In detail, they tended to spend more time in browsing the internet and using instant messaging app. While, focusing on their prior game experience with digital devices, 45.1% did not usually play games, 22.5% usually played some minutes, 18.4% played about up to 1 hour per day, and 14.1% usually played one hour or even more per day. Moreover, they indicated a preference for using digital devices to stay informed and acquire knowledge (M = 3.13) rather than for entertainment purposes (M = 2.62). Regarding self-assessed digital competence, 5.7% of respondents identified themselves as novices, 70% considered themselves moderately skilled, and 24.3% defined themselves as experts. The most frequently used device was the smartphone (M = 3.16) followed by the computer (M = 2.80) and iPad/tablet (M = 1.22).

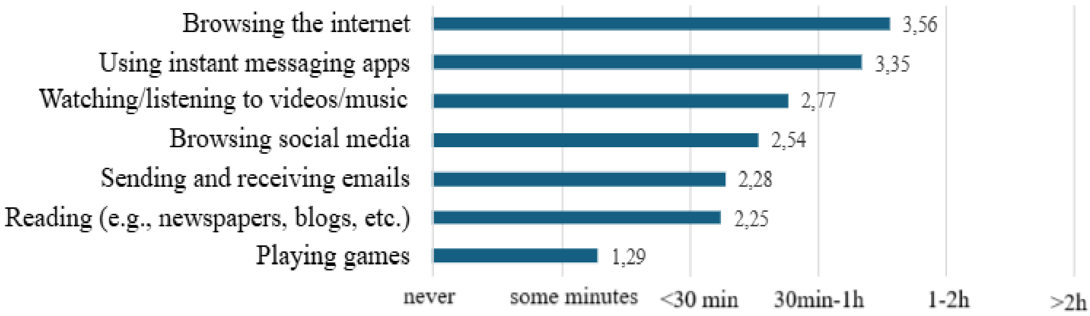


Figure 14. Average time spent per day on each activities using digital devices.

Involvement when using digital devices. Responses regarding perceived engagement, as well as the EFA result, are presented in Table 1. Curiosity appears to be the first factor influencing user engagement when considering the elements that drive the use of digital devices (M = 2.90). No statistically significant differences emerged between the two categories of workers and the aggregated scores.

Table 1. Perceived engagement when using digital devices.

Factor	Item	M	SD	Factor Loading
Positive engagement (POS)	When I use digital devices, I lose track of time	2.28	0.78	.601
	Digital devices spark my curiosity	2.90	0.74	.591
Negative engagement (NEG)	I feel frustrated when using digital devices	1.49	0.68	.824
	Using digital devices makes me feel disoriented	1.29	0.49	.747
	Using digital devices is tiring	1.37	0.69	.787

Digital devices as a supporting tool for safety training. The respondents reported a moderate level of interest (INT) in using electronic devices as tools for training purposes (M = 3.07, SD = 0.70). Furthermore, digital devices as supporting tools for safety were mainly perceived as faster. Mean scores and the EFA result for perceived benefit (BEN) are reported in Table 2. Furthermore, when comparing technicians with workshop-based workers (assemblers/maintainers and specialized machine operators together), a t-test showed that no differences were found between the two groups regarding benefits perception in using digital devices.

Table 2. Perceived benefits.

Item	M	SD	Factor Loading
Faster	3.38	0.66	.823
More accessible	3.23	0.68	.806
More effective	2.96	0.74	.777
More engaging	2.89	0.76	.856

Preferences regarding content delivery formats are detailed in Table 3. High scores were reported for all items, including game solutions (quizzes with scores and leaderboards).

Table 3. Perceived engagement and level of preferences regarding contents format.

Item	M	SD
Manuals	2.92	0.77
Audio lessons / podcasts	2.94	0.71
Video lessons	3.03	0.79
Exercises in the form of questionnaires	2.82	0.72
Exercises in the form of games (e.g., quiz with scores/leaderboards)	2.99	0.81

Thinking about the use of an app or web application based on occupational safety content, nearly half of the participants (47.9%) reported that the workplace would be the primary context in which they would use it. Some differences can be found between job roles (Table 4). Furthermore, when comparing technicians with workshop-based workers (assemblers/maintainers and specialized machine operators), a chi square test showed a significant difference in willingness to use tools at home ($p = .036$). Finally, participants perceive that their peers can be willing to adopt this type of tool and technology (M = 2.99, SD = 0.36).

Table 4. Where workers are willing to use digital safety training tool.

Item	Technicians	Assemblers/ maintainers	Specialized as machine operator
		N (%)	
At home*	7 (20%)	10 (47.6%)	5 (33.3%)
During working hours	21 (60%)	7 (33.3%)	6 (40%)
During work breaks	7 (20%)	4 (19.1%)	4 (26.7%)
	35 (100%)	22 (100%)	15 (100%)

* Significant difference

In conclusion, Table 5 shows that there is a negative correlation between age and positive engagement (POS) and time spent using digital devices per day. The variables concerning the interest in using digital devices to stay updated/informed about health and safety in the workspace (INT) resulted in significant correlations with perceived benefits in using digital devices (BEN) and perceived positive engagement. Furthermore, POS and BEN positively correlate to each other. POS is also positively correlated with quiz and game contents and time spent using digital devices.

Table 5. Correlation analysis.

	1-age	2-EXP	3-educ	4-train	5-INT	6-POS	7-NEG	8-BEN	9-manual	10-audio	11-video	12-quiz	13-game	14-TIME
1	1	.840***	-.131	.052	-.182	-.457***	-.121	-.172	-.047	-.007	.146	-.168	-.314	-.633***
2		1	-.263*	.129	-.029	-.304*	-.102	-.056	.152	.023	.119	-.056	-.253*	-.602***
3			1	.086	.147	.189	.084	.067	.073	-.030	.114	.042	.294*	.071
4				1	.016	-.144	-.115	-.044	.214*	-.259*	-.065	.008	-.093	-.174
5					1	.310*	.100	.547***	.194	.050	.025	.161	.212	-.028
6						1	.000	.292*	.158	.014	.000	.433***	.320**	.426***
7							1	.111	-.155	.008	-.121	.085	.130	-.086
8								1	.172	-.038	-.054	.302*	-.218	.172
9									1	-.139	.004	.100	-.183	-.004
10										1	.381**	-.075	.243*	-.025
11											1	.009	.133	.048
12												1	.309**	.142
13													1	.232
14														1

Note: * $p < .05$, ** $p < .01$, *** $p < .000$.

Figures 15 and 16 present graphically the analysis and results of participants' feedback concerning the intended overall structure and architecture of the digital system, its content, and the preferred game features and mechanics.

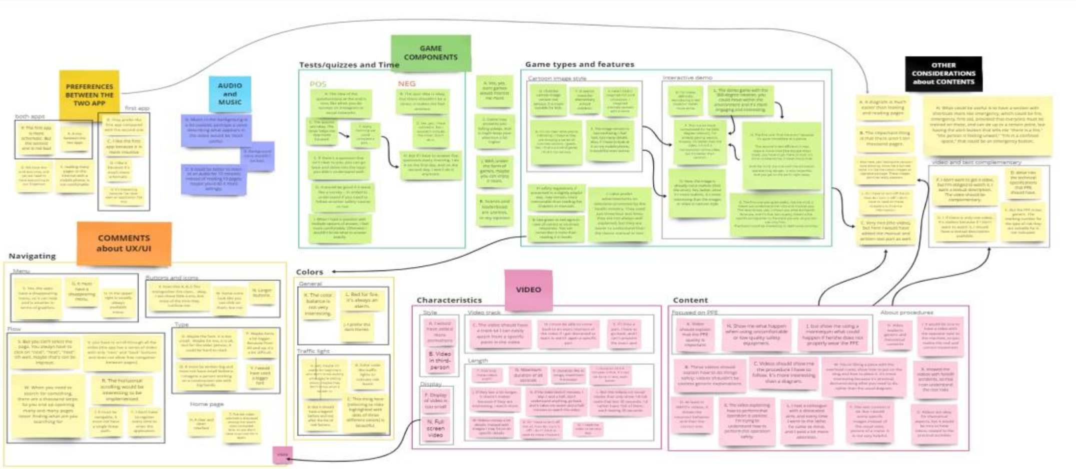


Figure 15. Transcription of main responses collected during the interviews and interaction with digital devices (https://www.miro.com).

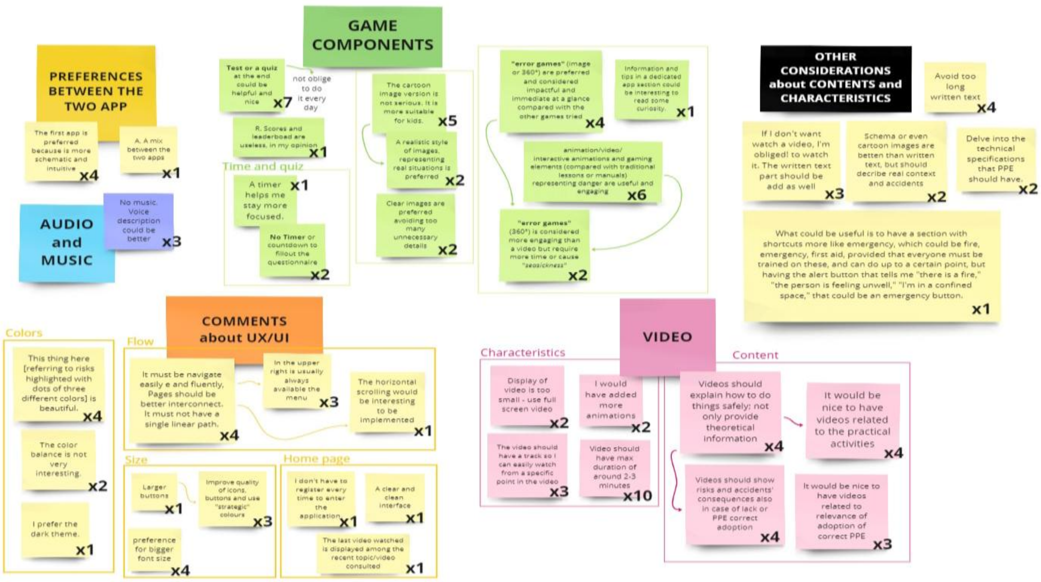


Figure 16. Categorization of responses collected during the interviews and interaction with digital devices (https://www.miro.com).

The participants' responses can be grouped in three different sections, referring to i) the preferred channel, ii) the preferred/main characteristics for digital content for safety training tool, iii) UX/UI and color codes and iv) opinion and preferences in relation to game features.

1) The preferred channel to convey safety messages was videos, since some concepts might be better explained through dynamic images rather than written text. However, some others expressed contrasting opinions because videos were perceived as more boring:

> *"Videos convey a lot of details. Instead of images I may focus on specific details"* [man, 44 years, technician], *"I prefer to read training materials and information myself, rather than having someone present them in a video"* [man, 19 years, machine operator], *"I am not a big fan of videos, but they are the quickest option. Given the choice between reading 15 pages and watching a video, you're probably more likely to go for the video"* [man, 32 years, maintainer] and *"The problem with videos is that if I miss something, I have to rewind, and it's often difficult to find the exact spot I'm looking for"* [man, 26 years, technician].

However, these latter comments did not imply that the text should be eliminated, as some workers have emphasized the importance of having both channels complement each other. For some others, long text as in manuals are not recommended:

> *"The text content is ok. But I would have some specific interactive images instead of the usual static picture"* [man, 44 years, technician], *"If I don't want to watch a video, but I'm obliged to watch it...I would also like a textual description. Both the video and text should complement each other"* [man, 26 years, technician], *"I find reading manuals pretty boring"* [man, 19 years, machine operator] and *"In general, the less text there is, the better, because it takes less time. However, manuals are more convenient than videos. Indeed, if you missed something in a video lesson, you could quickly look it up in the*

manual, and it's faster. Plus, you can easily use them while doing exercises" [man, 29 years, technician].

In addition, availability of lessons and information followed by the opportunity to test their knowledge was highlighted:

> *"I think this format, with an initial explanation supported by slides and a final test, is an effective approach"* [man, 24 years, maintainer] and *"Plus, you can easily use them while doing exercises"* [man, 40 years, maintainer].

2) Regarding the preferred characteristics for digital content for safety training tool, participants explained that written texts should not be too long, whereas, videos should have a maximum duration of 2-3 minutes and should explain how to perform operations safely, not providing theoretical information only:

> *"Duration of 2-3 minutes is fine, if it can be done in less, even better"* [man, 36 years, maintainer], *"The video should have a track so I can easily watch from a specific point in the video"* [man, 27 years, machine operator] and *"Videos are okay for theoretical aspects, but it would be nice to have videos about safety procedures"* [man, 35 years, machine operator].

Also, contrasting opinions were related to the music in the background and voice description:

> *"Background music is not really necessary, and it might take away my focus"* [man, 27 years, machine operator], *"Having a voice read it out is fine, but sometimes listening to that voice isn't exactly pleasant, it can be a bit monotonous. Background music, on the other hand, feels a bit fresher"* [man, 29 years, technician] and *"Even the classic robotic voice could work for reading the text, especially if I don't feel like reading it myself"* [man, 21 years, maintainer].

Furthermore, participants' preferences were also shaped by the content they referred to during the interview:

"I don't have anything against videos, but it really depends on the topic being addressed. For subjects involving barriers or obstacles, a single image can convey the message clearly enough. There is no need to spend excessive time on a lengthy video, when just a couple of images can be equally effective" [man, 34 years, technician], *"For learning how to correctly put on PPE, I think a video is probably the best option. It allows you to clearly see the proper procedure, and it could be followed by a short quiz or final test to reinforce learning"* [man, 32 years, maintainer], and *"Show me the effective risks and the consequences of using equipment that is uncomfortable or of poor quality"* [man, 35 years, machine operator].

3) Regarding the UX/UI, workers mentioned that the adoption of strategic colors could make the interface more engaging and maximize the intuitiveness:

"Color code like traffic lights, red, yellow and green, to indicate risk levels" [man, 27 years, machine operator], *"I prefer the dark theme"* [man, 35 years, technician], and *"There are no overly bright colors, and that's fine"* [man, 34 years, technician].

Adoption of bigger texts and icons was highly recommended:

"Maybe bigger text size and no small buttons. Starting at the age of 40, it begins to become difficult to read on devices" [man, 44 years, technician] *and "It must have a drop-down menu, and the interface should be kept as simple as possible"* [man, 35 years, technician].

Similarly, better internal links between pages to enhance the user flow are even suggested:

"The horizontal scrolling would be interesting to be implemented" [man, 35 years, technician], *"Some icons should be clickable and link directly to the page they appear to reference"* [man, 41 years, machine operator], *"A slide-based system isn't convenient. If I want to go directly to page 5, do I really have to go through all the pages first?!*

I believe it's always better to provide multiple ways to access the same pages or specific content, so that it remains quick and easy to use" [man, 27 years, machine operator], *"At first glance, I like it because it's very straightforward, because with just two buttons I can access categories and cards, and quickly see if there's something of interest to me. Scaffolding… ladders… it all feels quite intuitive"* [man, 26 years, maintainer], *and "It would be useful to have quick-access shortcuts for emergencies such as fire, first aid, or rescue. Such an alert or panic button to signal 'fire,' 'medical emergency,' or 'confined space' could be highly effective"* [man, 35 years, technician].

4) Regarding the game features/mechanics, participants expressed their preferences for a realistic graphic style to represent the shop floor, while the interactivity proposed by "find the error" and "fire Safety" games was appreciated:

"I find the cartoon image more suitable for kids" [man, 28 years, technician], *"They make you aware of the risks and engage you a bit more. For example, there you realize that you could trip over the pipe. The fire extinguisher one shows you what to do, which is fine, but usually there is an extinguisher specific to the location you are in, so you can't really use anything else. Still, it lets you see the consequences"* [man, 35 years, technician], *"Ah, that's nice. In the end, the concepts and information stick in your head"* [man, 24 years, maintainer], *"Use green or red signs in case of correct or incorrect responses"* [man, 44 years, technician], *"Find the error" mechanic quite immediate at a glance"* [man, 26 years, technician], *"I like it because it really grabs your attention. I don't play the game anymore, but I still enjoy it, so if I need to look at something like that and analyze it, I'll happily set aside time for it and actually, I enjoy doing it"* [man, 32 years, technician], and *"I mean, I don't usually play, but if there's a chance to play, I will"* [man, 34 years, technician].

While some participants positively perceived the interactive 360° panoramas, others expressed uncertainty, noting that such images may induce seasickness.

> *"This one is the least efficient because it probably takes more time, the Google Maps–style one, since you must go there and look. It is more cumbersome and takes longer"* [man, 35 years, machine operator], *"The demo game with the 360-degree rotation is more engaging and interesting"* [man, 40 years, maintainer], *"This is a bit more complicated for me [360° panoramas]. I'm already getting seasick. Anyway, it is better than a video"* [man, 48 years, maintainer].

Quizzes were widely appreciated, whereas the time feature was the least enjoyed game mechanic:

> *"The idea of the questionnaire at the end is nice, like when you do surveys on Instagram or social networks"* [man, 26 years, technician], *"Yeah… the timer isn't really necessary, but it's not a big deal either. I actually enjoy the quiz at the end, especially since it's multiple choice, so it doesn't feel too demanding"* [man, 28 years, technician], *"I like it… the scoring works well… the time limit, not so much"* [man, 26 years, technician], *"Quizzes just for fun? No, not in that sense. Quizzes at the end of a lesson are fine to check whether I've learned everything or if I still have some gaps. If they are part of a course, it makes sense to have them at the end, and they are also helpful for me to see if everything is clear"* [man, 34 years, technician], *"Even with the quiz, it's quick, and I assume there's a correction afterwards"* [man, 32 years, maintainer], *"The idea of implementing quiz is okay, but there shouldn't be a timer; it makes me feel anxious"* [man, 34 years, technician].

Causes associated to accidents and injuries

Regarding the causes associated to accidents and injuries, the most critical mean values were reported for items related to the contribution of human behaviors and actions (e.g., Failure to use the required PPE, M = 3.27, incorrect use of work equipment or substances, M = 3.25, and failure to comply with work instructions M = 3.05). Furthermore, the Mann-Whitney tests revealed no statistically significant differences between the two categories of workers and those who had previously experienced a workplace accident (see Table 6).

Table 6. Analysis of items investigating general conditions and actions that can lead to accidents.

	Item	M	SD	Factor Loading	Expl. variance
ID	**working conditions in leading to accidents**				
WC	Short timelines and tight deadlines	2.80*	0.97	.752	61.70
	Heavy working hours	2.53*	0.96	.819	
	Highly repetitive, incomplete, or limited tasks	2.55*	1.06	.810	
	Mentally exhausting working conditions	2.58*	0.92	.843	
	Personal conditions	2.82*	1.05	.765	
	Unfavorable physical work environment	2.41	0.95	.837	
	Lack of adequate training for the worker/team	2.93*	1.04	.656	
	contribution of human behaviors in leading to accidents (HB)				
HB	Failure to comply with work instructions, safety rules (CE)	3.05*	0.91	.861	74.15
	Failure to use the required personal protective equipment (PPE)	3.27*	0.98	.899	
	Incorrect use of work equipment or substances used	3.25*	0.84	.898	
	Lack of controls	2.69*	0.88	.869	

* mean responses higher than 2.5, indicating a higher degree of perception.

Regarding risk perception (Table 7), the most critical mean values were reported for items related to need for great concentration and attention (M = 3.56, SD = 0.60). It should be noted that human errors are considered more impactful in leading to accidents compared to system failures (reporting a mean score of 3.03 and 1.90, respectively). Positively, the sample involved seemed to feel well-informed about safety procedures in their company. Regarding overall perception of risk ('my job is dangerous'), participants reported a relatively low overall average rating (M = 2.41, SD = 0.79). This finding is also aligned with responses from interviews, as most workers tend to underestimate risks, often leading to inattention and indifference. However, the Mann-Whitney tests revealed that workshop workers perceived their workplace as significantly more dangerous compared to technical staff ($U = 73.5$, $p = .004$); additionally, workers without previous accident experience were more likely to attribute accidents to system failures ($U = 126.00$, $p = .029$), suggesting a perception shaped more by structural concerns than by direct personal experience.

Table 7. Descriptive statistics of items investigating perception in their specific working context.

ID	Item	M	SD
p1	My job is dangerous	2.41	0.79
p2	My job is tiring	2.34	0.77
p3	My job requires great concentration and attention from me	3.56 *	0.60
p4	My job is repetitive and does not involve alternating with other tasks or activities	1.62	0.82
p5	My tasks are well-defined	2.77 *	0.81
p6	There is enough manpower to complete the daily work	2.97 *	0.71
p7	There is too much work to do compared to the available time	2.33	0.74
p8	I have the possibility to decide my work pace	2.44	0.85
p9	My earnings are proportional to my work	2.64 *	0.90
p10	Most accidents are caused by system failures	1.90	0.55
p11	Most accidents are caused by human behavior	3.03 *	0.63
p12	I feel well-informed about safety procedures	3.28 *	0.51
p13	There is good communication within my work group	2.12	0.75

* mean responses higher than 2.5, indicating a higher degree of perception.

Regarding the perceived level of risk of machines and equipment on work sites, the forklift, grinding machine, and column drill were the most used machineries (21, 20, and 18 out of 39, respectively). However, the manual lathe was perceived as the most hazardous (despite the low number of workers that use it, 4 out of 7 workers perceived a high level of risk), followed by forklift (10 out of 21 indicated a medium and high level of risk), and guillotine shear (4 out of 9 indicated medium and high level of risk) (Figure 17). Regarding the experience of previous accidents, 21 (54%) workers reported at least one accident with an injury in the past five years.

