Professional Training for Industrial Accident Prevention with Time Travel Games

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Abstract—Industrial accident prevention is a critical problem that must be solved in order to avoid loss of human lives, injuries, damage of installations and financial losses. Training is only effective and sustainable if the human trainees are affected by their training experiences. Time travel games, in general—and time travel prevention games, in particular—are an innovative category of edutainment media, having high potential in areas such as environmental education and prevention training. Time travel prevention games for purposes such as accident prevention in the industries are advantageous due to their conservation of resources including human health and lives. They are affective by allowing for unprecedented learner/player/trainee experiences, and they are effective due to the fascination of application-oriented game play including opportunities to influence the fate, the latter being less close to reality but more attractive and worth telling. Digital storyboarding is the ultimate design methodology allowing for properly dovetailing pedagogical and game design. It works simultaneously bottom-up, top-down or both at once in interdisciplinary teams flexibly in space and time. Storyboarding is the organization of future learner/player/trainee experiences. The expressive power and the reach of digital storyboarding is due to its roots in dynamic plan generation for the mastery of disturbances in the industries. The technology particularly supports the design of time travel adaptive to the players' needs and goals, aiming at affective experiences and effective learning.

Keywords—industrial accidents, accident prevention, prevention training, training experience, time travel games, time travel prevention games, design patterns, didactic design, game design, pedagogical patterns, storyboarding

1 Introduction

This publication is a substantially revised and extended version of the four authors' contribution to the 2021 Learning Ideas Conference. Considerably more emphasis is put on the design of potential trainee experiences and on the dovetailing of didactic and game design. There are novelties in the underlying VR implementation.

1.1 Conventional training

It is known to all who deal with human resources, in general—and with education, in particular—that a majority of practitioners are not in favor of safety briefings and the like. If related training is particularly time-consuming, reluctance is even higher.

Psychological issues play a role. Human behavior—even under conditions of risk—is largely driven by heuristics as studied in sources from [1,2,3,4]. There are good reasons to name certain heuristics *fast and frugal* [2,4]. Practitioners who are used to performing quite well with fast and frugal heuristics have their doubts about the necessity of being trained by others who are considered theoreticians.

The effectiveness of training depends substantially on the engagement of trainees and sustainability requires trainees to be affected.

1.2 Game-based training

As stated in [5], it makes a difference whether a human learner or trainee has experienced an accident, especially a self-induced one. However, this shall not be misinterpreted as a call for a didactic principle of deliberately damaging industrial installations or injuring humans for more affective and effective prevention training.

The authors' alternative approach is virtual training environments in which humans can act and interact without fear and without the danger of real damages and injuries. The key of this approach is to offer affecting experience to learn from—preferably human experience so touching and exciting that trainees find it worth telling.

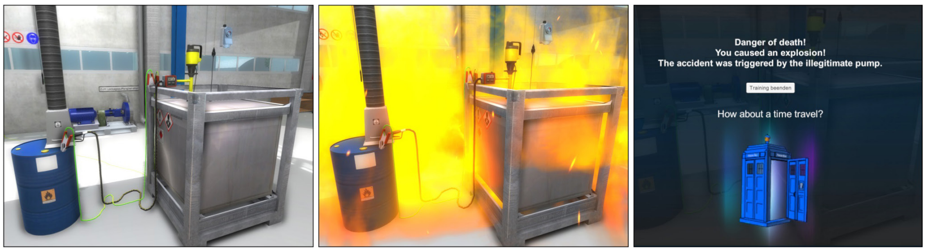

Fig. 1. Experiencing a self-induced accident

In Figure 1, there are screenshots from a training session with the authors' digital training game. The first screenshot shows the trainee's installation of an illegitimate pump followed by a virtual accident on display in the middle. Finally, the third screenshot illustrates the gimmick of the authors' approach to game-based training—*virtual time travel*. More precisely, this is the Tardis-like entrance point to virtually turning back the wheel of time.

