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Education and Training to Enhance Risk Perception and Safety Culture in High-Risk Plant

Carlo Rusconi[a], Marianna Madonna[*b], Loriana Ricciardi[c], Andrea Tonti[c], Carlo Vicini[a]

[a] Sogin S.p.A., Via Marsala, 51/c, 00185 Roma, Italy.
[b] INAIL, Unità Operativa Territoriale di Certificazione Verifica e Ricerca di Napoli, Via Nuova Poggioreale, 80143 Napoli, Italy.
[c] INAIL, Dipartimento Innovazione Tecnologica e Sicurezza degli Impianti, Prodotti e Insediamenti Antropici, Via Roberto Ferruzzi, 38, 00143 Roma, Italy.
m.madonna@inail.it

The growing technological complexity, due to the advent of Industry 4.0, allows high-risk plants to be designed with safer operation thanks to intelligent control and supervision systems. However, to seize the opportunities that intelligent technologies offer in terms of risk reduction, efforts must be directed towards increasingly human-centered design and an evolution of organizational models. The environment surrounding the worker is increasingly interconnected and integrated with intelligent systems, so that risk scenarios are changing and consequently the skills of the user who will interact with them. In this innovative and interconnected context, in fact, the worker's skills profile is also changing in order to allow him/her to act in dynamic and unexpected situations safely also thanks to advanced technologies. This new complexity of intelligent environments and systems requires new educational and training interventions. These interventions should be aimed at enhancing worker's ability to perceive and identify elements of context, which could represent risk sources not only for their intrinsic hazards (e.g. hot surfaces, cutting edges, chemicals etc.) but also for their capacity to modify risk scenarios related, for example, to potential impact of their mechanisms on human operators or other technological equipment.
A sound approach for providing workers the necessary skills to face this challenge is based on innovative education and training methodologies where operators live an immersive experience of the interconnected context through simulation tools and realistic interaction with context elements and agents in order to test and become aware of hidden dynamics related to socio-technological systems evolution.

1. Introduction

After Three Mile Island accident in 1979, several methodologies for Human Reliability Analysis (HRA) have been developed in order to have a tool for comparing the human error probability with failure probability of technological systems and integrate these results within the conceptual frame of Safety Analysis methodologies such as Fault Tree and Event Tree (Foster et al., 2006) (Kolaczkowski, 2005).
Most of the HRA methodologies represent the context where workers act in terms of parameters that modify failure probability distributions (Chandler et al., 2006). Each one of these parameters refers to context dimensions as Human-Machine Interface (HMI), available time, crew quality and so on. Measure of these items is often very difficult, because they have an intrinsically complex and qualitative nature.
Bhopal chemical disaster in 1984 and Chernobyl nuclear accident in 1986 showed unequivocally the leading role of organizational culture regarding safety and security issues in high-risk industrial plants. Indeed, no standard safety and security analysis, as much as accurate and exhaustive it could be, would have been able to foresee the scenario of Bhopal, where somebody, in a chemical plant in decommissioning, introduced half ton of water in MIC (Methyl Isocyanate) tank while safety systems were out of service or the scenario of Chernobyl where operators were demanded to test a working nuclear power plant violating several safety procedures. In both cases, only a deep assessment of hidden dynamics among Individuals, Technology and

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Organization (ITO) could have given some hints about the real risks related to managing those industrial plants. For this reason, interactive methodologies for education and training developed in the nuclear field to enhance risk perception and safety culture fit very well also in high-risk industrial plants management.
In this contribution the authors want to highlight how the educational and training process, taking place on a complex socio-technical system, is difficult to design as the interrelationships between the factors that influence it are complex and often hidden. The authors propose a framework of a virtuous educational and training process that highlights the main exogenous and endogenous factors that influence it. According to the state of the art, it is difficult to act on the individual's endogenous factors to calibrate the training process, the framework therefore allows it to be improved, through effective methods of training evaluation, with a feedback mechanism on exogenous factors. Moreover, the authors want to show how the methodology proposed by Rusconi (Rusconi, 2016) is well suited to the proposed framework, as it allows, through the simulation and the high commitment of participants, to increase the culture of safety within the organization and to increase their perception of risk.