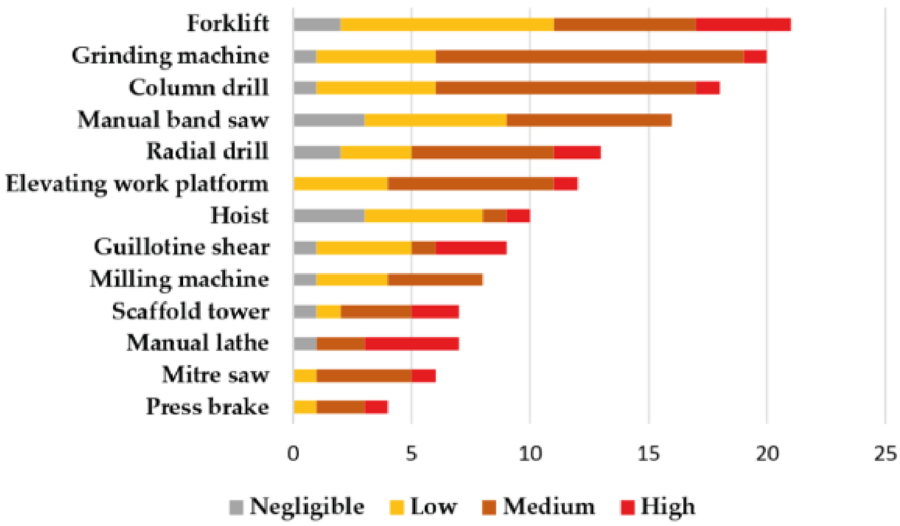


Figure 17. Use and level of perceived risk of machinery and tools among workers.

Among the reported causes of workplace accidents investigated, the most frequent were impact-related injuries and the presence of foreign bodies in the eyes, both with 7 occurrences. These were followed by inhalation of fumes (4 cases) and electrocution (2 cases). Less frequent were severe falls (1 case), while no incidents were recorded for overturning, third-party involvement, falls from height, or accidents occurring during commutes. Overall, 48.5% of workers interviewed have had at least one accident in the last five years.

Table 8 shows that there was a positive correlation between age and experience, and between education and need of attention (p3). The obtained factor HB correlates with training, WC, need of attention (p3), task definition (p5) and sufficient manpower (p6). In addition, the need of attention (p3) also correlates with education and task definition (p5). Workers who perceive their job as more tiring also tend to report higher levels of risk perception and level of repetitiveness (p4). Finally, perception of system failure (p10) as cause that led to accidents, positively correlates with safety training attended and sufficient manpower available (p6).

Table 8. Correlation of specific selected variables.

	1-age	2-EXP	3-educ	4-train	5-WC	6-HB	7-p1	8-p2	9-p3	10-p4	11-p5	12-p6	13-p10	14-p11
1	1	.916***	-.189	.131	.212	.132	-.121	.115	-.233	.067	.086	-.248	-.049	.154
2		1	-.193	.076	.259	.177	-.052	.058	-.090	.130	.131	-.180	-.029	.148
3			1	.141	.054	.024	-.074	-.081	.369*	-.182	.004	-.039	.146	.037
4				1	.001	.336*	.108	.124	.104	.074	.189	-.034	.328*	-.011
5					1	.392*	-.050	-.126	.117	.290	.201	-.220	.257	.107
6						1	.093	.022	.448*	.055	.474*	-.389*	.027	.012
7							1	.629***	.181	.194	.209	.002	.071	-.008
8								1	-.095	.456*	.621	-.046	.108	.204
9									1	.079	.502*	-.096	.134	.129
10										1	.194	.085	-.119	-.128
11											1	.053	.242	.247
12												1	.373*	-.490
13													1	.276
14														1

Note: * $p < .05$, ** $p < .01$, *** $p < .000$.

When considering the data from the interviews, half of the interviewees considered it necessary to enrich training courses with more concrete case studies and discussions on the consequences of unsafe or inappropriate behaviors, to make the safety training tool more engaging. In addition, 18 participants reported that it would be helpful to further clarify which Personal Protective Equipment (PPE) should be used for specific tasks and how to wear it correctly.

Specifically, the analysis of interview responses showed some recurring themes and critical reflections regarding workplace safety practices and training. Hereafter the key insights that emerged are reported, offering a deeper understanding of workers' perceptions:

1) risks were often underestimated, leading to inattention and indifference:

> *"Often, habit and the monotony of work operations can lead you to perform them incorrectly, even if you've always done them safely"* [man, 35 years, machine operator], *"When you become confident in something, you tend to overlook the danger and pay less attention"* [man, 19 years, machine operator], *"You have to stay alert, since the machinery is dangerous, but if you don't turn it on, the machinery won't harm you. And if you keep your hands out of the open guards, nothing happens. But it only takes one moment for things to go wrong. In my opinion, that's the real difference between a construction site and a machine workshop"* [man, 35 years, machine operator], *"But honestly, I've seen, and I'll probably keep seeing, things done poorly. There are people who simply don't realize what are the risky situations and behavior"* [man, 35 years, machine operator] *and "With traditional machines, the error rate is higher, especially when your attention is focused elsewhere"* [man, 35 years, machine operator],

2) external factors that lead to accidents, that can negatively affect safety and concentration levels:

> *"Fatigue, extreme temperatures, whether hot or cold, and a million other factors can significantly impact on safety and concentration*

levels" [man, 35 years, machine operator], *"Personally, I prefer the winter months. Here we have heating, and the temperature stays between 15 and 18 degrees, which I find ideal. What I really struggle with in the summer is the heat, the humidity, and the sun, especially during the early afternoon hours, when you need to stay focused on slightly more complex programming"* [man, 32 years, machine operator], *"If you work with cranes, forklifts, scaffolding, or during the replacement of heavy components, you're exposed to higher risks, and that's exactly where having alert and well-trained personnel becomes essential"* [man, 24 years, machine operator], *"Being in a hurry doesn't help either. It's not a good thing"* [man, 46 years, machine operator] and *"In the workshop, you can manage your own working hours and pace, whereas on construction sites it's not quite the same. It also depends on the locations we work in. Generally, deadlines are a bit tighter there, but still manageable. Here, on the other hand, I have more time frames, and I can work at my own rhythm. I do have schedules to respect, but they're so flexible that it's easy to keep up"* [man, 19 years, machine operator].

3) experience with accidents and more real-life case studies and consequences of wrong behaviors should be shared during training:

"The experience of a near-miss, whether personally lived or seen with your own eyes, can be shocking" [man, 20 years, maintainer], *"From my personal experience, I've never seen a serious injury caused by extreme cold or heat. Minor injuries like small cuts, however, occur quite frequently. Fortunately, we've never had any severe incidents"* [man, 35 years, machine operator], *"It did happen during school: one of my classmates was using the lathe. It wasn't a serious injury, but he received an earful"* [man, 19 years, machine operator], *"A lathe operator was wearing a long coat. The machine caught his sleeve and ripped it right off. Luckily, it only tore the sleeve, but it could have been much worse. After that, he was really shaken"* [man, 46 years,

machine operator], *"In my experience, about 80% of the accidents I've seen, heard of, or directly witnessed were primarily due to operator-related issues not because of carelessness, but because of the broader work context. Often, workers are asked to perform tasks they are not properly trained or qualified to handle. Given the current safety standards and safeguards in working place, it's now less common to encounter accidents caused by machine malfunctions"* [man, 46 years, machine operator], *"Here in the workshop, where we usually work on wiring control panels, there's normally no voltage, so the risks are quite low. The real risks come when we start testing the panels. If I were out on a construction site doing a repair or an emergency intervention, the risks would increase significantly, not only due to time constraints, but also because of the challenging and often unpredictable working conditions. You might be dealing with live electricity without knowing exactly where it's coming from, and you're required to disconnect it often without having full control over the situation"* [man, 50 years, machine operator] *and "Luckily, I've never seen anyone get hurt"* [man, 28 years, machine operator].

4) the relevance of keeping protective gears in place should be emphasized and use of Personal Protective Equipment (PPE) should be better clarified:

"At the workplace, there should be a strong emphasis on using Personal Protective Equipment correctly and educating what inappropriate clothes are when operating with machinery" [man, 35 years, machine operator], *"In a rush, a worker uses a machine and doesn't keep protective gears in place as they should be. It is dangerous!"* [man, 46 years, machine operator], *"It's not just about age. Even among colleagues, when someone makes a mistake, we call it out. Sometimes, even experienced workers, in a rush, start running through the workshop, and that should never happen. Or they use a machine in a hurry and fail to restore it to its original safe condition. It's one thing when you're the only one using a machine, because*

you're familiar with its status. But if someone else uses it afterwards and finds something out of place, it could lead to a serious accident" [man, 47 years, machine operator] *and "This job requires a high level of concentration, mental presence, and attention. You're dealing with moving parts, and in the past — before the modern machines we have today — it was even riskier. With manual lathes, for example, finger cuts were quite common. The operator needs to know what they're doing, understand the machine, and have proper training. They must be aware that metal chips can fly into their eyes, so safety glasses are fundamental. They must work with the machine's protective devices correctly positioned, because the workpiece itself can come loose unexpectedly"* [man, 42 years, machine operator].

5) Possible advice for new workers:

"Wearing appropriate clothing is important. It's strongly recommended to avoid accessories such as necklaces, earrings, bracelets, and watches. Piercings are generally not a major issue, but bracelets should be removed whenever possible, as they can pose a real safety risk" [man, 19 years, machine operator]*, "I remember when I was doing my internship. There was a guy a few years older than me who used to wear a watch all the time. I remember he was frequently warned about it for safety reasons"* [man, 35 years, machine operator]. *"On my very first day here, they spent an hour and a half explaining all the potential hazards and how I should be dressed. At the time, I didn't really think much of it and I was wearing a shirt, but it wasn't tucked in. I didn't realize the risk of getting it caught in a rotating lathe"* [man, 36 years, machine operator].

3.5. Phase 4 – Produce the design solutions and pre-test it with design experts to meet user requirements[6]

Designing digital mobile training solutions requires careful UI/UX design to ensure comprehension and ease of use. In the design context, prototypes ranging from low- to high-fidelity (Blank & Dorf, 2013), are widely recognized as valuable tools through which designers can evaluate whether the proposed interface effectively meets user requirements. Prototype fidelity corresponds to resolution, complexity, level of appearance, and interactivity details (Jensen et al., 2016; Lim et al., 2008). Thus, a low-fidelity prototype offers an abstract overview of the intended design without precise detail, and a high-fidelity prototype provides a more accurate and functional representation of the interface, including screen elements and interaction behaviors (Hidayah et al., 2021).

Conducting usability testing with high-fidelity prototypes in the early stage of interface development is particularly helpful. These tests involve users in performing representative tasks while researchers observe their behaviors, record errors, task completion times, and collect quantitative and qualitative feedback through questionnaires and/or interviews. Thus, designers have the possibility to refine the prototype based on empirical evidence before the full-scale implementation of the digital tool (Fauzi et al., 2024). Usually, the usability tests involve target users, usability experts, or both. Involving design students in the design phase is not unusual, as ergonomic studies commonly conduct usability tests with student participants (Vogel-Heuser, 2014). Furthermore, pre-test with them also help the researcher in

[6] This section is partially based on the following published contributions and an article currently in preparation:

Vigoroso, L., *Alce, G., & Caffaro, F. (2025, May). Gendered Perception of Gamified Safety Training in Manufacturing: Insights from a Pre-test Study. In: Stephanidis, C., Antona, M., Ntoa, S., Salvendy, G. (eds) HCI International 2025 Posters. HCII 2025. Communications in Computer and Information Science, vol 2524. Springer, Cham. https://doi.org/10.1007/978-3-031-94156-6_38*

Vigoroso, L., *Alce, G., & Caffaro, F. Mobile Safety Training Application for Manufacturing Sector: A Pre-test on Usability and User Interface design. (In preparation).*

evaluating the clarity and relevance of the usability survey questions and detect potential issues (Koo & Yang, 2025). According to Cheng (2016), the involvement of non-usability experts (design students) who are not directly involved in prototype development is acceptable, because they can even be more effective than end users due to their design expertise. Indeed, with their deep understanding of UI/UX principles, design students can contribute to the improvement of the tool's user interface and overall experience. In addition, because young design students apply the design strategies and skills they acquired throughout their study, they are representative of how professional designers operate (Kok et al., 2012). Moreover, students are often more familiar with modern app trends, and they can identify potential design flaws, strengths, and weaknesses, offering practical UX insights that may not be immediately evident to developers or experts. Moreover, the involvement of students facilitates the inclusion of both male and female participants in usability testing, an aspect that may be more critical in a manufacturing workplace context. In brief two research question were formulated for this phase:

- **RQ1:** Which aspects of UI/UX design can be improved, and which can be more effective in satisfying users' requirements?
- **RQ2:** What gender differences emerge in the design and development of a gamified prototype?

The following sections present an overview of the design process through which the digital interface and its interaction flow were developed. The subsequent subsections describe the participants involved, the instruments and procedures used for data collection, and the results.

3.5.1. Materials and Methods

Design process

To design the prototypes, perceptions and suggestions gathered from previous demos test of online safety applications (see phase 3) were used. Professional user interface design guidelines (Material Design, 2021) were also applied. In addition, based on such previous comments (phase 2), two alternatives were designed, each characterized by slightly different graphic features. Both prototypes consisted of the following five main screens: home, machinery and equipment list, machinery and equipment description, test and game, profile and information. Sketches and storyboards are presented in Figure 18.

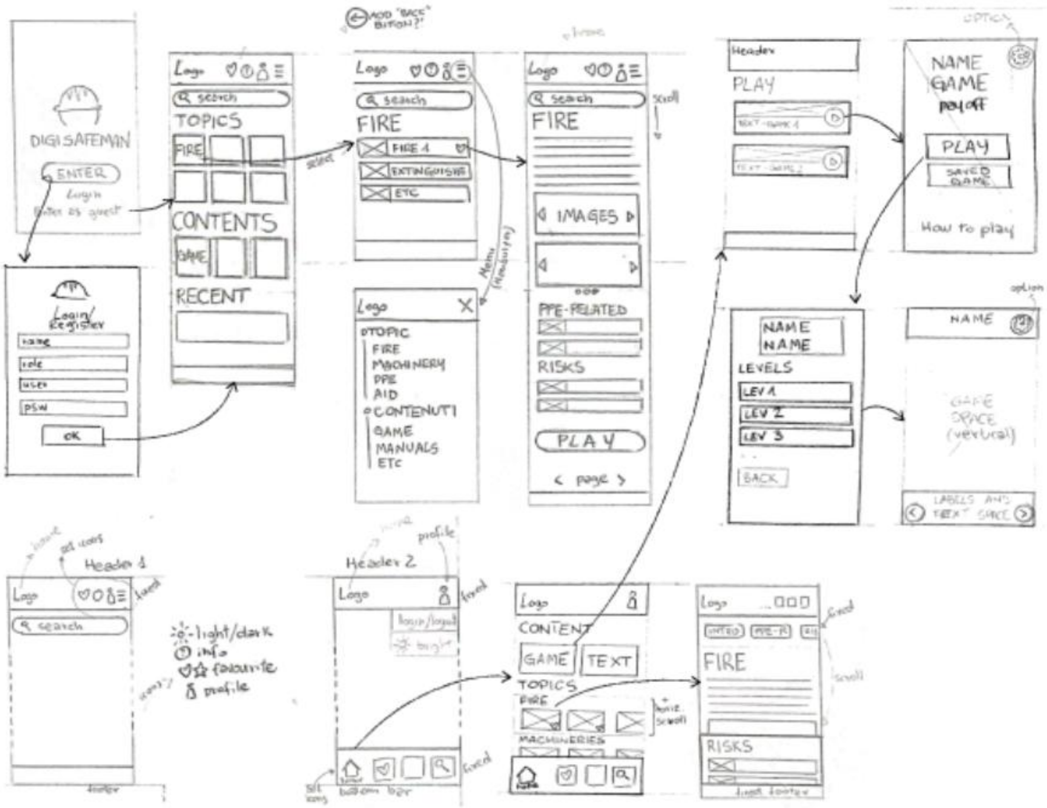


Figure 18. Sketches.

For convenience, the two proposed prototypes will be named “Model-1”, characterized by a light background, and “Model-2”, characterized by a dark background. For the color scheme, three core colors were used for each model (#DA0037, #171717, #EDF2F4 and #EE2B47, #303844, #FFFFFF, respectively), following the 60–30–10 color proportion principle (Akbar Putra, 2024). A three-color palette helped keep the interface clear and visually engaging (Kachan, 2019). In addition, traffic light colors (red, yellow and green) were used on specific screens to indicate the level of hazard associated with interacting with a particular machine. To save favorite pages, a small icon featuring a star for Model-1 and a heart for Model-2 was designed.

For the subsequent usability test, the interactive prototype with its several functionalities was designed using the Figma tool application (https://www.figma.com/). The logic flow of the app was as follows: after launching the prototype (welcome screen), users had to choose to log-in or proceed as a guest user. They were then directed to the main (home) screen, where a list of labels indicated categories and topics of interest (e.g., machinery, equipment, fire risks). Each interactive label provided access to a dedicated screen outlining the relevant machinery, necessary equipment, and associated safety procedures. Each screen presents both theoretical and practical explanations of OSH concepts through text and images. At the bottom of each screen, suggestions for related topics (in the form of a clickable button) are added. To support user orientation, a breadcrumb navigation system was incorporated, displaying a hierarchical path that allows users to trace their steps back to the homepage. The breadcrumb includes a back button to navigate to the previous screen. The navigation flow is presented in Figure 19. Examples of interfaces described above are in Figure 20.

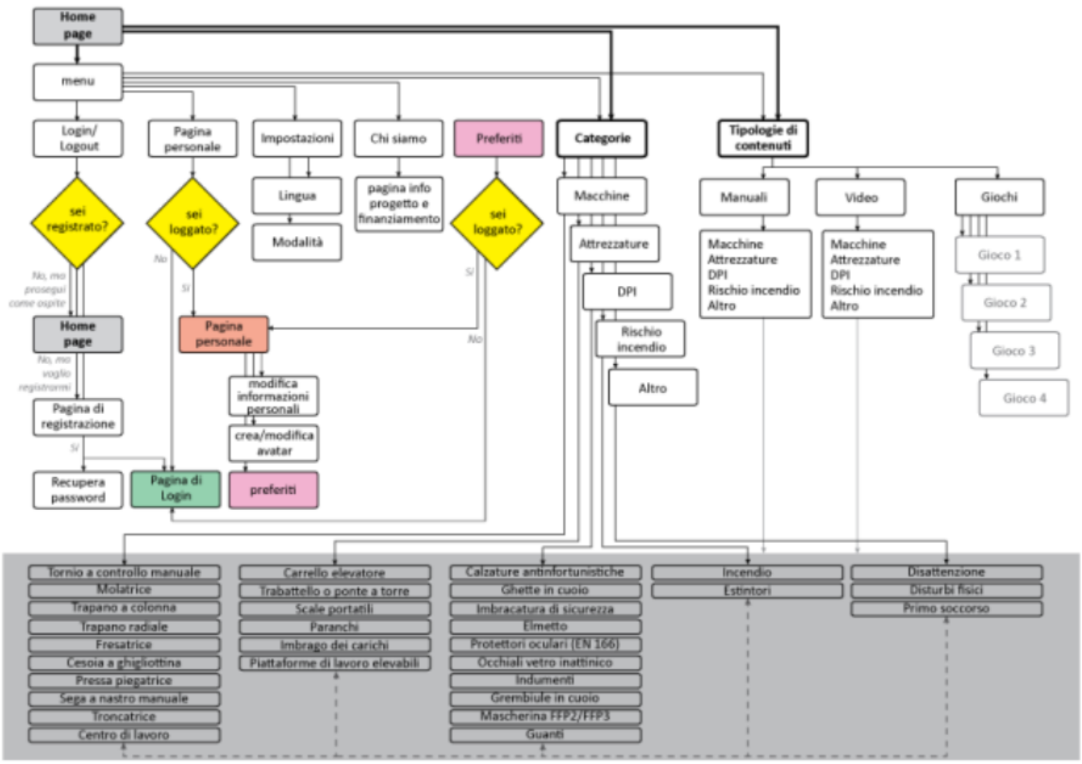
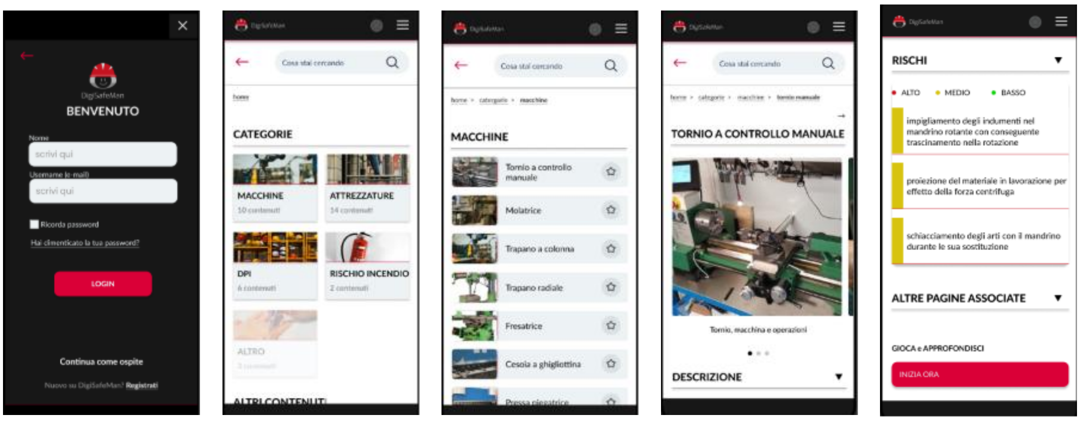


Figure 19. Flow diagram (created using https://miro.com/it/).