Training is especially relevant for tasks of high complexity and risk. Consequently, incorrect operations and inaccuracies are likely. If a virtual accident occurs in the virtual world, it is animated as illustrated in Figure 1. But trainees should not get stuck at any point of no return. Travelling back in time brings with it a chance to think about what went wrong and to act more successfully the next time.

2 Time travel games

Currently, the authors deal with varying types of educational games that allow for virtual time travel. The original term *time travel prevention game* has been coined at the conference and expo Deutscher Präventionstag (German Prevention Day) in 2015 with a focus on crime prevention [6]. This has been used as a launching pad for a series of investigations, designs, implementations, and applications in varying areas.

The present publication has a narrow focus on *time travel exploratory games* and on *time travel prevention games*, in particular. Throughout this paper, we deal with travelling *backwards in time* exclusively.

2.1 Time travel exploratory games

In *time travel exploratory games*, players get offered to travel back in time for the purpose of exploring the past, gaining information and insights, and possibly bringing back virtual artefacts from the virtual past. In [7], the authors describe such a game designed for environmental education, especially for learning about global ocean warming.

Fig. 2. The flying classroom—host of time travel exploratory games

Being in the virtual past, players may take pictures that are heatmaps at different time points and different oceanic regions. Coming back from time travel, they present their respective findings to their peer group and co-operatively construct a summary. The game is hosted by a permanently grounded Russian-made IL 18 aircraft (Figure 2).

2.2 Time travel prevention games

The *time travel prevention games* are a subclass of *time travel exploratory games*. In addition to exploration in the past, players have opportunities to act in the past, and in this way, change the past, including implications for the virtual present. By means of repeated journeys in time, players may experimentally explore the causal relations between actions in the past and changes to the present time.

This paper deals merely with *time travel prevention games for accident prevention*.

3 The experience of time travel

Assume a trainee is in a training session by playing a training game in the authors' virtual reality industrial installation, as described in the final application section of this paper. Assume the trainee has experienced an undesirable event such as the sudden explosion on display in Figure 1. By entering the appearing Tardis-like entrance, the trainee finds herself in a virtual time tunnel like the one shown in Figure 3, illustrated by means of three subsequent screenshots.

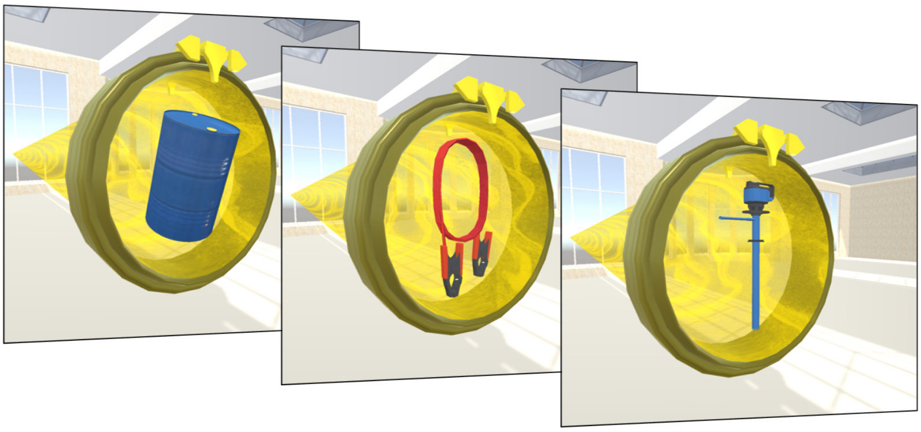

Fig. 3. Appearance of the authors' implementation of a virtual time tunnel

The objects in the tunnel represent a trainee's activities and move backward or forward, respectively, in dependence on pressing the upper left or right button. The past lies in the depth of the time tunnel slightly to the left in the pictures on display in Figure 3. Clicking to the central button selects the object on display and starts a journey in time back to the point of handling the selected object.