1.1 Educational and training needs in high-risk plants

High-risk plants are those that typically use equipment, machinery or facilities that pose a significant risk to health, safety or the environment if not managed properly. These plants are considered high risk because they use dangerous processes or substances or equipment that can cause accidents, injuries or significant environmental damage if they are not managed and maintained in strict compliance with safety protocols. Examples of high-risk facilities include oil refineries, nuclear power plants, or other chemical and storage facilities that handle toxic, flammable, or explosive substances or use machinery that is dangerous due to operating conditions. The management of these systems requires rigorous safety procedures, regular checks and inspections and careful education and training of operators, as well as requiring the constant maintenance of rigorous adherence to safety regulations. Knowledge of work and safety procedures are essential to minimize the likelihood of accidents and to protect workers, the community and the environment from potential harm. To this end, education and training on workplace safety become fundamental elements to contribute to the creation of a safer working environment.
Education is a teaching process through which the knowledge and skills necessary to carry out work safely are transferred to workers, while training is an activity aimed at teaching workers the correct use of equipment, machines, systems, devices and execution of work procedures. The training therefore has a more operational focus and can be carried out in different ways, real and virtual, in the classroom and directly on the plant. Therefore, training allows the worker to put into practice the knowledge and skills acquired through specific and specialized education process. While training in the correct use of prevention and protection devices and emergency equipment is aimed at protecting the worker from risks, in the case of machinery and equipment, for which specific competencies and skills are required, training is provided not only to ensure the operator's safety but also for the correct execution of the work activity. Another type of training is that aimed at the correct and safe execution of work and emergency procedures.
The introduction of intelligent systems in the management of high-risk plants requires new educational and training interventions. Education and training should make workers aware of the risks associated with their specific tasks and should aim to improve the worker's ability to perceive and identify sources of risk not only for their intrinsic hazards (e.g., hot surfaces, sharp objects, chemicals, etc.), but also for their capacity to modify risk scenarios related, for example, to the potential impact of their mechanisms on human operators or other technological equipment.
In general, training and education are more effective when the topics covered and the exercises performed are in line with the tasks really performed by the worker and with the potential accident scenarios related to his role. Therefore, for each training activity to be provided, it is necessary to appropriately calibrate the methods and timing of the courses. Furthermore, to promote effective training, taking into account the complexity of the working environment and tasks, communication channels must be clear and in a language accessible to all workers regardless of their nationality and cultural level.
A valid approach to provide workers with the skills necessary to face this challenge, is based on innovative teaching and training methodologies in which operators experience an immersive understanding of the working context through simulation tools and realistic interaction with elements and agents of the environment. In this way, workers could test and become aware of the hidden dynamics that characterize the complexity of socio-technical systems.
Innovative education and training methodologies should aim to increase risk perception also through the aid of virtual and augmented reality in the identification of hazards and the simulation of accident scenarios. Studies in the literature, in fact, highlight that the perception of risk is higher in individuals who have experienced accidents (Xie et al., 2021). This approach allows employees to practice decision-making under pressure and strengthens risk perception skills in a controlled environment. However, these new types of training should be complemented by other training activities. Indeed, it is necessary to ensure that employees receive

comprehensive training on regulations, standards and best practices related to safety and risk management. Compliance training helps employees understand their legal obligations and reinforces the importance of adhering to safety guidelines. Employees need to be educated on the importance of conducting thorough root cause analyses (RCA) following safety incidents or near-misses. Training on root cause analysis techniques helps employees understand the factors contributing to incidents or errors, enabling the implementation of effective preventive measures.