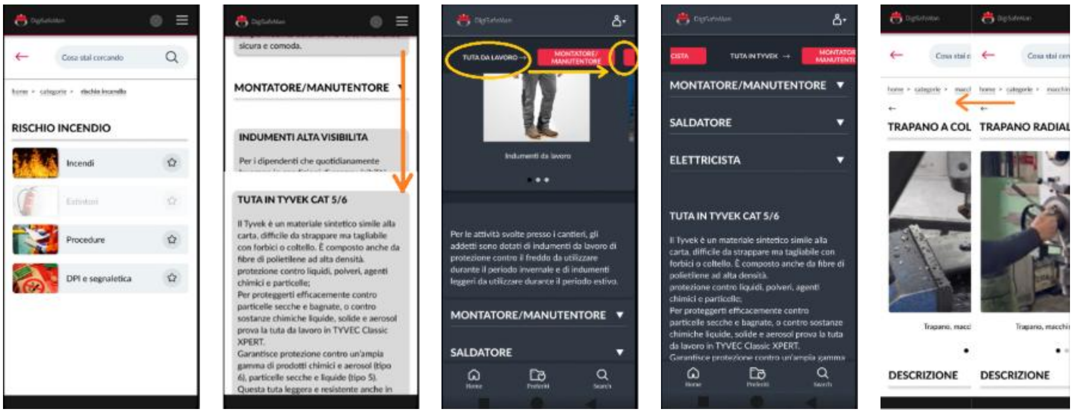
a) b) c) d) e)

Figure 20. Example of prototype interfaces (from Model-1): a) login, b) home, where labels indicating categories and topic of interest are listed, c) machinery list (category selected), d) and e) screens representing the selected machinery.

To assess which scrolling method was more effective, two home screens were created: *Model-1* featured vertical scrolling with a grid layout, while *Model-2* used horizontal scrolling. Scrolling refers to the movement of content presented on the screen, such as links, photos, and text (Sharma, 2019).

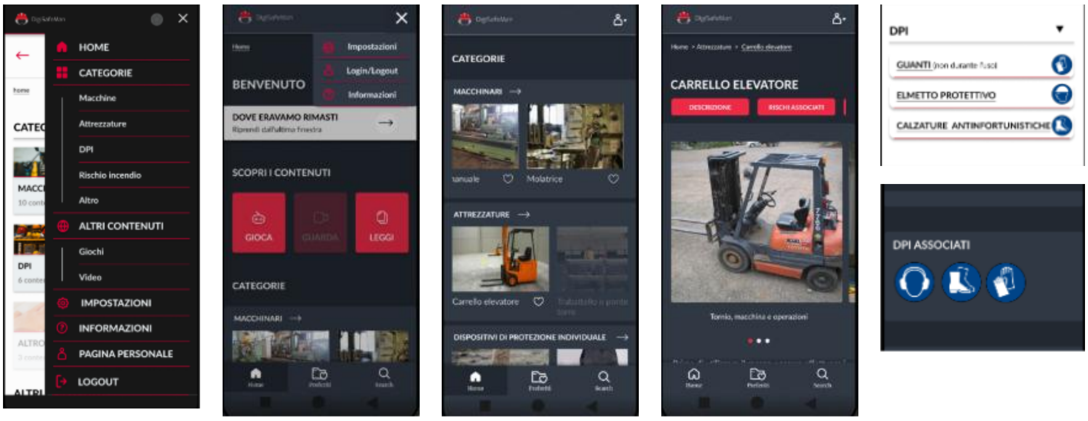
For some topics (e.g., fire risks and PPE) (Figure 21a), the screens contained more extensive content compared to those of other topics. Accordingly, the design also incorporated pagination, segmenting the content across several screens rather than maintaining a continuous vertical layout (Klyszejko et al., 2014; Viksten & Öberg, 2024) (Figure 21b). Previous studies have reported that, compared with continuous vertical scrolling, pagination can enhance learning and text comprehension while reducing reading time (Sanchez & Wiley, 2009; Viksten & Öberg, 2024). To test the pagination method (Figure 21c), a sub-navigation menu was implemented in *Model-2*. Examples are shown in Figure 21.

It is widely recognized that navigation features in mobile applications and websites must be designed to facilitate content exploration (Tsiodoulos, 2016). Users primarily navigate through a navigational menu which, given the limited interface space, is typically designed with at least two interaction methods: 1) a hover effect using the hamburger icon (*Model-1*), and 2) the bottom bar menu (*Model-2*) (Tsiodoulos, 2016). For visual clarity, see Figure 22. The overall architecture and content of the remaining screens were very similar across both models.



a) b) c) d)

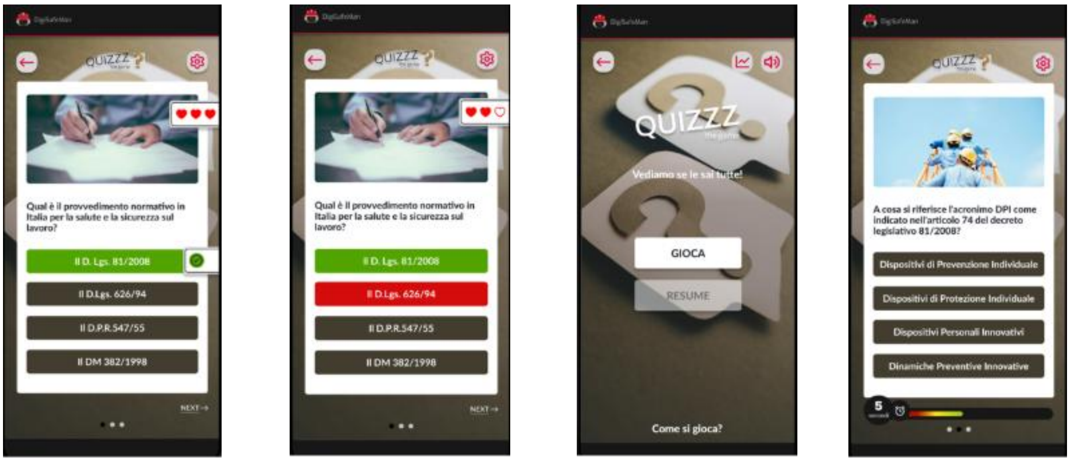
Figure 21. Examples of app screens focusing on pagination: a) fire risk screens, list of topics, b) clothes needed for work safely described in the same screen using continuous vertical scroll (method applied in *Model-1*), c) clothes needed for work safely using a subnavigation menu and pagination (highlighted in yellow circle in the figures, applied in *Model-2*) and d) horizontal scrolling between pages belonging to the same category (method applied in both Models).



a) b) c) d) e)

Figure 22. The two models tested, a) Model-1, home characterized by vertical scrolling and hamburger menu, b) Model-2, hidden menu reduced and implementation of a bottom bar menu, c) Model-2, home screen characterized by horizontal scrolling of elements listed in each category, d) example of screen characterized by a subnavigation menu and e) different use of icon related to the Personal Protective Equipment (PPE) within the two Models (Model-1 and Model-2, respectively).

In addition, graphical UI elements and visual assets for gamified screens, including buttons, tooltips, dialogs/pop-ups, labels, icons, and checkboxes, were considered (Pamudyaningrum et al., 2020) and designed with rounded forms. Button interactions should provide clear visual feedback through noticeable status changes that confirm whether an operation was successful or not. Accordingly, during gameplay (Figure 23a, 23b), correct and incorrect responses were highlighted in green and red, respectively. Similarly, game rules should be simple and easy to understand, and tutorials are usually strongly recommended (Ortet et al., 2021). “How to play" option is available on the first screen of the game interface and is briefly described in text format (Figure 23c). For time mode selection, a time bar was placed at the bottom of the screen (Figure 23d).



a) b) c) d)

Figure 23. Example of game interface and UI elements of one type of game prototyped.

For the gamified section, four demos were prototyped and implemented in Model-1 and Model-2, each inspired by different game genres: puzzle (Game 1), quiz (Game 2), narrative (Game 3), and 2D location-based (Game 4). These genres were selected for their cognitive and educational benefits: puzzle games are known to foster critical thinking and problem-solving skills by immersing players in realistic, simulated scenarios (Li & Liu, 2024); Quiz games enhance information retention, decisiveness, and analytical skills through frequent play (Capatina et al., 2024); Narrative games have the ability to engage players’ imagination, foster emotional connections, and encourage self-reflection. By involving players in decision-making, they make abstract concepts more concrete and memorable (Rizvi et al., 2022); Location-based games promote exploration, stimulate curiosity, and encourage interaction with other game elements (Zhao et al., 2023).

In brief, the main objectives of the games prototyped are as follows: 1) in the puzzle game, the player must identify and highlight errors and unsafe behaviors depicted in the images; 2) in the quiz game, the player must answer questions correctly to progress; 3) in the narrative game, the player select one of two possible responses to advance through the storyline. The narrative game was presented in two versions: the first one followed a branching story format, where players were given a brief scenario and asked to choose between two options (A or B); the second one adopted a more immersive mini-adventure style, characterized by more descriptive text and information and a role-playing game (RPG) tone. In both versions, player choices led to different story endings; 4) in the 2D location-based game, the player moves freely within a map in which they identify risks and hazardous situations, answer a series of questions, and complete several quests to resolve all the dangerous scenarios within the workplace. Examples of interfaces developed for each demo are shown in Figure 24.

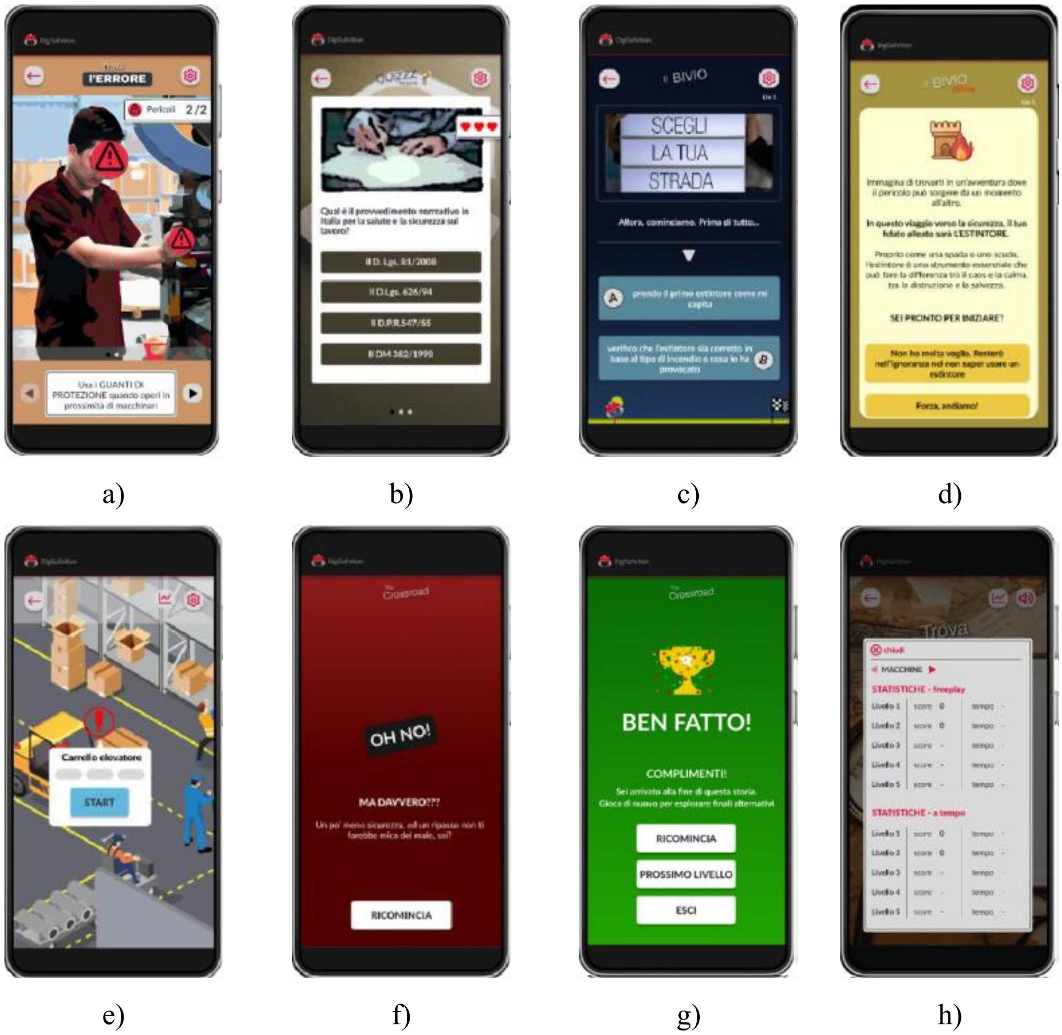


Figure 24. Example of interfaces for each tested demo and details: a) puzzle game, b) quiz game, c) narrative game as a branching story format, d) narrative game as text mini-adventure, e) 2D location-based game, f) narrative ending requiring player to restart the game g) positive final ending designed for each game and h) table of scores.

Participants

Participants involved in this usability test were selected from the Department of Design at the Politecnico of Torino (Italy). They were either in their final year of undergraduate studies or PhD students. A total of eight students took part in the test. They had a mean age of MD = 27.6 years (SD = 4.03, range: 20-33 years). Four of them were men, and the other four were women. All the students were selected based on their experience in graphic design and interactive interface creation, as well as their familiarity with safety protocols and the operation of work equipment (such as angle grinders). This expertise was gained through their participation in the department's model workshops, enabling them to closely approximate "real users," offering significant benefits for the research. (Miller-Cochran & Rodrigo, 2006; Ponciano et al., 2021). According to Conyer (1995) and Nielsen and Mack (1994), three evaluators are sufficient to identify key usability problems and detect errors (Vandewalle et al., 2020). Participant recruitment continued however until eight users were involved, when no new critical usability issues emerged.

The study used a convenient sampling technique. This sampling was helpful 'to obtain extensive information quickly and effectively' (Chin et al., 2021; Fareed et al., 2022, p. 5). Participation was voluntary, and no incentives were provided to the respondents. A university contact distributed the study invitation to eligible students via institutional channels. Expressions of interest in participating were collected, and the researcher received participants' contact information to organize the testing sessions. All participants were informed about the study's objectives, including that the sessions would be audio recorded and that their identities would remain anonymous during data analysis. Participants gave their verbal informed consent before their inclusion in the study.

Instruments and procedure

Figure 25 provides a detailed overview of the usability testing procedure adopted in this phase, illustrating the sequence of activities, the distribution of participants, which Model of prototypes was tested, and the integration of qualitative and quantitative data collection methods.

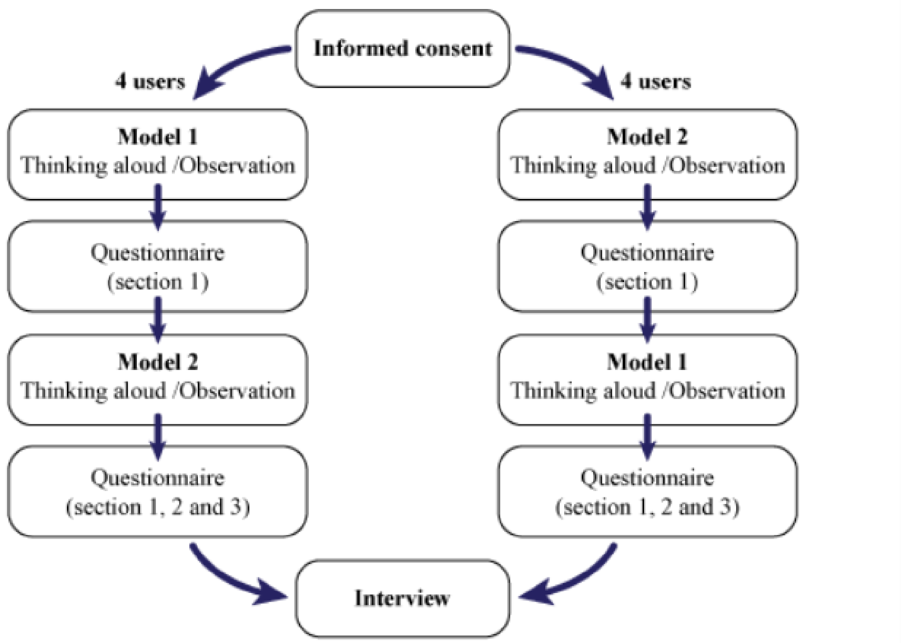


Figure 25. Test procedure

All participants interacted with both versions of the prototype (Model-1 and Model-2). To minimize practice effects, participants were randomly assigned to two groups: the first group (n=4) started testing Model-1, and the second group (n=4) started testing Model-2. Each participant was tested individually on the same smartphone provided by the researcher, with the screen recorded to track their movements and interactions.

During the usability trial, participants were allowed to use the prototyped app freely. However, to ensure that all sections were explored, each participant was asked to complete five main tasks for both Model prototyped: 1) simulate the processes of registration, login, and logout, 2) examine the personal page and explore the favorites saved topics, 3) explore at least one page from each designated section and, 4) explore the main navigation bar, 5) try all the demo games. Observation was used to monitor task completion and record any issues or errors identified by participants in the interface and interaction flow. Each session lasted about 1.5 h. Through the Thinking Aloud method, participants verbalized their thoughts and feelings and expressed any questions or concerns while interacting with the system.

At the end of each prototype model interaction (with Model-1 and Model-2), each participant was administered a questionnaire (see Appendix C.1): the first part included item from PSSUQ (Post-Study System Usability Questionnaire) (Lewis, 1995, 2002); more specifically, this part of the questionnaire was administered twice: the first time, it was completed after the usability testing session with Model 1, while the second time it was completed after the usability testing session with Model 2.The PSSUQ was selected for its standardized format, its easy administration, replicability, interpretation of results, and capability to capture users' satisfaction across multiple dimensions of usability (Lewis, 1995, 2002). PSSUQ is a 16-item standardized questionnaire, using a 7-point Likert scale (+NA option) (from 1=strongly agree to 7=strongly disagree). Thus, the lower the score, the better the performance and satisfaction are. It consists of an overall scale and three subscales, namely System Usefulness (SysUse), Information Quality (InfoQual) and Interface Quality (InterQual): the overall result is calculated by the average scores of questions 1-16, the SysUse score is calculated by the average scores of questions 1-6, the InfoQual score is calculated by the average scores of questions 7-12, the InterQual score is calculated by the average scores of questions 13-15. In the second section of the questionnaire, participants had to rate their level of satisfaction (from 1=very satisfied to 7=not-at-all-satisfied, according to the same scale used for PSSUQ) toward playability component (PC, 8 items) and learning content (LC, 3 items) (Khaleel et al., 2018; Zaibon, 2015), and how much they liked each game (4 items). A third section asked for information regarding their socio-demographic characteristics (i.e., age, gender, profession). The second and third parts of the questionnaire were filled out after the second usability session.

When each participant filled out the questionnaire, the researcher verbally asked if they had any additional suggestions for improving the prototype and which of the two versions of the prototype they preferred, along with the reasons for their choice (see Appendix C.2). Similarly, they had to explain the game they preferred the most and the least and motivate their responses.

Data analysis

Qualitative data. As done in phase 3 (see paragraph 3.4.1, Data analysis, *page 66*), for qualitative analysis, audio-recordings were transcribed, and notes from observations were coded and analyzed (Bengtsson, 2016). For this phase 4, four main themes were identified based on those previously outlined by Vasilevski and Birt (2019) (see Table 9): 1) Aesthetic and animations, 2) Entry points, 3) Transition, and 4) Quality contents. Comments on graphical UI (GUI) elements and visual assets of gamified screens were reported as an additional theme.

Table 9. Recurring themes.

Theme	Sub-themes	Description
Aesthetic and animation	• Color • Text • Design aspects	Including artwork and good design aspects and including adoption of appropriate colors, color contrast, and font, in terms of size and weight.
Entry points	• Buttons to manage the flow on the same screen • Buttons to manage the flow between the screens • Favorite contents and icons	Including the adoption of proper icons and navigation bars.
Transition	• Scrolling and flow • Animation	Including the flow.
Quality contents	• General • Layout • Hierarchy	Including layout and hierarchy.
GUI	• Graphical elements and visual assets	Including game GUI

Quantitative data. For quantitative data collected through the questionnaire, descriptive statistics were computed for all items. PSSUQ had Cronbach's alpha coefficients in line with earlier research, as they were 0.895, 0.856, 0.858, and 0.676 for the Overall scale, SysUse, InfoQual, and InterQual subscales, respectively. Considering that the criterion for acceptable reliability is a coefficient alpha greater than 0.60, the responses to the items were considered reliable and consistent (Heriadi & Alam, 2024; Lewis, 2018).

Then a mean score was calculated for items on playability component and for learning content. Considering the limited number of participants, non-parametric statistical tests were applied. Specifically, a Wilcoxon signed-rank test was used to examine differences between the two prototypes, while the Mann-Whitney test was conducted to assess any gender differences.

3.5.2. Results

Qualitative data

Through the Thinking Aloud technique, participants reported a series of comments that referred to both the prototypes tested. These comments are reported in Table 10.