To increase the safety culture, leadership from executives and managers is important. The management, through virtuous behavior that respects workplace safety procedures and requirements, demonstrates that safety is a priority at all levels of the organization. This context includes the contribution of workers who must be encouraged to share the critical issues identified and to propose strategies and solutions to improve safety. In addition to training on work procedures, in high-risk installations, operational training on emergency management is required, which includes simulations of evacuation systems and first aid procedures. These simulations are aimed at verifying the correct response to emergencies, also with reference to the effectiveness of communication strategies during them. By incorporating these educational and training initiatives into their operations, organizations can improve risk perceptions and cultivate a strong safety culture, ultimately reducing the likelihood of accidents and promoting a safer work environment for all stakeholders.

2. Framework of a virtuous educational and training process

Educational and training interventions are influenced by the socio-technical system in which they are developed and implemented. According to the systemic approach to safety of the International Atomic Energy Agency (IAEA), a sociotechnical system is characterized by the complexity and non-linearity of interactions between all individual, technical and organizational (ITO) factors (Smetnik & Murlis, 2016).

In the perspective of the IAEA's vision, at the basis of this complex socio-technical system there is the *safety culture*, which is not one variable among others but rather "something inherent in all aspects of the organisation". A strong safety culture, which refers to the shared values, beliefs, and norms that guide behavior within an organization can enhance employee motivation, engagement and commitment, leading to improved performance (Fitriana et al., 2021).

In this work, the authors have shown the factors that affect the education and training process in the framework in figure 1. These factors have been divided into exogenous and endogenous to the individual.

Endogenous factors are those closely linked to the individual cognitive process and to his/her risk perception, which in turn is a function of previous experience linked to accidents, his/her pre-training skill levels, culture and value system. Exogenous factors concern technology, organization, work environment, processes and procedures, communication and training times, methods and tools used. These factors are the result of organizational and physical characteristics of the work environment (Di Nardo et al., 2015).

As shown in figure 1, the exogenous factors could influence the success of the training process, for example the management's commitment to motivational and communication activities with workers could influence the final results on the goals and objectives of the training. The influence of the individual characteristics of the trainees on the effectiveness of the training process is difficult to determine, but according to the authors' point of view it is possible to intervene on exogenous factors. In fact, a strong safety culture underlying the organisation could influence how trainees view the training program in terms of improving their job performance. It is important to provide employees with regular training and development opportunities that focus on enhancing their skills and knowledge related to safety (Orikpete & Ewim, 2024).

The literature offers many training methods, but the main reviews have highlighted that the level of engagement of training has an impact on health and safety outcomes. These methods range from information-based techniques to computer based and to performance-based techniques (Burke et al., 2006).

Lectures, videos, pamphlets and other types of written materials, are the least engaging methods of safety and health training, are commonly used to present health- and safety-related information. Methods of moderately engaging training incorporate knowledge of results, for example feedback interventions in which performance information is provided in small groups, allowing trainees to correct their mistakes. Feedback is also a characteristic of computer-based interactive instruction. The most engaging methods of safety and health training include hands-on demonstrations combined with behavioral simulations, which require the trainee's active participation. In the case of behavioral simulations and hands-on training, interactions between trainees and trainers often go beyond one-way feedback to engage trainees in a dialogue regarding knowledge gained or actions taken. This dialogue, both in a virtual and real context, is important because it aims to improve the quality of reflection (thinking) with respect to the actions undertaken.

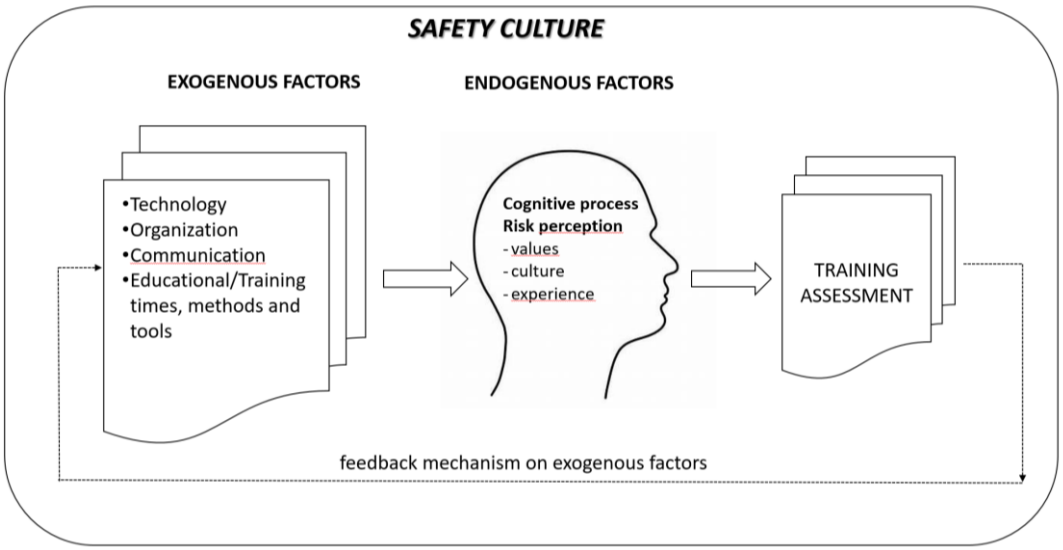

Figure 1: Virtuous educational and training process

Today worker training program have evolved to meet also the challenges of Industry 4.0 enabling technologies, such as virtual or augmented reality that could be considered one of the most engaging method.
Overall, literature reviews showed that the more engagement in the training, the more training impacts on reduction of negative safety and health outcomes.
The recent development of virtual environment techniques represents an opportunity to obtain highly engaging training. These technologies can be used for safety training by offering significant benefits due to immersive but risk-free learning. (Rey-Becerra et al., 2021). Conventionally, training occurs in physical facilities such as classrooms and laboratory spaces through presentations and hands-on exercises. To date, Virtual Reality (VR) technology allows to provide effective and engaging training through virtual environments. Virtual environments are used to train users to perform real-world tasks and procedures more safely with minimal exposure to dangerous situations. (Xie et al., 2021). Compared to navigating fully immersed VR scenes, augmented reality (AR) overlays real-world objects with a layer of virtual objects or information. This gives users more control over the physical world when using AR devices (e.g., AR-supported headsets and smartphones). An example of AR are labels and indicators added to machinery during training and maintenance that guide the operator in carrying out the task in a guided and safe manner.

2.1 Safety training assessment

Both endogenous and exogenous factors are linked together by complex relationships, often hidden and therefore difficult to determine. Due to the complexity of the interplays among all factors that could influence the outcomes of a proper educational and training program, it is difficult to define *a priori* on what factors intervene to improve it. Therefore, the effectiveness of the training process is better to be evaluated *a posteriori* in the training evaluation. Recently, an increasing attention is paid on training evaluation, and it is due both to mandatory laws and to the fact that many companies have started to perceive it as an investment in terms of less injuries and less productivity loss (Vignoli et al., 2014).
Training is considered effective when trainees achieve the training goals (Burke et al., 2006) and these could be evaluated through outcome criteria. There are many different tools to assess the effectiveness of training interventions. In order to evaluate whether there are changes in work performance after a training experience, many methods collect data on three different times: before the training start (pre), after the training (post), after some months (follow-up) (Blume et al., 2010).
One of the most widespread tools for learning assessment is the questionnaire which helps to understand the knowledge acquired by individual workers but does not provide feedback on the worker's level of commitment and the training in general (for example, whether it worked or not). The questionnaire can be proposed at different times (pre, post and follow up) to investigate different variables.
Another tool to better understand how training activities are effective is the interview. The workers interviewed on satisfaction and usefulness of the training perceived by the participant, knowledge acquisition and its impact on individual and organizational outcomes and safety climate.

Focus group discussion is a method that involves a focus on specific issues, with a predetermined group of people, participating in an interactive discussion. A trained moderator who facilitates the discussion to gain depth from participants' responses leads the group. Questions asked by moderators are carefully designed to stimulate discussion. A permissive, non-threatening group environment is essential so that participants feel comfortable to share their views without the fear of judgment from others (Hennink, 2013).
From data collected from classroom observations and learning assessments, it is possible to evaluate the effectiveness of the educational process and to detect critical issues emerged, so through a feedback mechanism on exogenous factors, we could calibrate the training interventions. The feedback mechanism also allows us to intervene on those endogenous factors that strengthen the safety culture and which indirectly affect the individual's endogenous factors.