Table 10. Participants' comments common for both prototypes interface (sub-themes used are adapted from Vasilevski & Birt, 2019).

Main theme: Aesthetic	
Sub-themes	**Comments**
Colors	*"About the colors, I believe the use of a palette with two or three colors is appropriate"* [woman, 30 years], *"I would appreciate the possibility to switch from a light theme to a dark one"* [man, 29 years], *"The palette with red color is more appealing"* [man, 24 years].
Text	*"In my opinion, the font works well, particularly the use of the bold text"* [woman, 25 years], *"There are bold elements"* [man, 29 years].
Design aspects	***Images*** *"I would suggest including more images between three and ten, to better illustrate both the machinery and the correct positioning of the operator. Based on my previous experience when I operated with a lathe, it could also be helpful to show the operator's workspace"* [man, 29 years], *"Images placed on the top of the screen are ok, but the labels placed under the images may not be necessary. The title of the machine is already provided, and this extra text distracts me from seeing the step-by-step operations clearly*" [woman, 24 years], *"I would make the images larger"* [woman, 30 years]. ***Layout*** *"I appreciate that on the favorites page, the saved topics are organized by category"* [woman, 25 years].
	Continue…

	Video *In the videos, if available, I would add more text, perhaps even subtitles. Even though the videos are short, the use of titles could help maintain focus* [woman, 24 years], *"It would be helpful include a textual description of the action taking place during the video. In environments with loud noises, it may be challenging to hear, and I might need to rewind. Adding a video navigation bar or marking key moments would be useful"* [woman, 25 years].

Main theme: Entry points	
Sub-themes	**Comments**
Buttons to manage the flow on the same screen	*"I would also block the "go back" button and the "what are you looking for" element on the top, so you don't need to scroll back up"* [man, 29 years], "*I like the "back to top" button"* [man, 29 years].
Buttons to manage the flow between the screens	*"I'm used to clicking on the app logo because it typically takes me back to the homepage"* [woman, 25 years], *"Ah,* [in game quiz] *'next' to move forward. Maybe it is too small"* [man, 29 years], *"In the quiz game, the button to move to the next question is not clearly visible"* [woman, 30 years].
Favorite contents and icons	*"I appreciate the ability to save favorite content"* [woman, 30 years], *"If I save content without being logged in, the system should provide me clear feedback, prompting me to register or log in to access the list of saved content"* [woman, 25 years].

Main theme: Transition	
Sub-themes	**Comments**
Scrolling and Flow	*"Oh, that's nice. I hadn't noticed before, but with horizontal scrolling, I can view the machine pages. Oh, I love it! I think it makes sense because it takes into account the possibilities and preferences of each type for the users"* [woman, 30 years], *"At the top, the flow of pages and categories is indicated, so I know exactly where I am and how to go back. I'm not sure if it would be useful for it to remain fixed while scrolling the page"* [man, 34 years], *"I also like the option to access the favorites page directly from my personal page"* [woman, 24 years], *"I would suggest improving the linkage to the games section. For instance, when consulting the PPE materials, it should be possible to directly access the games addressing this topic. Otherwise, there are too many transtitions"* [man, 34 years].
Animations	*"I like the animations that appear to confirm successful login and logout"* [woman, 30 years].

Continue…

Main theme: Quality contents	
Sub-themes	**Comments**
General	*"In the fire risk section, I like that there is a dedicated section addressing the presence of smokers as a potential fire ignition risk"* [woman, 25 years].
Layout	*"I like the way the severity of the main risks are categorized into high, medium, and low and coded using the traffic light colors, red, yellow and green. However, I would place them in a more prominent position instead of at the bottom of the page"* [man, 29 years], *"I think it would be a good idea to modify the order of the PPE and present them in a different sequence. Start from the head and work down to the feet, or vice versa. For example, place the headphones, helmet, and other headgear first, then move on to the torso, and finally cover the rest of the body. As for the harnesses, you could place them either separately or at the end"* [man, 24 years], *"There are two types of glasses listed. I would recommend merging them into a single entry titled "protective glasses" and then making the distinction within the page. This way, you also reduce the length of the PPE list, and as consequence reduce the need for excessive scrolling"* [man, 29 years].
Hierarchy	*The fire risk section is quite detailed, with a lot of information, including general concepts like the fire triangle. However, the procedures to follow are located elsewhere. In addition, for the risks to people section, I expected something different... maybe there are too many sections and bullet points. I would suggest adding more images and diagrams to help break up the text"* [woman, 24 years], *"For the fire risk section, I would emphasize it differently, as it's crucial to consider, especially in certain industries. Adding a more prominent SOS button that explains the initial steps to take would be useful. The information on how to use the fire extinguisher is good as a supplementary detail"* [woman, 25 years], *"The card on the homepage suggesting 'resume from the last page viewed' is a nice feature. It's new to me—while I typically see it in browsers asking if I want to restore closed tabs, I hadn't encountered it in an app before, which made it a bit unusual. For this reason, it might be better to position it at the bottom rather than at the top as the first thing I see"* [woman, 24 years], *"The "resume from the last page viewed" card is useful if you frequently visit the same page, although the favorites feature serves a similar purpose"* [woman, 25 years].

Continue…

Main theme:	GUI
Sub-themes	**Comments**
Graphical elements and visual assets	*"I would like feedback regardless of positive or negative responses"* [man, 29 years], *"I would expect to receive feedback if I have made a mistake, selected an incorrect answer, or performed an incorrect action"* [man, 24 years], *"I like this button that show me the statistics of how many times I played and score achieved"* [woman, 25 years], *"Oh, here there are instructions how to play at the beginning. But I think a tutorial would be useful here too"* [woman, 25 years], *"Maybe a tutorial is needed"* [man, 29 years], *"I knew some things, but it took me a while to read some questions. Maybe it's me, but they were a bit too complex or are too long"* [woman, 24 years].

Other comments focused mainly on the entry points, particularly the navigation menu and icons, pointing out the key differences between the two Models. They provide additional clarification on the rationale behind their preference. These comments are reported in Table 11. In Figure 26, the screens mainly commented on this Table are depicted. In conclusion, although some differences and some areas for improvement were noted between the two Models, both were perceived as intuitive and easy to use: *"They are very intuitive; I do not feel the need to comment further as I find them straightforward"* [woman, 25 years].

Table 11. Participants' comments identifying differences and preference between the two prototypes (sub-themes used are adapted from Vasilevski & Birt, 2019).

Main themes: Aesthetic		
Sub-themes	**Model**	**Comments**
Colors	2	*"I am a fan of dark themes, but offering the customization option is definitely helpful"* [woman, 25 years].
Design aspect	1	***Icons quality*** *"I would make the icons representing the Personal Protective Equipment (PPE) more visible, as they tend to get lost, and the text stands out more"* [man, 24 years], *"The icons related to PPE in some sections are too small, it might be better to delete these icons"* [woman, 30 years].

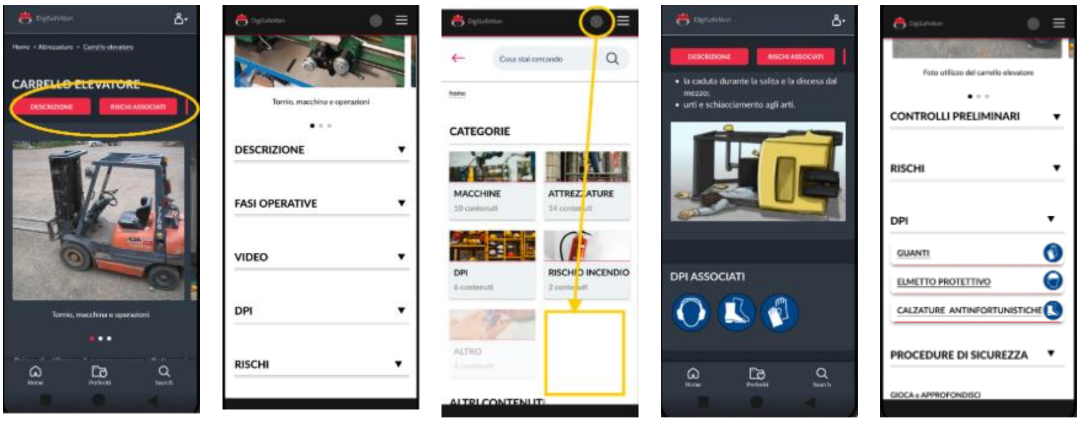
Continue…

	2	*"I didn't feel inclined to click on them; I thought they were just a list. However, I thought… "why not give clicking a try?""* [man, 29 years].

Main themes: Entry points		
Sub-themes	**Model**	**Comments**
Buttons to manage the flow between the screens	1	*"Its layout is much more intuitive for me, with the hamburger icon menu enhancing navigation and facilitating a clearer understanding of available categories"* [man, 29 years], *"The organization of information appears more coherent and accessible. Furthermore, the inclusion of a dropdown submenu could be particularly advantageous, allowing access to any page from the main menu, regardless of their current location within the system"* [woman, 30 years], and *"When I am on the homepage and open the menu, the categories listed there appear to be the same as those listed on the homepage and seem to lead to the same content and pages. In some cases, this process feels unnecessarily lengthy, while in others, it seems more efficient"* [woman, 30 years], *"You could change in a dropdown submenu"* [woman, 25 years].
	2	*"In most cases, there are labels with CTAs [call to actions] that clearly indicate clickable cards. However, for some other icons, I must rely on intuition, as their meaning is less clear graphically"* [man, 24 years]; *"Here, I may not have a dropdown menu, but I do have the bottom bar that takes me back to the homepage, and the top navigation bar [referring also to the breadcrumbs] is useful for returning to a previous page"* [man, 29 years].
Favorite contents and icons	1	*"I like the star-shaped icon for favorites"* [man, 29 years], *"I see the star-shaped icon [placed near the hamburger icon], but I'm not sure what it represents. It might be too small at the top to clearly indicate that these are my favorite pages. I would suggest placing it in a larger block, perhaps next to the other categories"* [man, 29 years].

Continue…

Main themes: Transition		
Sub-themes	**Model**	**Comments**
Scrolling and Flow	1	*"I found it inconvenient to open each piece of content individually within every page. This approach can be discouraging, as it may lead to overlooking certain sections and potentially missing important information"* [woman, 30 years], and *"I find it somewhat tedious…"* [man, 24 years].
	2	*"It is understandable that in the specific pages, such as those describing machinery or PPE, these pages are somewhat longer due to the extensive content. However, I prefer having dropdown menus to open, rather than navigating through so many separate pages"* [man, 24 years].



a) b) c) d) e)

Figure 26. Components mainly commented on by participants for further improvements: a) the top navigation bar (Model-2), b) heading and its content contained within a dropdown section, c) star-shaped icon for favorites (Model-1), d) PPE icons not perceived as clickable in Model-2, e) favorite icon on Model-1.

During the interview, most participants clearly expressed a stronger preference for Model-1, even though Model-2 was perceived as more interactive and dynamic. The most valued aspects in Model-1 included its alignment with users' mental models, particularly regarding scrolling behavior, the well-structured grid layout, and the clearly defined list of contents on both the home and individual category screens. On these aspects, here are selected quotations extracted from participants' responses:

"I prefer the organization of Model-1" [man, 29 years], *"Between the two versions, I definitely prefer Model-1. It has a stronger visual impact. While horizontal scrolling is useful, I find it more intuitive to have a list available where I can immediately click a button to access another list and the page with the topic of interest. This preference likely stems from the fact that we are accustomed to scrolling and no navigating through horizontal scroll"* [woman, 24 years], *"In Model-1 the scrolling method is exactly what I expected in the main navigation"* [woman, 25 years], *"In my opinion, the way the information is arranged is better and works more effectively"* [man, 24 years], *I did not think there were any issues with Model-2, but now that I see how the information is organized in Model-1, the latter seems better organized"* [man, 21 years, maintainer], *"At first glance, I prefer the Model-1, because it has a list. In contrast, in Model-2, I have machinery, equipment, etc., but I need to scroll horizontally to see the contents"* [man, 29 years]. *At first glance, Model-1 seems to provide the information I need most"* [woman, 25 years].

One participant only explained their preference for Model-2:

"The option to scroll horizontally through the categories seems to be more interactive and innovative, making the experience more user-friendly. Overall, I prefer horizontal scrolling. The dual-scroll functionality enables users to access a large amount of information without disrupting the smooth and intuitive vertical flow. On the homepage, I don't need to scroll excessively to find everything. With just a few swipes, I can easily explore the entire page" [woman, 30 years].

Regarding the *most preferred game* among the four demos tested, the quiz was the most preferred (by four males and one female), followed by puzzle (by one male and two females) and narrative (by one female). In detail, one participant indicated a double preference, being unable to distinguish one option as superior to the other, and consequently rated the two demos as equivalent. The quiz game was preferred by half of the participants involved. Participants explained that this game:

> *"It is simpler"* [woman, 25 years], *"It's a game that everyone knows, and I find it more intuitive"* [man, 35 years] and *"It's the most common and classic game"* [woman, 25 years].

The puzzle game was identified as the second preferred demo by 3 of the 10 participants. Participants said:

> *"I liked the freedom to click anywhere on the screen to find the error. The high level of interactivity gave me time to think about the solution. There were no pre-set answers, making it more engaging and enjoyable since it required more effort on my part"* [woman, 25 years], *"This game was the best because it had real photos to interact with,"* and [woman, 24 years] *"It was the nicest one, but I can't really say why. It was just a feeling"* [woman, 25 years].

Then, one participant preferred the narrative game, explaining that:

> *"I found it different from other games I usually come across. It intrigued me more because it felt like I was building my own path"* [woman, 30 years].

Conversely, the narrative game was *the least preferred* of the four demos (chosen as last by two male and two female participants), followed by the puzzle game (two males and one female) and the quiz game (one female). Participants motivated their choices regarding the narrative game:

> *"I didn't particularly enjoy it because I struggled to understand how the narrative worked. Maybe it's because I don't usually associate this format with a game, so it felt more like reading text than playing"* [woman, 25 years], *"Perhaps the narrative wasn't the best medium for this type of content, it is a bit weird"* [man, 24 years], *"I didn't find it really enjoyable"* [man, 29 years] and *"some call-to-action buttons*

> *need to be refined to get clearer feedback from the game"* [man, 29 years].

Hereafter are the responses provided by participants who expressed uncertainty regarding the puzzle game:

> *"At first glance, I didn't understand the rules of the game. Maybe a tutorial for this game, and even for the other could be useful"* [woman, 34 years] and *"I really can't say why, but out of all of them, this one intrigued me the least"* [woman, 30 years]. Finally, one participant did not prefer the quiz game *"Because it excites me less. Maybe its rules were too simple. And maybe, the timed mode was a bit more challenging"* [man, 24 years].

In conclusion, it should be noted that the 2D location-based game was neither cited among the most preferred nor among the least preferred.

With regard to the observation, no additional major critical issues emerged. All five assigned tasks were successfully completed without relevant difficulties, suggesting that each section and page of the application were generally easy to access and navigate. Nevertheless, it should be noted that within the games section, only one participant noticed and explored the "how to play" option. The lack of exploration of the game rules may have influenced the identification of usability issues related to gameplay in the "find the error" and "procedure" games. Specifically, although participants did not show difficulties in identifying errors in the "find the error" screens, some uncertainty was observed among users when no system feedback was provided following unsuccessful clicks. In such cases, participants tended to seek clarification from the researcher regarding the game rules. As a result, several participants pointed out that clicking near, but not exactly on, the error location was confusing, suggesting that the clickable area should be larger or that clearer feedback should be provided to indicate incorrect selections. Similarly, in the "procedure" game, navigation within the scene was perceived as slow and lacking clarity. Participants reported difficulties in understanding the number of risks present in the scene and perceive the extent of the explorable area unintuitive, hindering the identification of hazards. These observations are consistent with the preferences and evaluations reported through the questionnaire and interview data.

Quantitative data

PSSUQ. Descriptive statistics for the investigated items for both Model-1 and Model-2 are reported in Table 12. The Wilcoxon signed-rank test revealed a significant difference between the two models regarding the Overall scale (z = -2.03, p = .042) (Model-1 M = 2.44, SD = .78, and Model-2 M = 3.01, SD = .53) and the SysUse scale (z = -2.10, p = .035) (Model-1 M = 2.06, SD = .81, and Model-2 M = 2.68, SD = .20). No differences were reported for the InfoQual and InterQual subscales. Overall, quantitative results confirm the findings of qualitative comments.

Table 12. PSSUQ scores, scores and comparison between Model-1 and Model-2.

ID	Questions	(Model-1 + Model-2)	Model-1	Model-2
			Mean (SD)	
1	Overall, I am satisfied with how easy it is to use this system	2.12 (1.08)	1.75 (1.38)	2.50 (.53)
2	It was simple to use this system	2.00 (1.03)	1.62 (1.06)	2.50 (.75)
3	I was able to complete the tasks and scenarios quickly using this system	2.50 (.81)	2.00 (.75)	3.12 (.35)
4	I felt comfortable using this system	2.18 (.91)	1.62 (.74)	2.75 (.70)
5	It was easy to learn to use this system	1.94 (.85)	1.62 (.74)	2.37 (.74)
6	I believe I could become productive quickly using this system	2.62 (1.08)	2.37 (1.18)	2.87 (.99)
7	The system gave error messages that clearly told me how to fix problems	4.00 (1.67)	3.87 (1.88)	4.12 (1.55)

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8	Whenever I made a mistake using the system, I could recover easily and quickly	3.00 (1.03)	2.62 (.74)	3.37 (1.18)
9	The information (such as online help, on-screen messages, and other documentation) provided with this system was clear	2.94 (1.38)	2.37 (1.06)	3.50 (1.51)
10	It was easy to find the information I needed	2.62 (1.67)	1.62 (1.06)	3.62 (1.59)
11	The information was effective in helping me complete the tasks and scenarios	2.56 (1.20)	2.00 (.75)	3.12 (1.35)
12	The organization of information on the system screens was clear	2.75 (1.06)	2.25 (.46)	3.25 (1.28)
13	The interface of this system was pleasant	2.25 (.77)	2.00 (.92)	2.50 (.53)
14	I liked using the interface of this system	2.44 (.96)	2.50 (1.30)	2.37 (.51)
15	This system has all the functions and capabilities I expect it to have	2.94 (1.48)	2.50 (1.41)	3.37 (1.50)
16	Overall, I am satisfied with this system	2.62 (.88)	2.37 (1.06)	2.87 (.64)
scale				
SysUse*	Average of question items 1-6	2.26 (.83)	1.83 (.98)	2.68 (.68)
InfoQual	Average of question items 7-12	2.97 (1.20)	2.46 (.99)	3.50 (1.41)
InterQual	Average of question items 13-15	2.54 (1.03)	2.33 (1.21)	2.75 (.85)
Overall*	Average of question items 1-16	2.60 (1.01)	2.19 (1.03)	3.01 (.98)

* Significant difference by model. Note: according to the scale used in PSSUQ, the lower the score the better the performance and satisfaction are.

When considering the gender differences, females reported better mean scores for Model-2 (11 out of 16 items). For Model-1, females performed better in 8 out of 16 items, and males performed better in the other 8 items. Furthermore, two significant differences were found for two single items (see Table 13), which are "easy to learn to use this system" for Model-1 (z = -2.00, p = .046) and "I liked using the interface of this system" for Model-2 (z = -2.05, p = .040). However, no overall wider statistical differences were found comparing the two models between gender (see Table 13).

Table 13. PSSUQ scores considering gender differences.

ID	Questions	Mean (SD)			
		Model-1		Model-2	
		Males	**Females**	**Males**	**Females**
1	Overall, I am satisfied with how easy it is to use this system	1.50 (0.57)	2.00 (2.00)	2.50 (0.57)	2.50 (0.57)
2	It was simple to use this system	1.50 (0.57)	1.75 (1.50)	2.50 (1.00)	2.50 (0.57)
3	I was able to complete the tasks and scenarios quickly using this system	2.25 (0.50)	1.75 (0.95)	3.25 (.50)	3.00 (0.00)
4	I felt comfortable using this system	1.75 (0.50)	1.50 (1.00)	3.00 (0.81)	2.50 (0.57)
5	It was easy to learn to use this system	2.00 (0.81)	1.25 (0.50)	2.75 (0.95)	2.00 (0.00)
6	I believe I could become productive quickly using this system	2.75 (0.95)	2.00 (1.41)	2.75 (0.95)	3.00 (1.15)
7	The system gave error messages that clearly told me how to fix problems	3.75 (1.50)	4.00 (2.45)	4.25 (1.50)	4.00 (1.82)
8	Whenever I made a mistake using the system, I could recover easily and quickly	3.00 (0.81)	2.25 (0.50)	3.75 (0.50)	3.00 (1.63)
9	The information (such as online help, on-screen messages, and other documentation) provided with this system was clear	3.00 (0.81)	1.75 (0.95)	3.75 (1.50)	3.25 (1.70)
10	It was easy to find the information I needed	2.25 (1.25)	1.00 (0.00)*	4.00 (1.82)	3.25 (1.50)
11	The information was effective in helping me complete the tasks and scenarios	2.50 (0.57)	1.50 (0.57)	3.50 (1.00)	2.75 (1.70)
12	The organization of information on the system screens was clear	2.00 (0.00)	2.50 (0.57)	3.50 (1.29)	3.00 (1.41)
13	The interface of this system was pleasant	2.00 (0.00)	2.00 (1.41)	2.50 (0.57)	2.50 (0.57)
14	I liked using the interface of this system	2.50 (0.57)	2.50 (1.91)	2.75 (0.50)	2.00 (0.00)*

Continue…

15	This system has all the functions and capabilities I expect it to have	2.50 (1.29)	2.50 (1.73)	3.50 (1.73)	3.25 (1.50)
16	Overall, I am satisfied with this system	2.50 (0.57)	2.25 (1.50)	3.00 (0.81)	2.75 (0.50)
scale					
SysUse	Average of question items 1-6	1.95 (0.47)	1.71 (1.20)	2.79 (0.25)	2.58 (0.56)
InfoQual	Average of question items 7-12	2.75 (0.64)	2.16 (0.57)	3.79 (0.95)	3.20 (1.37)
InterQual	Average of question items 13-15	2.33 (0.60)	2.33 (1.63)	2.91 (0.56)	2.58 (0.32)
Overall	Average of question items 1-16	2.36 (0.22)	2.03 (1.01)	3.20 (0.50)	2.82 (0.56)

* Significant difference

Descriptive statistics for the playability of components and learning content are presented in Table 14. Overall, all items received positive ratings. In detail, better mean scores were reported among females in 7 out of 11 items compared to males' responses. However, female participants perceived the overall system as slightly more repetitive than male participants. Furthermore, no significant gender differences emerged for the items investigated.

Considering questions on how much they liked each game, descriptive statistics are reported in Table 15. Based on the mean scores, female participants gave slightly higher ratings to the quiz game and, in particular, to the location-based game. Males reported a somewhat better mean score in the narrative game. A Mann–Whitney test indicated that females appreciated the location-based game significantly more than males ($U = 152.50$, $z = -2.165$, $p = 0.030$). Overall, the quantitative results confirm the findings from the qualitative comments.

Table 14. Mean and standard deviation related to playability and learning content.

ID	Questions	Overall	Male	Female
			Mean (SD)	
1	The games provide clear objectives	2.00 (1.07)	2.50 (1.29)	1.50 (.57)
2	I have control over the game actions	2.37 (.74)	2.50 (.57)	2.25 (.95)
3	Challenges and strategy are balanced	2.50 (1.07)	2.50 (1.29)	2.50 (1.00)
4	I felt comfortable using these games	1.75 (.46)	1.75 (.05)	1.75 (.50)
5	The first gaming experience was encouraging	2.50 (.756)	2.50 (1.00)	2.50 (.57)
6	There are no repetitive and boring tasks	3.62 (1.84)	3.50 (1.91)	3.75 (2.06)
7	The game does not stagnate	2.87 (1.24)	3.50 (1.00)	2.25 (1.25)
8	The game is consistent	2.12 (.64)	2.25 (.50)	2.00 (.81)
9	The content can be easily learned	1.75 (1.03)	2.25 (1.25)	1.25 (.50)
10	It provides good educational content	1.50 (.53)	1.75 (.50)	1.25 (.50)
11	The content is understandable	1.62 (.74)	2.00 (.81)	1.25 (.50)
12	Playability component	2.46 (.55)	2.62 (.30)	2.31 (.74)
13	Learning content	1.62 (.60)	2.00 (.60)	1.25 (.32)

Note: according to the scale used in PSSUQ, the lower the score the better the performance and satisfaction are.

Table 15. Mean and standard deviation related to game preferences.

ID	Questions	Overall	Male	Female
			Mean (SD)	
1	Game 1: puzzle	2.75 (1.48)	2.75 (1.70)	2.75 (1.50)
2	Game 2: quiz	2.37 (1.06)	2.50 (1.00)	2.25 (1.25)
3	Game 3: narrative game	2.87 (1.24)	2.75 (1.25)	3.00 (1.41)
4	Game 4: location-based*	2.25 (1.03)	3.00 (.81)	1.50 (.57)

* Significant difference by gender. Note: according to the scale used in PSSUQ, the lower the score the better the performance and satisfaction are.

3.6. Phase 5 – Evaluate the design against the requirements

Based on the insights from the preliminary usability evaluation conducted with design students, a usability test was carried out with real end users (i.e., workers at Olivero Impianti), as part of Phase 5 of the HCD process. This phase aimed to validate the refined high-fidelity prototype in a realistic usage context, ensuring that the interface, interaction flow, and gamified elements effectively support users' expectations and tasks. Involving real users allowed the assessment of usability, clarity, and overall user experience under conditions that reproduce the intended operational environment, thereby strengthening the validity of the findings and supporting final design decisions prior to full implementation. The study aimed at answering the following research question (RQ):

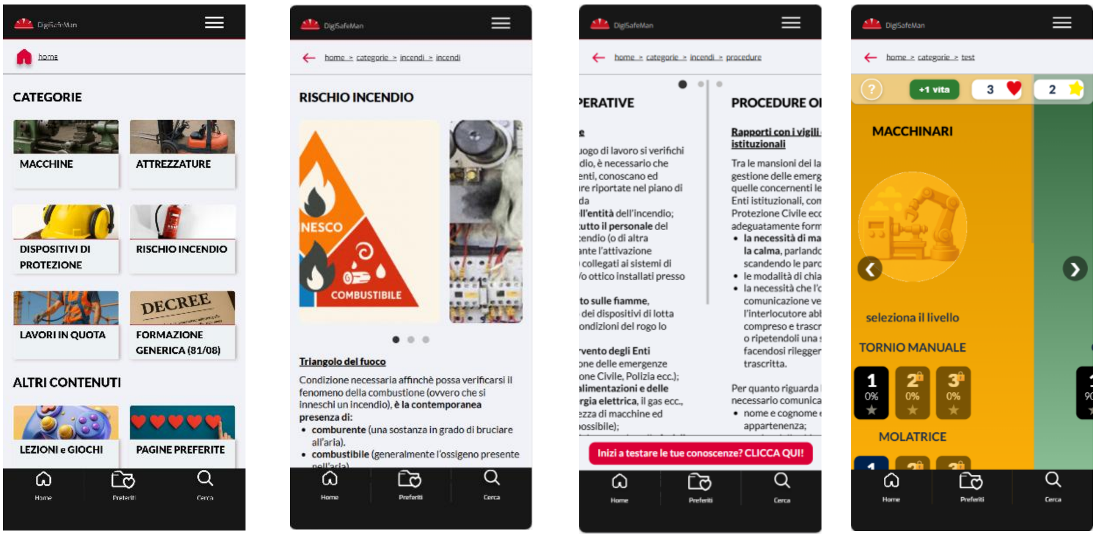
- **RQ:** To what extent does the refined high-fidelity prototype effectively support usability, clarity, and user experience for real end users in a realistic operational context?

3.6.1. Materials and Methods

Design adjustment

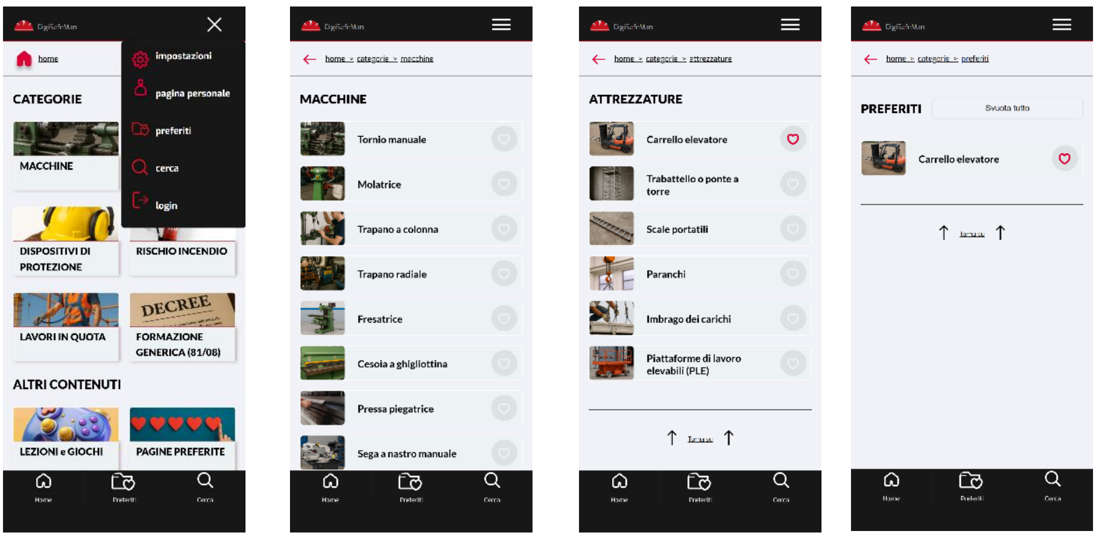
Based on the suggestions that emerged from Phase 3 of the present research, the prototype was refined. Particular attention was given to the critical elements identified, which were subsequently improved. First, considering the logistic aspect and the lengthy time required for usability testing, we decided to adopt a single model that would represent a synthesis of the most effective features among those previously tested. In particular, considering the strong preference expressed for a white background and vertical scrolling as the primary navigation method, the visual style of Model 1 was maintained. Horizontal scrolling, where present, retained the use of dot indicators typical of carousels, ensuring recognizability and ease of understanding (Figure 27).

Similarly, given the complexity and user uncertainty regarding the use of the navigation bar (either bottom navigation or side hamburger menu), it was decided to retain both solutions, allowing users to choose which they considered more effective by having both available (Figure 28a). With regard to graphic aspects and the selection of favorite contents, the heart icon was retained (Figure 28b,c,d), as it is widely used in contemporary social platforms and received positive feedback.



a) b) c) d)

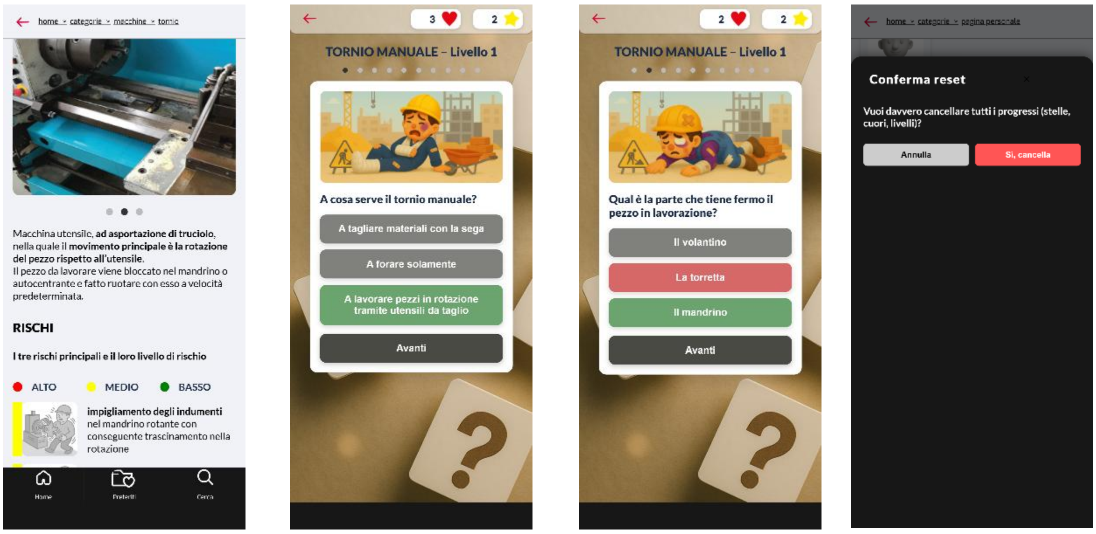
Figure 27. Example prototype interface adjusted and improved: a) interface with white background, b) horizontal scrolling retained in carousel image, c) carousel structure retained between pages, and d) carousel structure retained in game section.



a) b) c) d)

Figure 28. Example prototype interface adjusted and improved: a) implementation of both bottom navigation and side hamburger menu, b) and c) heart icon retained for favorite contents and d) favorite page list (with content selected).

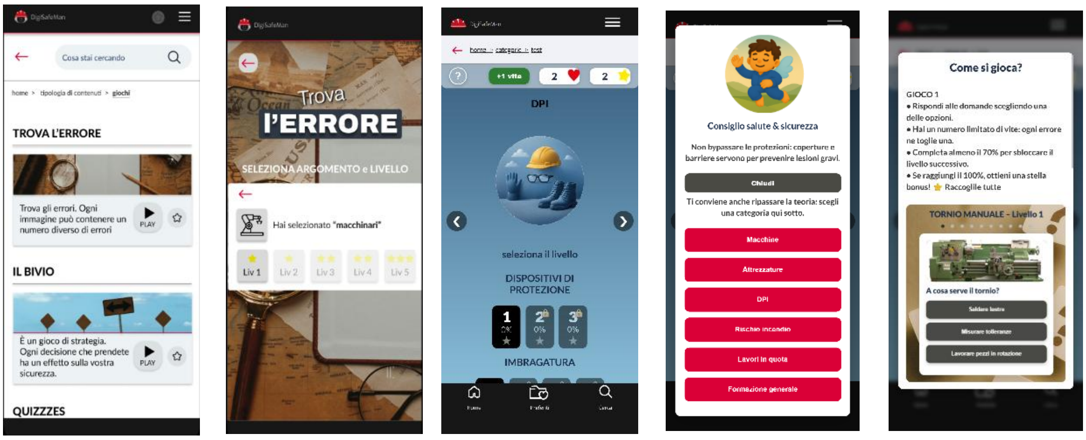
Particular attention was devoted to textual content, with the introduction of bold text where necessary, especially in sections that previously lacked visual emphasis (Figure 29a). In the gamified section, the use of green and red was more strongly emphasized to distinguish between correct and incorrect responses (Figure 29b,c). Likewise, throughout the rest of the prototype, binary choices such as “yes” and “no” or “continue” and “cancel” were highlighted through the use of two different colors, rather than being flattened through the use of a single color, as in the previous version (Figure 29d).



a) b) c) d)

Figure 29. Example prototype interface adjusted and improved: a) bold text use, b) and c) correct and incorrect responses emphasized through color use, d) binary choices emphasized through color use.

As done with the choice of Model 1, a selective approach was also adopted for the gamification section, for a twofold reason: first, the time required to administer usability tests; second, because the results of HCD-phase 4 (see pharagraph 3.5.2, page 98) largely confirmed the suitability of specific game formats for specific types of content, as already suggested by the pre-tests conducted in HCD-phase 3 (see paragraph 3.4.2, page 72, i.e., simplicity, reduced pressure, avoidance of excessive navigation within a page or scene, and a preference for text-based interactions and quizzes). Consequently, two game prototype formats were further developed. In addition to the previous version, the game menu was also improved by prioritizing the category of machinery, equipment, PPE, and related items, followed by the game category (Figure 30a,b,c). Furthermore, a life-recovery system was implemented in order to further motivate players to engage with the game and to consult the textual content (Figure 30d).



a) b) c) d) e)

Figure 30. Example prototype interface adjusted and improved: a) and b) game menu, previous version c) game menu, new version, d) menu to recover lost lives and e) how to play games.

Instruments and procedures

During the usability test, participants were allowed to use the prototyped app freely. Each participant was tested individually on the same smartphone provided by the researcher, with the screen recorded to track their movements and interactions. To ensure that all sections were explored, each participant was asked to complete at least five main tasks: 1) simulate the processes of registration, login, and logout, 2) examine the personal page and explore the favorites saved topics, 3) explore at least one page from each designated section and, 4) explore the main navigation bar, 5) try both demo games. Observation was used to monitor task completion and record any issues or errors identified by participants in the interface and interaction flow. Each session lasted about 40 minutes. Through the Thinking Aloud method, participants verbalized their thoughts and feelings and expressed any questions or concerns while interacting with the system.

At the end of usability test, each participant was administered a questionnaire (see Appendix D.1): the first part included item from PSSUQ (Post-Study System Usability Questionnaire) (Lewis, 1995, 2002) (see paragraph 3.5.1, instrument and procedure)[7]. In the second section of the questionnaire, participants had to rate their level of satisfaction toward (from 1=very satisfied to 7=not-at-all-satisfied, according to the same scale used for PSSUQ) graphical interface (GU, 5 items), playability component (PC, 8 items) and learning content (LC, 5 items), learning opportunities (LO, 2 items) and perceived intention to use (INT, 3 items) (Khaleel et al., 2018; Zaibon, 2015). Using the same evaluation scale, they were asked to rate how much they liked the two prototyped games (2 items). A third section asked for information regarding their socio-demographic characteristics (i.e., age, gender, profession).

When each participant filled out the questionnaire, the researcher verbally asked if they had any additional suggestions for improving the prototype (see Appendix C.2). Furthermore, they had to explain the game they preferred the most and the least and motivate their responses.

Data analysis

Qualitative data. Audio-recordings were transcribed, and notes from observations were coded and analyzed (Bengtsson, 2016). Four main themes were identified (Table 16): 1) training content, 2) the overall graphical user interface, 3) navigation, and 4)

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[7] *As already mentioned in paragraph 3.4.1, the PSSUQ was selected for its standardized format, its easy administration, replicability, interpretation of results, and capability to capture users' satisfaction. It is a 16-item standardized questionnaire, using a 7-point Likert scale (+NA option) (from 1=strongly agree to 7=strongly disagree). Thus, the lower the score, the better the performance and satisfaction are. It consists of an overall scale and three subscales, namely System Usefulness (SysUse), Information Quality (InfoQual) and Interface Quality (InterQual): the overall result is calculated by the average scores of questions 1-16, the SysUse score is calculated by the average scores of questions 1-6, the InfoQual score is calculated by the average scores of questions 7-12, the InterQual score is calculated by the average scores of questions 13-15.*

game features. The latter were further subdivided into two subcategories, one corresponding to each game developed.

Table 16. Recurring themes.

Theme	Sub-themes	Description
Training content	• Topics • Quality of content	Clarity and accuracy, of the information presented in supporting understanding and learning and game preferences to convey safety training knowledge.
Overall GUI	• Favorite page and icons	Including the adoption of proper icons and navigation bars.
Transition	• Flow	Including the flow.
Game elements	• Graphical elements • Clarity • Feedback	Different for both game type

Quantitative data. For quantitative data collected through the questionnaire, descriptive statistics were computed for all items. PSSUQ had Cronbach's alpha coefficients in line with earlier research, as they were 0.895, 0.856, 0.858, and 0.676 for the Overall scale, SysUse, InfoQual, and InterQual subscales, respectively. Considering that the criterion for acceptable reliability is an alpha coefficient greater than 0.60, the responses to the items were considered reliable and consistent (Heriadi & Alam, 2024; Lewis, 2018). Similarly, Cronbach's alpha was calculated for items on graphical interface, playability component, learning content, learning opportunities and perceived intention to use. Then, a mean score was calculated. Considering the limited number of participants, non-parametric correlation analysis between selected variables and demographic information (age and years of working experience) was used to determine the strength and direction of possible associations between the variables of interest.

3.6.2. Results

Participants

A total of 15 male workers agreed to be involved. Their mean age was 30.07 years (SD = 11.89, range: 17 - 51 years) and ethe mean working experience of 15.3 years (SD = 11.68, range: 1 - 37 years). Regarding their job role, 61.54% were assemblers/maintainers, and 38.46% specialized as machine operators. Regarding education, 38.46% of them had completed junior high school, and 61.54% had a high school diploma.

Qualitative data

Through the Thinking Aloud technique, participants reported several comments. The majority of comments were positive, while some other detected areas for improvements. Comments are reported in Table 17.

Table 17. Participants' comments.

Main theme: Training content	
Sub-themes	**Comments**
Topic	*"For the forklift, on its first page, add the importance of the horn. Because many people take this for granted. Imagine you step out of here and you hear the horn approaching. It's not a trivial aspect to consider"* [man, 37 years, machine operator], *"For the forklift, it says to pay attention to the seat belt and to the height of the forks while driving"* [man, 22 years, machine operator], *"Create a section on working at height, because I also did the refresher course last week and it would be useful."* [man, 37 years, maintainer], *"In the working-at-height section, include the use of elevated platform and harnesses"* [man, 37 years, maintainer], *"Fire risks should be included—specifically the procedures to avoid starting a fire. So, procedures on what to do in the event of a fire. And, also, how to prevent them: what to watch out for in a workshop to avoid something catching fire—wooden pieces, for example…"* [man, 27 years, maintainer].

Continue…

Quality of content	*"The PPE section is well done because it gives you the symbols and icon of corresponding signs and CE and it goes in order and is well done"* [man, 21 years, maintainer], *"As for the length of the texts, if you have to scroll through everything and read everything in the category, that's fine, but it takes you longer. Instead, if you want to be quicker, you go to the 'games, lessons, and tests' section here. I like that idea"* [man, 21 years, maintainer], *"from what I can see so far, it's well done and I like it"* [man, 42 years, maintainer] and [man, 23 years, maintainer].
Main theme: Overall GUI	
Sub-themes	**Comments**
Favorite page and icons	*"It's nice that I can save my favorite content"* [man, 17 years, maintainer], *"High, medium, and low risk… what does that mean? Ah, okay, it's the risk level… because at first I didn't understand why there was a yellow bar to look at for the risk level"* [man, 21 years, maintainer] and [man, 17 years, maintainer].
Main theme: Transition	
Sub-themes	**Comments**
Flow	*The text size is fine, there are images, and I'd say the navigation arrows at the bottom of each section should be a bit bigger. Aside from that, I'd say it works quite well"* [man, 22 years, machine operator], *"Maybe these could be made a little bigger as well"* [referring to the text in the breadcrumb at the top of the screen] [man, 22 years, machine operator].
Main theme: Game elements	
Sub-themes	**Comments**
Graphical elements	***Find the error game*** *"The label with the risk description is readable, but it might be positioned too low. If it were closer to where I point or click, it would stand out more"* [man, 23 years, maintainer], *Ah, so I have to find all of them? Ah, okay, so these are the numbers of hazards to find. I hadn't understood that"* [man, 21 years, maintainer], *"But there's text underneath—I wasn't reading it."* [man, 22 years, machine operator]. ***Quiz game*** *"Convenient, but the way I am, it's too many things… I mean, once I give the answer without using the 'next' text, it could go straight to the next question"* [man, 23 years, maintainer] *"And what are these hearts here? The mistakes? So, I have three lives now?* [man, 21 years, maintainer].