3. Proposed methodology for improving risk perception and safety culture

The authors want to show how the training methodology proposed by Rusconi (Rusconi, 2016), within the IAEA, combines well with the virtuous training process framework as shown in the figure 1.
The proposed methodology has changed the initial "classic" concept, where most of the time teachers explain the main topics and verify learning through questions and exercises, into a dynamic one based on an interactive approach. Teachers become coordinators of brainstorming sessions during which students, divided into work groups, participate in simulations aimed at making players aware of their roles in improving the organization's safety culture. Main features of this methodology are represented by a continuous counterpoint between exposure of contents, focused on fundamental concepts about complex systems and theory of organization (e.g. opened and closed systems, non-linear dynamics and feed-back, network structures and information flow, cognitive models) and simulations of Safety Culture Evaluation regarding organizations which have been involved in transportation and industrial accidents (Kletz, 2007).
Thus, players are ready to deal with the case-study by simulating an investigation on the immediate and root causes of one of the most severe industrial accidents: Bhopal.
After a presentation by the coordinators on the sequence of events and on the socio-technological context in which the accident occurred, students are asked to identify root causes and their inter-dependencies.
Participants are then divided into heterogeneous groups to highlight the potentiality of brainstorming approaches and critical thinking and to show how important it is to correctly compare and integrate different points of view and backgrounds. After the analysis session, the coordinator starts a collective brainstorming session, during which each group shares results and observations with the other groups to reach a joint conclusion. At the end of the brainstorming session, class outcomes are compared with the outcomes of experts that have carried out in-depth analyses of the Bhopal accident (Kalelkar & Little, 1988), (Sriramachari, 2004).
Of course, this simulation does not claim to be a thorough assessment, but it is worth noting that the class generally identifies and classifies several causes and connections recognized by international experts.
This simulation highlights the potentiality of brainstorming approaches and critical thinking and shows how important it is to correctly compare and integrate different points of view and backgrounds. As a result of these activities, participants learn to recognize the hidden causes that determine severe accidents, for example, lack of clear leadership and accountability, communication problems etc. During simulations and role-plays, participants learn that accident dynamics are not comparable if you look at them merely from a technical point of view. Nuclear facilities are very different from chemical plants and industrial factories are very different from aerospace or railway systems, but things change if you apply Root Cause Analysis and consider the Safety Culture of the organizations involved. They learn to search for unexpected analogies and common causes related to human and organizational factors. For this reason, the course is focused on developing skills to look in depth at events that highlight the need to have a deeper and wider vision of safety, grasping the explicit and implicit connections among technological, social, human and organizational features. In a nutshell: a systemic vision. At the end of the course, students take part in a collective discussion in which each of them expresses his/her feelings and opinions about simulations, role-playing and interactions with the other participants and the actions he/she is thinking of taking to contribute to the improvement of his/her organization's safety culture.

4. Conclusions

Safety and health training remains a fundamental element in workplace to reduce occupational risk of injury and disease. This paper showed the factors underlying safety education, which is characterized by organizational and technological factors and by characteristics of human factors and safety culture that generates an environment suitable for learning. An effective training intervention aims to generate behaviors that reduce level of risks and create a safety culture to improve risk-oriented thinking (Aleksandrova et al., 2016). A framework of a virtuous educational process based on the training assessment results is presented. Thanks to a feedback

system on exogenous factors, the training interventions could be calibrated in a cyclical process to achieve learning continuous improvement. The methodology proposed by Rusconi fits well into the framework illustrated above. Participants are encouraged to look for the root causes that lead to an incident event promoting trainees' engagement, motivation and commitment. This methodology, developed in the nuclear field, is well suited to be implemented even in high-risk plants where the safety culture has to be inherent in all aspects of the health and safety management system.

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