Continue…

Clarity	***Find the error game*** *Ah, so I have to find all of them? Ah, okay, so these are the numbers of hazards to find. I hadn't understood that"* [man, 21 years, maintainer], *"What am I supposed to do? Do I have to press it?* [man, 22 years, machine operator] and [man, 21 years, maintainer], *"Ah, so the score of 6 is low because before I wasn't looking for all the errors"* [man, 21 years, maintainer]. ***Quiz game*** *"When you make a mistake, I would add a short comment underneath that explains the correct one, so it's clearer"* [man, 17 years, maintainer].
Feedback	***Find the error game*** *"And in some cases, I don't know where to click, even if the area is correct"* [man, 22 years, machine operator], *"Some images should be improved to avoid ambiguity"* [man, 22 years, machine operator]. ***Quiz game*** *"Okay, earlier I made a mistake. To correct that mistake, I should start over from scratch. Can I review the answers that were given?"* [man, 21 years, maintainer], *"If it shows it in green, that means it's correct. Ah, thank goodness"* [man, 51 years, maintainer].

During the interview, most participants clearly expressed a slight preference for the "quiz game" while still acknowledging the usefulness of the system's content and the higher level of engagement compared to a traditional manual.

> *"…but I prefer the questions. Maybe the images are more dynamic, and they're also useful for understanding some things better. For example, when identifying a hazard, the image in the question is more useful"* [man, 21 years, maintainer], *"I mean, the error wasn't hard to find. Because you could understand what it was, but the exact point* [to make the exclamation mark appear] *was hard. In my opinion, a multiple-choice question is better"* [man, 27 years, maintainer], *"I like it [quiz game] because it's more intuitive"* [man, 37 years, maintainer], *"I liked the game system, answering the questions like that… and I also have slides where I can go look for some topics to answer the questions correctly"* [man, 42 years, maintainer], *"It's a good system, because it teaches you something. But I liked the one where I made fewer mistakes more* [the quiz game]. *But in the one*

> *where I made those three mistakes, I probably wasn't prepared enough"* [man, 51 years, maintainer], *"I liked the quiz game more because it feels like I'm doing more realistic things, and I found it better than the image-based one"* and "[find the error game] *is a bit more like a game and, in my opinion, it can be something a bit more engaging compared to the other one* [quiz game]. *The only thing I would change is the text that appears at the bottom label when it explains the hazard or the risk"* [man, 23 years, maintainer].

In addition, one worker expressed his preference for the 'find the error' game:

> *"In my opinion it's just nicer. It engages you a bit more. And then there are figures, and visually it's nicer. It's also quite intuitive. Instead, in the one with the questions I would make the 'next question' button bigger or more centered, or more visible. But it's fine as it is too, it's okay. As for the content, it's really packed with content, but it's never too much. When it comes to safety, it's better to have plenty"* [man, 17 years, maintainer].

With regard to the observations, they confirmed participants 'comments. Focusing on the gamification component, the 'find the error' game required greater concentration, and when it was first launched, participants took a few seconds to comprehend the game's goal. Likewise, it was not immediately clear that each screen contained more than one risk or error; as a result, some workers tended to identify only a single risk before moving on to the next screen.,. Participants' concentration was also reflected by their responses regarding their preference between the two proposed games. As for the duration of the games, each level took participants nearly 5–6 minutes to complete for the quiz and 3–4 minutes for the find-the-error game, demonstrating their focus on finishing the level correctly and showing commitment to avoiding mistakes or asking questions in the case of an incorrect answer.

Navigation experience within the prototype was also noteworthy. Despite the presence of both a bottom navigation bar and a hamburger menu, almost none of the participants used them to navigate specific categories (they usually came back to the home page and then selected a new category). However, it should be noted that for consulting the personal page and the search function, the bottom navbar was the most used, as it provided a direct link to the page of interest. Everyone used the breadcrumb and the 'back' arrow present there to freely navigate backward through the pages (even more than one page). This behavior can be explained considering the comment of one participant: *"I use the arrow because I'm used to swiping to go back"* [man, 23 years, maintainer].

Quantitative data

PSSUQ. Descriptive statistics for the investigated items for both Model-1 and Model-2 are reported in Table 18. Cronbach's alpha coefficients were greater than 0.60 (Heriadi & Alam, 2024; Lewis, 2018) as they were 0.804, 0.720, 0.721, and 0.817 for the Overall scale, SysUse, InfoQual, and InterQual subscales, respectively.

Descriptive statistics related to the second part of the questionnaire are reported in Table 19. Cronbach's alpha coefficients were 0.739 for GU, 0.741 for PL, 0.744 for LC, .785 for LO and 0.880 for INT.

Table 18. PSSUQ scores, overall scores.

ID	Questions	Mean (SD)
1	Overall, I am satisfied with how easy it is to use this system	1.69 (.63)
2	It was simple to use this system	1.65 (.75)
3	I was able to complete the tasks and scenarios quickly using this system	2.46 (1.12)
4	I felt comfortable using this system	1.77 (.72)
5	It was easy to learn to use this system	1.38 (.50)
6	I believe I could become productive quickly using this system	2.15 (1.14)
7	The system gave error messages that clearly told me how to fix problems	3.09 (1.37)
8	Whenever I made a mistake using the system, I could recover easily and quickly	2.46 (1.50)

Continue…

9	The information (such as online help, on-screen messages, and other documentation) provided with this system was clear	2.31 (1.54)
10	It was easy to find the information I needed	1.61 (.96)
11	The information was effective in helping me complete the tasks and scenarios	2..00 (1.00)
12	The organization of information on the system screens was clear	2..00 (1.41)
13	The interface of this system was pleasant	1.92 (1.38)
14	I liked using the interface of this system	1.77 (1.16)
15	This system has all the functions and capabilities I expect it to have	2.38 (1.04)
16	Overall, I am satisfied with this system	2.20 (.78)
scale		
SysUse	Average of question items 1-6	1.85 (.38)
InfoQual	Average of question items 7-12	2.24 (.50)
InterQual	Average of question items 13-15	2.02 (.32)
Overall	Average of question items 1-16	2.05 (.42)

Note: according to the scale used in PSSUQ, the lower the score the better the performance and satisfaction are.

Table 19. Mean and standard deviation related to playability and learning content.

ID	Questions	Mean (SD)
GU	The audio-visual presentation supports the game system	2.66 (1.07)
	Layout is efficient and visually appealing	2.07 (.86)
	Navigation is consistent, logical, and minimalist	1.77 (.92)
	The game provides feedback on player actions	2.08 (.79)
	Guidance and instructions are appropriate	1.84 (.80)
PL	The games provide clear objectives	1.46 (.87)
	I can see my progress (or failures) and compare results	2.00 (.91)
	Challenges and strategy are balanced	2.53 (1.26)
	I felt comfortable using these games	1.61 (.87)
	The first gaming experience was encouraging	2.00 (1.00)
	There are no repetitive and boring tasks	1.84 (1.40)
	The length of each end-game/quiz session is clearly indicated	1.72 (.64)
	There is the option to restart the game	1.72 (.64)
LC	The content can be easily learned	1.92 (1.03)
	It provides good educational content	1.46 (.66)
	Providing content in the form of tests and games is interesting	1.61 (.87)
	It provides many examples and exercises	1.58 (.79)
	The content is understandable	2.07 (.86)
LO	This system also allows me to test my current knowledge	1.38 (.65)
	It gives me the opportunity to think critically	1.61 (.77)
INT	I would be willing to use this system in the future	1.75 (.96)
	I would probably recommend it to others	1.50 (.79)
	Scoring systems increase my engagement	1.61 (.65)

Note: according to the scale used in PSSUQ, the lower the score the better the performance and satisfaction are.

Considering questions on how much they liked each game, the "find the error" game reported a mean score of 3.07 (SD = 1.60), while the "quiz" game reported a mean score 2.23 (SD = 1.01). In conclusion, Table 20 shows that there was a negative correlation between age and graphical user interface (GU). Furthermore, INT positively correlated with InterQual, overall, GU, PL, LC and LO variables. No differences for game preferences were found for age and worker' experience.

Table 20. Correlation analysis.

	1-age	2-EXP	3-error game	4-quiz game	5- SysUse	6- InfoQual	7- InterQual	8-overall	9-GU	10-PL	11-LC	12-LO	13-INT
1	1	.953 ***	-.152	.140	.175	-.193	-.241	-.147	-.654 *	-.202	-.123	-.340	-.459
2		1	-.046	.174	.185	-.062	-.292	-.064	-.508	-.129	-.047	-.322	-.502
3			1	-.418	.075	.507	.391	.348	.207	.274	.281	.183	.146
4				1	.390	.280	-.029	.247	.004	.212	.317	.053	-.157
5					1	.598 *	.532	.823 **	.346	.461	.700 **	.486	.299
6						1	.497	.832 ***	.540	.566 *	.810 **	.625 *	.414
7							1	.736 **	.550	.566 *	.697 **	.798 **	.672 *
8								1	.694 **	.637 *	.951 ***	.801 **	.601 *
9									1	.515	.651 *	.756 **	.666 *
10										1	.521	.748 **	.590 **
11											1	.789 **	.605 *
12												1	.889 ***
13													1

Note: * $p < .05$, ** $p < .01$, *** $p < .000$.

CHAPTER 4 – Discussion

This chapter provides a critical discussion of the results presented in the previous chapters, with the aim of interpreting the findings in relation to the research objectives and the HCD approach adopted in developing the DigiSafeMan tool. For each HCD phase the discussion critically examines the findings in relation to the existing literature, highlighting where the findings are consistent with, or differ from the previous studies. The analysis is also oriented toward deriving design-oriented insights, illustrating how the empirical evidence supports the design choices made throughout the project and how the identified patterns reflect workers' needs, training practices, and interactions with digital safety tools. Finally, practical implications, limitations, and opportunities for further development are presented.

4.1. Phase 3 – Specify the user requirements

In phase 3 of the present research, manufacturing workers' familiarity and interest in using digital devices for safety training, as well as their perceived risks and working conditions were investigated. These findings should be interpreted in light of the specific industrial context examined. In particular, the study was conducted in a metal and metal-mechanical manufacturing environment, where workforce composition is usually characterized by a limited female participation (ILOSTAT, 2023), particularly in operational roles. This helps explain the absence of women in the present research.

4.1.1. Use and familiarity with digital devices

Consistent with previous studies (Andone et al., 2016; Meyer, 2008), the time spent using digital devices over the day negatively correlated with age. This is in line with previous research showing that younger individuals, who can be considered digital natives (Prensky, 2001), tend to report more positive perceptions of smartphone use, particularly regarding its contribution to flexibility and access to diversified opportunities (Kalmus et al., 2018), although they also recognize the potential downsides and problems associated with smartphone use (Kalmus et al., 2018). This more positive perception may be partly explained considering that they have grown up in an environment in which digital technologies are pervasive and normalized, fostering higher levels of confidence, familiarity and perceived usefulness in relation to smartphone use. When considering the point of view of older users, consistent with Van Deursen et al. (2015), older adults tend to spend less time on smartphones. They may be less likely to develop addictive smartphone behaviors, highlighting a potential challenge when designing a digital safety training tool for older workers (Angelini, 2023). Based on this, the design of such tools should ensure low entry barriers, progressive onboarding (i.e., sequence of actions that a user takes gradually to become familiar with your product using interactive features and a hands-on approach), and alternative access modes (e.g., desktop or supervised use), in order to avoid excluding workers with lower levels of mobile technology use.

In contrast with previous studies (Winn & Heeter, 2009), the result of the present research reported neither a significant correlation between age and time spent playing on digital devices nor between age and interest in using them. Moreover, the level of interest in using digital tools for safety training, yielded a high score ($M = 3.07$ on a 4-point scale), consistent with Dodoo et al. (2024, 2025). This suggests that game-based activities among our participants may not be primarily driven by age-related factors, but rather by other variables, such as motivational, contextual and usability aspects. This evidence highlights the challenge that game designers need to face to develop highly engaging and easy-to-use interfaces which can be acceptable across the different age groups.

Then, a positive attitude toward new digital training solutions was found as expected, considering the correlation between INT and BEN and the correlation between POS and BEN. Indeed, according to Davis (1989), the more a system is perceived as able to enhance job performance, the more users are interested in using it. While the correlation POS-BEN is also consistent with the findings of Fuchs (2022), which state that the greater engagement, the stronger the perception that mobile applications help achieve workplace learning goals more quickly. Likewise, in Irani (2000) study, the authors observed that when workers perceive a device as engaging and stimulating for learning, they are more likely to recognize its benefits and its educational and training role. By contrast, if digital tools are perceived merely as entertainment tools, or if the experience is limited or hindered by poor usability or low-quality resources, users may fail to fully exploit their potential (Irani, 2000).

Overall, these correlations underlined the central role played by BEN perception in fostering acceptance and adoption (INT). From a practical point of view, the adoption of digital training solutions may be supported by actions such as providing preliminary training sessions that enable users to perceive the system advantages, ensuring accessibility across different contexts and devices, and integrating feedback and progress-tracking features that make the perceived benefits more salient. These strategies may contribute to fostering the acceptance and effective integration of digital training solutions into everyday training practices.

Finally, the correlation between game and quiz (as a type of training support) should be highlighted, as a similar result was also reported by participants during the interview. Indeed, quizzes were considered the most suitable and the preferred game solution. This preference may be associated with the fact that quizzes are popular, are considered easy to use and allow users to check their comprehension and obtain immediate feedback without requiring high levels of cognitive or technological effort (Zali et al., 2019). This observed preference among workers helps to explain the positive reception of the game-based components subsequently implemented in the training prototype. From a practical perspective, designing quiz game components that are simple, accessible, and feedback-oriented may facilitate acceptance and support a smoother integration of game-based tools into training activities. Moreover, the findings of this study suggests that the game applications should be designed to be straightforward and intuitive, thus avoiding complex game mechanics that may potentially discourage users who do not engage with games on a regular basis.

Taken together, these results underscore the importance of assessing both opportunities and limitations to identify the conditions under which such tools are likely to be accepted and effectively integrated into everyday safety practices.

4.1.2. Causes associated to accidents and injuries

The results of this section highlighted that participants did not exhibit a high-risk perception in their job (p1, mean score < 2.5). However, workshop-based workers significantly perceived their work as more hazardous compared to technicians. This result is not surprising because workshop-based workers are more frequently exposed to highly risky situations (Pérez Floriano & Pacheco, 2018).

In addition, in contrast with previous research (Torres et al., 2021), manufacturing workers did not perceive their work as particularly tiring (p2, considering the mean score < 2.5). As explained by Lu (2005), workers usually described their jobs as tiring, particularly in the case of routine tasks or when tasks are performed under close supervisory control, or when the regular production of new or higher-quality outputs is required. The fatigue among manufacturing workers is widely recognized in the literature as a significant concern (Emmanouilidis et al., 2024; Lu et al., 2017) as shift work, fluctuating work rhythms and changing environmental temperature conditions may contribute to drowsiness and performance decline, leading to slower reaction time, reduced executive functions and decreased level of attention (Elliott et al., 2022; Nordlöf et al., 2015; Zhang, Murphy et al., 2015).

To reduce fatigue and tiredness, the recognition of high performance through rewards (Lu, 2005), along with the provision of planned and timed breaks throughout the workday, helps workers to maintain performance and reduce their fatigue (Tucker, 2003). Thus, a possible explanation for the lower fatigue perception reported by the participants in the present research may lie in the measures introduced in the company, such as more structured break scheduling. This interpretation highlights the importance of careful work design through an organizational ergonomics perspective, where elements such as break planning, workload distribution, shift organization, and performance-recognition practices can play a crucial role in reducing fatigue and supporting workers' well-being, attention, and safe performance. Furthermore, previous studies suggest that workers are aware of the presence of tiring and strenuous conditions and therefore recognize the need to adopt strategies to maintain awareness and task focus under these circumstances (Sneddon et al., 2006; Zadehgholam et al., 2015). This awareness may explain the high mean score reported for the item related to the importance of maintaining focus and concentration and the need to pay attention throughout operational tasks (p3) (Wachter & Yorio, 2014). Such score was supported by participants' answers from the interview, as some of them clearly explained that external (and environmental) conditions can affect their work.

The lower score reported for the perceived level of work repetitiveness (p4), is also surprising since the manufacturing sector is often associated with cyclic production processes involving standardized and repetitive tasks, as handling loads at varying frequencies (Bosch et al., 2011; Botti et al., 2021; Gattamelata & Fargnoli, 2022). However, this characterization does not necessarily apply uniformly across all manufacturing contexts. In particular, while repetitive manufacturing is typically based on assembly lines, high-volume and standardized production processes (such as automobiles), other forms of production, such as discrete or customized manufacturing, are characterized by greater flexibility, shorter production runs, and variability in task execution (Safety Culture, 2025). In the specific case examined in the present study, for example, the reported perceptions suggest that workers may experience a certain degree of variability in their tasks and work organization. This variability is related to the specific production context, where activities are not perceived as strictly repetitive, due to differences in operations, task sequences, or work rhythms and increase in breaks (Tucker, 2003).

Clear task allocation is essential for optimizing work efficiency and minimizing the risk of accidents (p5). In a manufacturing context, having different types of tasks implies that the skills needed to complete them must be also different (Torres et al., 2023). This issue is particularly evident when an insufficient number of personnel is assigned to specific tasks/activities, leading to an increased risk of accidents. Previous studies have indicated that workers who have experienced understaffing in shift teams were compelled to assume greater risks due to the additional workload while production expectations remain unchanged (Nordlöf et al., 2015).

When considering communication in the manufacturing workplace, it is acknowledged that an effective communication process is fundamental to ensure the smooth flow of operations (Puvanasvaran et al., 2009). Previous studies have emphasized the need for frequent, honest, and open communication between employers and employees (Liu et al., 2015; Pun et al., 2001), while few studies have considered communication between workers (Mazzei, 2014). The low score reported in the present study (p13) can be explained by considering the results from Nugraha and colleagues (2020), which acknowledged that machine operators are rarely engaged with their colleagues as they are primarily focused on ensuring the proper and safe functioning of the machines, limiting their interaction with other operators to avoid potential oversight and injuries. Thus, the oral communication between colleagues (or with the employer or team leader) may occur only when necessary (Nugraha et al., 2020). In contrast, Nordlöf et al. (2015) reported that neglecting communication with colleagues in order to maintain workflow continuity may increase the risk of injury. However, the interviewed participants in the present research stated that colleagues often remind each other (particularly to younger or less experienced workers) what safety measures should be adopted. This behavior is part of the so-called safety citizenship behaviors in the workplace (Hofmann et al., 2003) and it reflects the shared belief that it is essential to recall and keep in mind promptly the proper safety procedures, to prevent injuries and issues that could compromise both the health and safety of others and the overall work rhythm. In addition, peer interaction, when incorporated into a training session, can be useful for enhancing socialization among co-workers during breaks and increasing social well-being in the workplace. Training sessions and breaks may serve as valuable opportunities to encourage discussions and knowledge-sharing aimed at promoting appropriate and safe behaviors, which tend to happen more naturally in face-to-face settings (Soudière, 2023). Regarding the perceived risks associated with the use of specific machinery in the workplace, the findings indicate that participants are aware of the high levels of risk to which they are exposed during working operations. Indeed, as also mentioned by interviewed workers, although several safety measures are implemented, including protective gear, laser beams, and safety cabs, some hazards persist (Trbojevi´c et al., 2021) related to: clothing entanglement in moving parts, the absence or improper use of safety guards on drills, and exposure to flying chips and waste from lathes (Kulinska & Dendera-Gruszka, 2018).

In this research, no significant differences were found in perceived WC and risks between participants who had previously experienced an accident and those who had not. This result contributes to the current debate on this topic (Gonçalves et al., 2008; Kouabenan, 2009; Ngueutsa & Kouabenan, 2017; Payani & Law, 2020) and it is consistent with the results of a study conducted by Jafari et al (2019) among foundry workers. This evidence also suggests that when developing new safety training tools, workers' previous history of accidents may not be a critical factor to consider to improve workers' safety behaviors.

From a design perspective, this phase suggests that a new digital safety training solution should be developed with explicit attention to the operational conditions in which workers perform their activities. Rather than focusing exclusively on the transmission of safety procedures, training tools should support workers in recognizing fatigue-inducing conditions and in monitoring potential declines in attention or situational awareness.

4.2. Phase 4 – Produce the design solutions and pre-test with design experts to meet user requirements

This phase examined the usability and UX of a high-fidelity interactive prototype of the designed mobile safety training tool through the involvement of a group of design experts. By comparing two interface models using both qualitative and quantitative methods, key factors that may influence user satisfaction were identified. The phase emphasized the role of design students in identifying usability issues and providing targeted design feedback, confirming the value of involving near-expert users during the prototyping phase (Kok et al., 2012; Ponciano et al., 2021). Overall, participants showed a consistent preference for Model-1, featuring vertical scrolling, a traditional grid layout, and a hamburger menu, rather than Model-2, which employed horizontal scrolling and a bottom bar menu.

In the following subsections, the themes that emerged from the comparison between the two interface models tested will be discussed:

1) Regarding scrolling and pagination, current literature shows that users interact with digital interfaces in various ways, including swiping, tapping, and scrolling horizontally or vertically. It also highlights that navigation bars typically contain a range of buttons and other interactive elements. Based on this, the two models tested have incorporated these interaction techniques and features differently. Considering the scrolling and swiping directions, both vertical and horizontal

present advantages and limitations (Dou & Sundar, 2016). For instance, although horizontal scrolling is commonly used especially when vertical space is limited (Harvey et al., 2019), it has often been criticized and viewed as less effective than vertical scrolling (Nielsen, 2005; Nilsson, 2009). Whereas, vertical scrolling is perceived as more cognitively demanding and may negatively affect text comprehension and learning (Viksten & Öberg, 2024). However, Braganza et al. (2009) noticed that users are generally more comfortable with vertical scrolling due to familiarity and its widespread use in standard web-browsing layouts. Findings of the present research are consistent with these previous studies: participants still preferred vertical scrolling over horizontal scrolling due to familiarity and ease of locating information within a linear flow. This outcome may also be explained by considering that each page was designed with a limited and appropriate length, rather than an infinite vertical scrolling as commonly found in social media platforms (Jovicic, 2021).

2) Regarding the navigation bar, results align with Garczarek-Bąk's (2016) and Nesler's (2016) findings, who argued that the hamburger menu, with its hidden navigation, is more popular and recognizable and it was perceived as helpful in reducing interface complexity by providing additional space for design elements. This popularity may also be explained by the shared characteristics of web and mobile design, both of which involve the arrangement of semantically related elements (e.g., text, images, and buttons) within a 2D space (Desideria & Bandung, 2020). Furthermore, participants in the present study did not perceive the hamburger icon as an element that adds steps to access specific content. The result is instead in contrast with Zieher and Probst (2024), according to whom most users struggle to reach the upper edge of the display when holding and operating the device with the same hand, mainly due to the size of contemporary smartphones.

3) Regarding graphical elements (icons, colors, and text), participants' comments were mainly focused on icons and colors. Such comments were consistent with suggestions provided by Herlina (2024), who recommended the use of accompanying text to make icons more visually appealing and easier to understand and touchable. Indeed, PPE buttons designed in Model 1 were

perceived as clickable, due to the combination of several elements, i.e., text, icon, and surround shape. Despite the common assumption that navigation icons are self-explanatory, current best practices recommend including text labels, using carefully selected words, as they reduce ambiguity and increase the area selection (Laubheimer, 2021). The favorite button, represented by a star or a heart, did not elicit any notable comments. This may be due to the widespread use of these symbols in previous studies and existing applications (Bucher & Helmond, 2018; Paysan-Lafosse et al., 2023), which makes their function easily recognizable.

Regarding text, its size was considered appropriate; however, as highlighted in previous literature, particular attention should be paid to the use of boldface, since bold text attracts readers' attention (Macaya & Perea, 2014) and increases the efficiency of word recognition (Paysan-Lafosse et al., 2022). Regarding the colors used in both versions, the lack of specific comments on color quality suggests they were appreciated. However, additional comments indicated that, despite a general preference for the light mode, perceived as tidier and more balanced in terms of color, users nonetheless valued the option to switch between light and dark modes, suggesting that personalization remains an important design requirement.

Participants provided several comments regarding the buttons in the game section. The main controls considered were those associated with "exit" and "restart," as well as functions such as "Save/Load," which can alter the flow or progress of a game if activated unintentionally or used incorrectly. Such interactive elements were not perceived as ambiguous (Palmquist et al., 2024). However, given that colors like red and green were used to highlight critical interactions (e.g., incorrect and correct responses, respectively), participants suggested emphasizing these two colors also to reinforce the options for exiting the game (i.e., highlighting "no" in red and "yes" in green). An optimal arrangement of interactive interface elements is not only a matter of aesthetics but also supports anticipating users' actions and facilitates a seamless, error-free gaming experience. Overall, the button size used throughout the prototype was perceived as adequate.

4) Regarding game preferences, the sample allowed for an examination of potential gender-related differences in user experience. No gender differences emerged between the two models tested and although the literature provides limited evidence on this issue (Weichbroth, 2022), the present result is consistent with previous studies (Kortum & Sorber, 2015; Sonderegger & Sauer, 2010; Weichbroth, 2022). Conversely, it is in contrast with only a few other studies that reported gender differences (Imhof et al., 2007; Lin & Chen, 2013), with men demonstrating superior performance on specific tasks (i.e., recreate and edit a set of slides within a time limit, Imhof et al., 2007).

Although the difference was not statistically significant, female participants reported better outcomes in both evaluating the playability components and the learning content. This result aligns with findings from Koivisto and Hamari (2014) and Piquer Martínez et al. (2024), suggesting that women tend to report higher engagement and satisfaction and even better results in knowledge acquisition (Tsai et al., 2017) with gamified learning studies compared to males.

Similarly, an analysis of the results for each game revealed outcomes that contrast with those reported in the leisure industry and in previous studies. For instance, the quiz and the puzzle game were generally labeled as games preferred by women (Procci et al., 2024; Toda et al., 2019), especially considering the opportunity to take time to reflect on the correct answers (see comments related to puzzles and quizzes). On the other hand, consistent with the studies by Spieler and Slany (2018) and Tsai (2017), quizzes for learning experiences are more popular in both genders. Regarding the narrative game, although no significant difference emerged, in contrast to previous evidence (Gerber-Barron & Si, 2013), it has been slightly more preferred by men. This result should not be surprising. Indeed, in this context, the narrative game was not designed as an RPG game or visual novel (genres traditionally preferred by females), but employed mechanics more closely aligned with strategy games, which are usually more appealing to male players. Finally, the last gamified solution preferred by females was the one based on a 2D map. According to the literature, men tend to have an advantage over women in spatial cognition and interacting in 3D virtual spaces (Procci et al., 2024), while women perform better using 2D interfaces (Lin & Chen, 2013; Procci et al., 2024). This can help explain the significant difference observed between the two groups.

Based on these considerations, the design of gamified components presents greater challenges than the development of games for entertainment or other game contexts, such as serious games. This is because the context in which gamification is applied influences users' perception, going beyond the conventional gender differences usually observed in other contexts. Thus, some recommendations should be considered for future development:

1) With regard to interaction preferences and layout design, future designs should balance user familiarity with layout, ensuring that new interaction models (e.g., pagination, horizontal scrolling) do not disrupt task flow or learning effectiveness.
2) With regard to navigation and flow, ensuring consistent and intuitive visual cues to support user navigation, particularly when searching for specific content, returning to previously visited pages, or resuming partially completed tasks. Features such as breadcrumb trails, persistent navigation buttons, and "resume where you left off" prompts can greatly enhance task continuity within complex applications.
3) Regarding visual affordances and icon clarity, icons intended as interactive elements should be clearly distinguishable through size, color contrast, labels, and shape to strengthen their affordance.
4) Concerning content structure and visual hierarchy, structuring written content with clear hierarchies, consistent formatting, and visual segmentation (e.g., bullet points, headings, bolding key terms) enhances readability and comprehension.
5) With regard to gamification elements and UI feedback, game interactions should prioritize clarity and error prevention by applying strong feedback cues (e.g., color coding, motion, sound).

6) Regarding gamification genre, components such as quizzes and puzzles can be equally appreciated by both genders, particularly because they provide time for reflection on the correct answers, as well as quick testing.

Some limitations should be acknowledged, for this study. First, the evaluation of the gamified components focused primarily on interface design aspects rather than on assessing the educational outcomes. Future research will explore these dimensions in greater depth to better understand the role of gamification in safety training. Second, in future studies, integration of eye-tracking techniques could provide more defined insights into users' attention patterns and help identify which interface elements attract or fail to capture focus on compact mobile screens.

4.3. Phase 5 – Evaluate the design against the requirements

Phase 5 represented the final validation stage of the high-fidelity prototype, allowing the evaluation of its usability, clarity, and overall user experience with real end users. Following the HCD approach adopted throughout this project, this phase made it possible to verify whether the refinements introduced after Phase 4 effectively supported users' needs and interaction patterns during safety-related learning activities. Overall, the results of this phase supported the applicability of the design changes made after the preliminary usability assessment with design students.

It is worth noting that the evaluation conducted with real end users provided complementary insights that had not emerged during the testing with design students, thereby enriching the understanding of how the prototype was experienced. Whereas the design students primarily oriented their feedback toward graphical coherence, interaction flow, and UI layout, workers also provided helpful comments on UX/UI, but they placed greater emphasis on aspects directly related to the clarity, readability, and practical relevance of the training content. This difference reflects the different roles and perspectives of the two groups: while design students acted as near-expert evaluators of interface structure, workers interacted with the system from the standpoint of situated practice and operational experience.

Several interface refinements introduced after Phase 4, including the increased use of bold text, differentiated color coding, and enhanced visual feedback to indicate changes in system states, did not receive explicit comments from the workers (Macaya & Perea, 2014; Paysan-Lafosse et al., 2022). This pattern suggests that users perceived these elements as intuitive and experienced them as seamlessly integrated into the interaction flow. By contrast, workers' feedback was more frequently focused on text legibility and font size, especially by older participants, who experienced greater visual effort when reading longer textual sections. This result is consistent with current literature and design guidelines, which indicate that, despite the existence of a minimum font size, older users tend to prefer adjustable or larger text when interacting with digital devices and smartphones, due to age-related declines in visual acuity and reading comfort (Bernard et al., 2001; Hou et al., 2022; Pak & McLaughlin, 2010). This finding has implications for the development of digital safety-training tools, indicating that typographic flexibility, support for visual comfort, and attention to age-related perceptual decline should be treated as core design requirements. Accordingly, a key design should provide a customizable and user-controlled text layout that can be adapted to individual visual needs and the diverse age profiles of the workforce.

The decision to retain both navigation bar systems (i.e., bottom navbar and hamburger menu) simultaneously was intentionally unconventional, yet it enabled a more nuanced observation of users' behavioral strategies during navigation. Consistent with the behavior observed in the tests conducted with design students, the bottom navbar was used less frequently than the upper navigation elements. However, and rather unexpectedly, workers did not rely on the hamburger menu, but they predominantly used the breadcrumb trail to move across sections of the digital system. This preference may be partially explained by the widespread presence of breadcrumb structures in widely used Google-based web environments, which may have strengthened users' familiarity with this navigation pattern (Lida et al., 2003; Rogers & Chaparro, 2003). Thus, users did not merely rely on the breadcrumb to recall their current location within the system (Rogers & Chaparro, 2003; Rosensweig & Kurose, 2009). This outcome confirms that the refinements successfully addressed structural and interaction-related issues identified during the earlier evaluation stage.

In addition, the selective refinement of two game formats (the quiz-based and the error-identification games) was consistent with the outcomes of earlier HCD phases, where participants had expressed a preference for straightforward interaction flows, limited navigation demands, and text-based tasks that encourage reflection rather than speed-based performance. In Phase 3, differences in workers' familiarity with digital tools suggest the need to minimize cognitive overload and ensure progressive, accessible interaction with digital learning content. This outcome confirms that the refinements successfully addressed structural and interaction-related issues identified during the earlier evaluation stage.

In addition, the selective refinement of two game formats (the quiz-based and the error-identification games) was consistent with the outcomes of earlier HCD phases, where participants had expressed a preference for straightforward interaction flows, limited navigation demands, and text-based tasks that encourage reflection rather than speed-based performance. In Phase 3, differences in workers' familiarity with digital tools suggest the need to minimize cognitive overload and ensure progressive, accessible interaction with digital learning content. This outcome confirms that the refinements successfully addressed structural and interaction-related issues identified during the earlier evaluation stage.

Furthermore, the adoption of a game quiz-based format is supported by the current literature. Indeed, a quiz game encourages learners to rapidly and continuously exercise and consolidate their knowledge, functioning as an effective learning mechanism supported by the instantaneous performance feedback provided during play. Such immediate feedback helps sustain concentration and reinforces learners' intrinsic motivation (Lameras et al., 2014).

By contrast, although the "find-the-error" game also received generally positive feedback and obtained a favorable mean evaluation score, it generated a greater degree of uncertainty than the quiz-based game, particularly in relation to the definition of the game goal and the interpretation of the initial game screen. Importantly, these misunderstandings did not concern the ability to recognize hazards as such, but rather emerged from the lack of clear and immediately interpretable system feedback. This pattern indicates that the rules and objectives were not sufficiently apparent within the first interaction, thereby requiring users to infer the intended meaning of the task instead of encountering it as an integral and explicit feature of the interaction design. Based on this, this type of game can be considered as more challenging and cognitively demanding, since successful performance relies on sustained attentional engagement and a higher degree of cognitive processing during the visual search activity (Wolfe & Horowitz, 2017).

The game developed in this project adopts a structure that is not widely represented in the existing literature (Salleh et al., 2024) yet it offers engagement with realistic work-related situations scenarios, such as identifying and responding to hazards, navigating challenging work and machine conditions, and making safe decisions while working, the game can offer players practical insights into workplace safety practices and enhance their understanding of safe behaviors in industrial context (Salleh et al., 2024).

Despite these minor critical issues, the overall outcome was considerably more satisfactory than in Phase 4, as several interface-related problems were successfully addressed through the introduction of explicit cues and enhanced visual support during interaction with the digital content, overcoming the lack of clear system-feedback. This interpretation is consistent with research in cognitive ergonomics, which indicates that when rules and task goals are not embedded within the interaction itself but remain implicit, users are required to rely on inference and guesswork, thereby increasing uncertainty and cognitive load (Norman, 2013). In safety-related learning environments, this condition is particularly critical, as ambiguous or insufficient feedback may unintentionally reinforce incorrect behavioral interpretations rather than challenging them (Norman, 2013; Kirschner et al., 2006). For instance, when users fail to identify a hazard within an image, or engage with the task in a superficial manner without receiving explicit corrective indications, they may continue to interpret an unsafe condition as acceptable, consolidating a misleading mental model instead of revising it. Therefore, a key practical implication is the need to design an error-identification game, which can provide immediate and explanatory feedback, explicitly articulating why a given element constitutes a risk and how it should be appropriately managed. Embedding such corrective information within the interaction helps prevent the tacit reinforcement of erroneous assumptions and supports the development of accurate and safety-aligned conceptual representations.

4.4. Conclusions

Overall, the study shows that the iterative, HCD process adopted for the development of the DigiSafeMan prototype contributed to improving the clarity, usability, and perceived relevance of the training experience. In detail, Phase 4 and Phase 5 highlighted the complementary value of involving both near-expert evaluators (design students) and real users (workers), who focused on different kinds of issues: the first were mainly focused on interface structure and interaction coherence, the latter more closely connected to content interpretation, task goals, and feedback clarity in safety-relevant situations. While the quiz-based game is more popular and was generally perceived as intuitive and purpose-driven, the "find-the-error" game emerged as more cognitively demanding and prone to ambiguity when rules and objectives were not sufficiently evident during the first interaction, reinforcing the importance of explicit system-mediated guidance in hazard-recognition tasks.

A key strength of this research lies in the adoption of a mixed methods approach, which enabled a comprehensive understanding of users' needs, perceptions, and interactions with digital solutions across the different phases of the HCD process. Quantitative data provided structured evidence on these aspects, while qualitative insights offered a deeper interpretation of the findings, capturing nuances that did not have emerged through numerical analysis alone. This iterative interplay between quantitative and qualitative strands strengthened the robustness of the conclusions and ensured that the development of DigiSafeMan was both evidence-based and contextually grounded.

Taken together, these findings suggest that effective digital safety-training tools should integrate usability, accessibility, and cognitive-ergonomic principles with contextualised and meaningful representations of work practices. At the same time, the study highlights the need for further research to assess the long-term educational and behavioral impact of such tools, and to explore how different game formats and design configurations can best support learning across diverse workers, tasks, and organizational contexts.

Based on this, some limitations should be acknowledged in the present research. The author acknowledges that the small number of participants limits the generalizability of the results. Even though the short-term implications of these results may be at the local level, the methods and the process of analysis may be replicated, involving larger samples in other geographical areas and also in other productive sectors, to provide insights for the development of innovative and engaging safety training that considers similarities and differences between the occupational contexts.

The second limitation is related to the gender issue, since all workers who took part in the study were men and we could not investigate any gender differences. Regarding this, it should be said that the sample involved was consistent with the current Italian context, where the sector under investigation remains male dominated (INAIL, 2023), as often occur in other industries like mining, quarrying, and construction (ILOSTAT, 2023). However, it should be mentioned that the gender composition in manufacturing is not homogeneous across all subsectors. For example, industries such as textiles, apparel and leather manufacturing and food manufacturing, employ a large proportion of women, in some cases representing a majority or an equal proportion of men workers (Fernández-Arias, 2022). By contrast, metal product manufacturing (more closely aligned with the context examined in this study) often reports the lowest participation of women in the workforce (Saulsbery, 2022). According to ILO statistics, only 11% of females work as metal processing plant operators, 7% work as metal working machine tool setters and operators and 4% as metal moulders and coremakers (ILOSTAT, 2023). Considering this framework, future research aiming to extend the present approach to manufacturing contexts characterized by a higher presence of women (WM Foundation, 2025) should adopt gender-balanced research designs.

The study may also be affected by self-selection and response biases. Participation in the usability tests was voluntary, and it is plausible that workers who were more motivated, more digitally confident, or more interested in safety topics were over-represented in the sample. In addition, the quantitative evaluation relied on self-report scales, which are susceptible to social desirability, especially in organizational contexts where safety is a normative expectation. This may have led to an overestimation of satisfaction and perceived usefulness. Future research should aim to include more diverse samples, as well as objective usage data and performance metrics, to mitigate these biases.

Finally, the evaluation primarily focused on usability, clarity, and user-experience outcomes during short interaction sessions. While these dimensions are essential within a HCD process, and are crucial to consider for the future adoption of these new tools, they do not provide direct evidence of knowledge acquisition, long-term retention, or changes in safety-related behaviors and decision-making on the shop floor. No follow-up measures were collected to assess whether interacting with the tool led to more accurate hazard recognition, safer choices, or a reduction in near misses and incidents over time. Future studies should therefore integrate performance-based and longitudinal measures to evaluate the educational and behavioral impact of the tool beyond initial usability.

Further studies should extend this work by adopting longitudinal and multi-site research designs, involving a broader range of organizations, professional roles, and demographic groups, in order to explore how the DigiSafeMan prototype performs across heterogeneous contexts and over time. In addition, future research should investigate the relationship between usability, engagement, and learning outcomes, examining whether positive user experience translates into improved hazard recognition, safer decision-making, and measurable behavioral change in real working environments. Further research should also perform comparative evaluations between gamified training approaches and traditional OSH training methods, such as classroom-based lectures and slide-supported sessions. A comparative analysis could help assess whether game-based solutions provide additional benefits in knowledge retention, risk awareness, engagement, and behavioral change. Such investigations would help clarify under which conditions gamified training approaches may complement or enhance traditional safety training practices in industrial contexts.

Overall, the findings of this research suggest that adopting a multidisciplinary Human-Centered Design (HCD) framework can support the development of effective and engaging safety training solutions. Ergonomics contributed to the analysis of workers’ tasks, risk conditions, and human–machine interaction, helping to identify operational constraints and safety-critical situations that should be addressed in training activities. Sociological perspectives supported the understanding of organizational dynamics, communication patterns, and workers’ perceptions of safety, highlighting the need for training tools to consider the broader social and organizational context in which safety behaviors emerge. Interaction design provided the methodological and technical basis for translating these insights into a usable and engaging digital training solution, guiding the iterative development and evaluation of the DigiSafeMan prototype. While further research is needed to evaluate its long-term effectiveness and compare it with traditional training approaches, the results of this study suggest that a multidisciplinary HCD framework is a promising direction for developing innovative OSH training solutions.

Notes

In accordance with the principle of transparency that guided the entire research process, I further declare that generative artificial intelligence tools (ChatGPT and Grammarly) were used in a limited and critical manner, exclusively for linguistic revision purposes, including the rephrasing of complex passages and the verification of textual coherence.

The use of artificial intelligence did not contribute in any way to the generation of scientific or interpretative content, nor to the coding or analysis of data. No personal data, transcripts, direct quotations, or sensitive information related to research participants were uploaded, as all the interview transcripts were produced autonomously using dedicated transcription software during the analytical phase. In the absence of specific guidelines issued by Roma Tre University, this work adhered to the principles of integrity and responsibility recommended by the international scientific community for the responsible use of artificial intelligence.

APPENDIX

Appendix A.1

SOCIO-DEMOGRAPHIC DATA

1. Gender ☐ Male ☐ Female ☐ Other

2. Age (completed years) ______

3. Education

☐ Primary school ☐ Lower secondary school ☐ Upper secondary school ☐ Degree

4. Role:

☐ Administrative employee ☐ Technical employee ☐ Commercial employee

☐ Assembler /Maintenance worker ☐ Machine tool operator ☐ Welder

☐ Warehouse worker ☐ Electrician ☐ Driver ☐ Other (specify ___)

5. How many years have you been performing this role? ____________________

6. How many training courses on workplace safety have you attended in the past 5 years? ____

Appendix A.2

GENERAL USE AND FAMILIARITY WITH DIGITAL DEVICES

We ask you to think about your experience with different digital devices (smartphones, iPads or tablets, and computers) and answer the following questions:

1. Indicate how much time on average you spend PER DAY on each of the following activities on digital devices

	Almost never	A few minutes	< 30 min	30 minutes- 1 h	1h- 2h	> 2 h
a. Reading (es. newspaper, blog etc)	☐	☐	☐	☐	☐	☐
b. Sendind and receiving e-mail	☐	☐	☐	☐	☐	☐
c. Using instant messaging apps (es. whatsapp)	☐	☐	☐	☐	☐	☐
d. Browsing the internet	☐	☐	☐	☐	☐	☐
e. Watching/listening to video/music	☐	☐	☐	☐	☐	☐
f. Broewising social media (es. Facebook, instagram)	☐	☐	☐	☐	☐	☐
g. Giocare	☐	☐	☐	☐	☐	☐
h. Altro (______________)	☐	☐	☐	☐	☐	☐

2. Please indicate your level of agreement with the following statements regarding your experience with digital devices (1 = not at all, 2 = slightly, 3 = fairly, 4 = very much)**:**

	1- not at all	2- slightly	3- fairly	4- very much
a. I use digital devices for entertainment purposes.	☐	☐	☐	☐
b. I use digital devices to keep myself informed/up to date and/or to acquire new knowledge or learn new things	☐	☐	☐	☐

3. In general, when using digital devices, the following definitions would apply:

☐ a. Novice ☐ b. Moderately skilled ☐ c. Expert

4. Now think about the following types of digital devices and indicate how long, on average, you use each of them per day (alone or with others):

	< 1 h	1h-1.5h	1.5h-2h	> 2 h
a. Smartphone	☐	☐	☐	☐
b. iPad or tablet	☐	☐	☐	☐
c. Computer	☐	☐	☐	☐

PERCEIVED ENGAGEMENT WHEN USING DIGITAL DEVICES

5. Thinking about your experience with digital devices, indicate your level of agreement with the following statements (1 = not at all, 2 = slightly, 3 = fairly, 4 = very much)**:**

	1- not at all	2- slightly	3- fairly	4- very much
a. When I use digital devices, I lose track of time	☐	☐	☐	☐
b. I feel frustrated when using digital devices	☐	☐	☐	☐
c. Using digital devices makes me feel disoriented	☐	☐	☐	☐
d. Using digital devices is tiring	☐	☐	☐	☐
e. Digital devices spark my curiosity	☐	☐	☐	☐

DIGITAL DEVICES AS TRAINING TOOLS

In the following section, we ask you to **THINK ABOUT APPS, WEBSITES AND WEB PLATFORMS THAT PROVIDE INFORMATION ON HEALTH AND SAFETY** in the workplace. Even if you have NEVER CONSULTED THESE WEBSITES/APPS/TOOLS, we still ask you to answer the following questions.

6. Indicate your level of interest in using digital devices to keep up to date/informed about health and safety in the workplace:

☐ 1- not at all ☐ 2- slightly ☐ 3- fairly ☐ 4- very much

7. Please, indicate your level of agreement with the following statements (1 = not at all, 2 = slightly, 3 = fairly, 4 = very much)**:**

THE USE OF PLATFORMS ON DIGITAL DEVICES AS A METHOD OF SUPPORTING TRAINING CAN MAKE SAFETY TRAINING...

	1- not at all	2- slightly	3- fairly	4- very much
a. … more accessible	☐	☐	☐	☐
b. … faster	☐	☐	☐	☐
c. … more interesting	☐	☐	☐	☐
d. … more effective	☐	☐	☐	☐

8. How important do you think it is for each of the following contents to appear? (1 = not at all, 2 = slightly, 3 = fairly, 4 = very much)**:**

	1- not at all	2- slightly	3- fairly	4- very much
a. Manuals	☐	☐	☐	☐
b. Audio lessons / podcasts	☐	☐	☐	☐
c. Video lessons	☐	☐	☐	☐
d. Exercises in the form of questionnaires	☐	☐	☐	☐
e. Exercises in the form of games (e.g., quizzes with scores and leaderboards)	☐	☐	☐	☐

9. In what context would you PREDOMINANTLY consult it (select only one answer):

☐ at home ☐ during working hours ☐ during work breaks

10. Would your colleagues be interested in using it?

☐ Defineiley NO ☐ Probably NO ☐ Probably YES ☐ Definitely YES

Appendix A.3

CAUSES ASSOCIATED TO ACCIDENTS AND INJURIES

Thinking **IN GENERAL about your professional role**, please indicate how true you consider the following statements, using a scale from 1 to 4 (1= not at all, 2= slightly, 3= fairly, 4= very much).

1.1. Working conditions – how much can they influence the occurrence of an accident? (1 = not at all, 2 = slightly, 3 = fairly, 4 = very much)

	1- not at all	2- slightly	3- fairly	4- very much
a. **Short timelines and tight deadlines** Frequent disturbances and interruptions, tight scheduling, etc.	☐	☐	☐	☐
b. **Heavy working hours** Overtime, shift or night work, irregular working hours or changes made without prior notice, lack of breaks, etc.	☐	☐	☐	☐
c. **Highly repetitive, incomplete, or limited tasks** Highly repetitive, incomplete, or fragmented tasks; isolated and individual workstations used by a single person, etc.	☐	☐	☐	☐
d. **Mentally exhausting working conditions** Mental overload, high emotional demands, stressful social conditions, etc	☐	☐	☐	☐
e. **Personal conditions** Physical or psychological overload, fatigue, effects of medication, alcohol, etc.	☐	☐	☐	☐
f. **Unfavorable physical work environment** Weather conditions, indoor climate, heat, cold, humidity, lighting, visibility, etc.	☐	☐	☐	☐
e. **Lack of adequate training for the worker/team**	☐	☐	☐	☐

1.2. Actions and behaviors – how much can they influence the occurrence of an accident? (1 = not at all, 2 = slightly, 3 = fairly, 4 = very much)

	1- not at all	2- slightly	3- fairly	4- very much
a. **Failure to comply with work instructions, safety rules, or CE markings**	☐	☐	☐	☐
b. **Failure to use the required personal protective equipment (PPE)**	☐	☐	☐	☐

	1	2	3	4
c. **Incorrect use of work equipment or substances used**	☐	☐	☐	☐
d. **Lack of controls** on compliance with instructions, employees' behavior, and the effectiveness of measures already implemented, etc	☐	☐	☐	☐

Thinking about the **work you perform at OLIVERO impianti**, please indicate how true you consider the following statements regarding **working conditions**, using a scale from 1 to 4 (1 = not at all, 2 = slightly, 3 = fairly, 4 = very much).

2. Working conditions – how much can they influence the occurrence of an accident? (1 = not at all, 2 = slightly, 3 = fairly, 4 = very much)

	1- not at all	2- slightly	3- fairly	4- very much
a. My job is dangerous	☐	☐	☐	☐
b. My job is tiring	☐	☐	☐	☐
c. My job requires great concentration and attention from me	☐	☐	☐	☐
d. My job is repetitive and does not involve alternating with other tasks or activities	☐	☐	☐	☐
e. My tasks are well-defined	☐	☐	☐	☐
f. There is enough manpower to complete the daily work	☐	☐	☐	☐
g. There is too much work to do compared to the available time	☐	☐	☐	☐
h. I have the possibility to decide my work pace	☐	☐	☐	☐
i. My earnings are proportional to my work	☐	☐	☐	☐
l. Most accidents are caused by system failures	☐	☐	☐	☐
m. Most accidents are caused by human behavior	☐	☐	☐	☐
n. I feel well-informed about safety procedures	☐	☐	☐	☐
o There is good communication within my work group	☐	☐	☐	☐

EXPERIENCES WITH MACHINES

Machines and equipment used/ present in the workshop	***I use it***	***PERCEIVED LEVEL OF RISK BASED ON YOUR EXPERIENCE***				**Potentially the most dangerous** (ONLY ONE)
		Negligible	**Low**	**Medium**	**High**	
1. Manual lathe						
2. Grinding machine						
3. Column drill						
4. Radial drill						
5. Milling machine						
6. Guillotine shear						
7. Press brake						
8. Manual band saw						
9. Mitre saw						
10. Forklift						
11. Scaffold tower						
12. Hoist						
13. Elevating work platform						

3. In the past 5 years, have you experienced any of the following INCIDENTS WITHOUT PHYSICAL INJURY?

Type of incident	**Never**	**Once**	**More than once**
a. Impact-related injuries			
b. Overturning			
c. Third-party involvement			
d. Severe falls			
e. Fall from height (>2 m)			
f. Electrocution			
g. Inhalation of fumes			
h. Foreign bodies in eye			
i. Commuting accidents			
l. Other (____________)			

Appendix B.1

INTERVIEW GUIDE

Introduction and explanation of the project and of the activities to be carried out during the interview.

Part 1- Based on the answers provided on the questionnaire, ask follow-up questions where appropriate:

Question 1: If they indicated that they play games, ask which games they usually play.

Question 2: Watching videos - should videos have a maximum duration based on their usual device usage? (If videos exceed a certain length, do they stop watching them?)

Question 3: If they answered *NOVICES*, ask why.

Question 4: Based on the answer given, why are they more or less interested?

Question 5: suggestions/incentives for commenting, in terms of[8]:

- Images and text balance (ratio between images and descriptions, font size, screen layout)
- Navigation (printable content, navigation support)
- Information value (innovation, reduced scrolling, article length, interactivity)
- Trust (privacy, security)
- Marketing (presence of advertising, banners, pop-ups)
- Appeal (graphics, animations, entertainment, drop-down menus, background images)
- Accessibility and multimedia (music, games, icons, logos, colors)

Question 6: Have you ever consulted a website or app that addresses workplace safety? If yes, which one?

Part 2- Hands-on demonstrations

Demonstration 1: Use of the "SAFETYAPP" app

Participant was asked:

- search for a specific risk category (e.g., machinery).
- search within the fact sheets for ladders (step ladders) or manual handling of loads.

Question 6: What is your first impression? (perceptions in terms of images and text balance, navigation, appeal, accessibility)

Question 7: What would you improve? What content would you add?

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[8] *Schmidt, K. E., Bauerly, M., Liu, Y., & Sridharan, S. (2003, November). Web page aesthetics and performance: a survey and an experimental study. In Proceedings of the 8th Annual International Conference on Industrial Engineering—Theory, Applications and Practice.*

Demonstration 2: Use of the "FIRE AWARENESS TRAINING" app

Question 8: What do you like and what do you not like?

Question 9: Considering other existing apps that you usually use, what could be the potential critical issues? What are the positive and negative aspects?

Demonstration 3: Selection of some demos available at: https://www.safetyapp.co.uk/app/demo

- UNDER PRESSURE - https://www.safetyapp.co.uk/app/games/play/under-pressure/1375
- SPOT THE HAZARD - https://www.safetyapp.co.uk/app/games/play/spot-the-hazard/53
- FIRE SAFETY - https://www.safetyapp.co.uk/app/games/play/fire-safety/174
- SAFETY TOUR 360 - https://www.safetyapp.co.uk/app/games/play/safety-tour-360/235
- FACTS - https://www.safetyapp.co.uk/app/games/play/facts/1374

For each demo, ask what they like, what they do not like, and identify positive and critical aspects.

Appendix B.2

INTERVIEW GUIDE

We will talk about safety, accidents, and near-miss incidents that may occur in the workshop or on construction sites, as well as personal experiences, either directly experienced or heard about from others. We will broadly follow an interview guide, with a few focused questions.

ACCIDENTS

What are the most common risks in your job, and which ones affect you personally the most?

Can you describe the most dangerous experience you have had? Please tell me about the most recent accident or near-miss that you experienced or witnessed. Was it due to the failure to use personal protective equipment (PPE)?

Did it have any influence on your attitude toward the use of PPE or on the way you work?

Do you ever knowingly perform unsafe work? Are you aware of the consequences of your actions?

LINKING BACK TO SOME QUESTIONS FROM THE QUESTIONNAIRE…

Imagine that I am a newly hired worker in the workshop and that I have already received my training. As an experienced worker, how would you behave toward me? Do you think younger workers are more at risk, or those with more experience? What could be an effective way to improve safety for younger workers?

SAFETY CLIMATE

Do your colleagues follow safety regulations and always adopt safe behaviors while working?

Do employees in the company care about the safety of other workers (e.g., observing one another, reminding each other to use protective equipment in case of oversight, helping one another)?

Speaking of collaboration for safety, how much is safety valued within the organization? Do you think it is well managed? What would you improve?

MACHINERY AND EQUIPMENT

Are there any machines (among those listed in the questionnaire or others present in the workshop) that are particularly risky because they involve high biomechanical load, excessive manual handling of loads, pushing or pulling activities, or repetitive upper-limb movements?

Appendix C.1

USABILITY TEST

Thinking about the prototype just used, in general, on a scale from 1 "Strongly agree" to 7 "Strongly disagree", please rate the following statements:

	Strongly AGREE						Strongly DISAGREE	
	1	2	3	4	5	6	7	n.a
1. Overall, I am satisfied with how easy it is to use this system	☐	☐	☐	☐	☐	☐	☐	☐
2. It was simple to use this system	☐	☐	☐	☐	☐	☐	☐	☐
3. I was able to complete the tasks and scenarios quickly using this system	☐	☐	☐	☐	☐	☐	☐	☐
4. I felt comfortable using this system	☐	☐	☐	☐	☐	☐	☐	☐
5. It was easy to learn to use this system	☐	☐	☐	☐	☐	☐	☐	☐
6. I believe I could become productive quickly using this system	☐	☐	☐	☐	☐	☐	☐	☐
7. The system gave error messages that clearly told me how to fix problems	☐	☐	☐	☐	☐	☐	☐	☐
8. Whenever I made a mistake using the system, I could recover easily and quickly	☐	☐	☐	☐	☐	☐	☐	☐
9. The information (such as online help, on-screen messages, and other documentation) provided with this system was clear	☐	☐	☐	☐	☐	☐	☐	☐
10. It was easy to find the information I needed	☐	☐	☐	☐	☐	☐	☐	☐
11. The information was effective in helping me complete the tasks & scenarios	☐	☐	☐	☐	☐	☐	☐	☐
12. The organization of information on the system screens was clear	☐	☐	☐	☐	☐	☐	☐	☐

13. The interface of this system was pleasant								
14. I liked using the interface of this system								
15. This system has all the functions and capabilities I expect it to have.								
16. Overall, I am satisfied with this system								

Thinking about the games just tested, in general, on a scale from 1 "Strongly agree" to 7 "Strongly disagree", please rate the following statements:

	Strongly AGREE						Strongly DISAGREE	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**n.a**
1. The games provide clear objectives								
2. I am in control of the game actions								
3. Challenges and strategy are balanced								
4. I felt comfortable using these games								
5. The first gaming experience was encouraging								
6. There are no repetitive and boring tasks								
7. The game does not stagnate								
8. The game is consistent								
9. The content can be learned easily								
10. It provides good educational content								
11. The content is understandable								

Thinking about the prototype games you have just tried, on a scale of 1 - 'Very satisfied' to 7 - 'Very unsatisfied', please rate each game as a whole:							
	Very SATISFIED					Very UNSATISFIED	
	1	2	3	4	5	6	7	n.a
1. Game "find the error"	☐	☐	☐	☐	☐	☐	☐	☐
2. Game "quiz"	☐	☐	☐	☐	☐	☐	☐	☐
3. Game "narrative"	☐	☐	☐	☐	☐	☐	☐	☐
4. Game "procedure"	☐	☐	☐	☐	☐	☐	☐	☐

SOCIO-DEMOGRAPHIC

1. Gender ☐ Male ☐ Female ☐ Other

2. Age (completed years) ______

3. Education

☐ Primary school ☐ Lower secondary school ☐ Upper secondary school ☐ Degree

4. Do you work? ☐ Yes ☐ No

If YES, what is your job role? ____

How many years have you been doing this job? ______________________________

Appendix C.2

Based on your opinion…

1. The mobile application uses attractive graphics…
2. The mobile application uses appropriate colors…
3. The mobile application does not overuse colors…
4. The mobile application makes the main function of the app immediately clear…
5. The mobile application uses intuitive controls / controls that are immediately evident…
6. The mobile application uses buttons that are sized appropriately for fingers / uses large controls / uses small controls that require careful aiming before being touched…
7. The mobile application uses a font of an appropriate size…
8. The mobile application uses animations appropriately…
9. The mobile application informs the user when moving from one screen to another / transitions smoothly between screens…
10. In general, what are the positive and critical aspects of each of the proposed games…

Appendix D.1

USABILITY TEST

Thinking about the prototype just used, in general, on a scale from 1 "Strongly agree" to 7 "Strongly disagree", please rate the following statements:

	Strongly AGREE						Strongly DISAGREE	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**n.a**
1. Overall, I am satisfied with how easy it is to use this system	☐	☐	☐	☐	☐	☐	☐	☐
2. It was simple to use this system	☐	☐	☐	☐	☐	☐	☐	☐
3. I was able to complete the tasks and scenarios quickly using this system	☐	☐	☐	☐	☐	☐	☐	☐
4. I felt comfortable using this system	☐	☐	☐	☐	☐	☐	☐	☐
5. It was easy to learn to use this system	☐	☐	☐	☐	☐	☐	☐	☐
6. I believe I could become productive quickly using this system	☐	☐	☐	☐	☐	☐	☐	☐
7. The system gave error messages that clearly told me how to fix problems	☐	☐	☐	☐	☐	☐	☐	☐
8. Whenever I made a mistake using the system, I could recover easily and quickly	☐	☐	☐	☐	☐	☐	☐	☐
9. The information (such as online help, on-screen messages, and other documentation) provided with this system was clear	☐	☐	☐	☐	☐	☐	☐	☐
10. It was easy to find the information I needed	☐	☐	☐	☐	☐	☐	☐	☐
11. The information was effective in helping me complete the tasks & scenarios	☐	☐	☐	☐	☐	☐	☐	☐
12. The organization of information on the system screens was clear	☐	☐	☐	☐	☐	☐	☐	☐
13. The interface of this system was pleasant	☐	☐	☐	☐	☐	☐	☐	☐

14. I liked using the interface of this system	☐	☐	☐	☐	☐	☐	☐	☐
15. This system has all the functions and capabilities I expect it to have.	☐	☐	☐	☐	☐	☐	☐	☐
16. Overall, I am satisfied with this system	☐	☐	☐	☐	☐	☐	☐	☐

Thinking about the games just tested, in general, on a scale from 1 "Strongly agree" to 7 "Strongly disagree", please rate the following statements:

	Strongly AGREE						Strongly DISAGREE	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**n.a**
1. The audio-visual presentation supports the game system	☐	☐	☐	☐	☐	☐	☐	☐
2. Layout is efficient and visually appealing	☐	☐	☐	☐	☐	☐	☐	☐
3. Navigation is consistent, logical, and minimalist	☐	☐	☐	☐	☐	☐	☐	☐
4. The game provides feedback on player actions	☐	☐	☐	☐	☐	☐	☐	☐
5. Guidance and instructions are appropriate	☐	☐	☐	☐	☐	☐	☐	☐
6. The games provide clear objectives	☐	☐	☐	☐	☐	☐	☐	☐
7. I can see my progress (or failures) and compare results	☐	☐	☐	☐	☐	☐	☐	☐
8. Challenges and strategy are balanced	☐	☐	☐	☐	☐	☐	☐	☐
9. I felt comfortable using these games	☐	☐	☐	☐	☐	☐	☐	☐
10. The first gaming experience was encouraging	☐	☐	☐	☐	☐	☐	☐	☐
11. There are no repetitive and boring tasks	☐	☐	☐	☐	☐	☐	☐	☐
12. The length/duration of each end-game/quiz session is clearly indicated	☐	☐	☐	☐	☐	☐	☐	☐
13. There is the option to restart the game	☐	☐	☐	☐	☐	☐	☐	☐
14. The content can be easily learned	☐	☐	☐	☐	☐	☐	☐	☐
15. It provides good educational content	☐	☐	☐	☐	☐	☐	☐	☐
16. Providing content in the form of tests and games is interesting	☐	☐	☐	☐	☐	☐	☐	☐

17. It provides many examples and exercises	☐	☐	☐	☐	☐	☐	☐	☐
18. The content is understandable	☐	☐	☐	☐	☐	☐	☐	☐
19. This system also allows me to test my current knowledge	☐	☐	☐	☐	☐	☐	☐	☐
20. It gives me the opportunity to think critically	☐	☐	☐	☐	☐	☐	☐	☐
21. I would be willing to use this system in the future	☐	☐	☐	☐	☐	☐	☐	☐
22. I would probably recommend it to others	☐	☐	☐	☐	☐	☐	☐	☐
23. Scoring systems increase my engagement	☐	☐	☐	☐	☐	☐	☐	☐

Thinking about the prototype games you have just tried, on a scale of 1 - 'Very satisfied' to 7 - 'Very unsatisfied', please rate each game as a whole:

	Very SATISFIED						Very UNSATISFIED	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**n.a**
1. Game "find the error"	☐	☐	☐	☐	☐	☐	☐	☐
2. Game "quiz"	☐	☐	☐	☐	☐	☐	☐	☐

SOCIO-DEMOGRAPHIC

1. Gender ☐ Male ☐ Female ☐ Other

2. Age (completed years) ______

3. Education

☐ Primary school ☐ Lower secondary school ☐ Upper secondary school ☐ Degree

4. Role:

☐ Administrative employee ☐ Technical employee ☐ Commercial employee

☐ Assembler /Maintenance worker ☐ Machine tool operator ☐ Welder

☐ Warehouse worker ☐ Electrician ☐ Driver ☐ Other (specify ____)

5. How many years have you been performing this role? ____________________

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