Moments of time in the virtual past have iconic representations as shown in Figure 3 by objects trainees are familiar with. Notice that representations like this might not exist when dealing with virtual time travel forward into the virtual future. However, for the authors' approach, this is irrelevant. The trainees need to become aware of and to learn about inaccuracies and mistakes in their earlier behavior—i.e., in the past of game play.

After a self-induced accident, trainees get an opportunity to do better the next time. If they succeed and avoid the undesired event that took place before, they consider the solution of the problem their own achievement. Trainers did not tell them what to do; they solved the problem out of their own resources—the experience of independence and self-determination. This experience is affective and, possibly, even unforgettable. In many cases, it is worth telling.

Communication among trainees in their peer group may attract other trainees who became interested in playing a time travel game, thus, extending the game's reach.

4 The design of time travel

The design of time travel means the design of potentially forthcoming experiences. Following [8], digital storyboarding is the technology of designing learner experience, an approach conceptually and algorithmically grounded in dynamic plan generation for complex industrial processes [9]. The emergence of storyboarding from dynamic planning is discussed by [5] in some detail.

The authors have adopted and adapted this *storyboarding technology* together with the *storyboard interpretation technology* [10] and applied it successfully to the design of educational games in areas such as crime prevention [11], civil protection, and disaster management [12,13]. Furthermore, the technology has been used in studies that aim at an understanding of pervasive games for purposes of learning [14] and for the systematization of pervasive games [15]. Last, but not least, digital storyboards are appropriate representations of pedagogical patterns [16] and allow for and support the systematic integration of educational theory into digital game design [17].

Storyboarding is the appropriate technology for the co-operative educational game design in highly interdisciplinary teams of domain experts; educators; psychologists; game design specialists; computer scientists, in general; and VR and AR technicians, in particular, and possibly further specialists such as health professionals when aiming at games for players with special needs. Digital storyboard components can be stored and maintained in databases including version management. Storyboarding works simultaneously bottom-up, top-down or both at once flexibly in space and time.

The necessary terminology and a few concepts will be introduced by example in the following two subsections.

4.1 High level storyboarding

Storyboards are hierarchically structured families of finite directed graphs [18]. We distinguish two types of nodes called *scenes* and *episodes*, respectively.

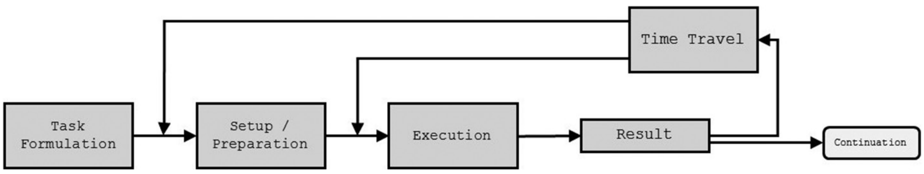

Fig. 4. High level storyboard graph placing the experience of time travel in an episode of play

Graphs are subsequently called schematics. The one on display in Figure 4 is not the top-level schematic of a storyboard, but a schematic that details what shall happen in a certain episode of game play. On a higher level, there exists a schematic with a single episode being a placeholder of what is shown in more detail in Figure 4. The larger boxes are episodes that may be replaced by other schematics. Alternative replacements are admitted and, thus, form a basis for adaptivity. The collapsed boxes are scenes that have an operational interpretation in game play.

The interpretation of nodes is not determined at planning time—i.e., when designing the game. Only all the potential alternatives are prepared and stored in the storyboard. At *execution time* (a term from the dynamic plan generation area), or in other words, at *the time of playing the game*, the interpretation of some node is determined based on data of the interaction history. By way of illustration, in a game play as sketched by Figure 1, when some illegitimate pump is installed, the game system does record this. Every substitution of a node, be it an episode or a scene, has a substitution condition. In the case under consideration, the interpretation of the result scene in Figure 4 depends on the correctness of the installation setup, and due to the failure, the particular interpretation is the animation of an explosion and fire as shown in Figure 1 and in Figure 14 and Figure 15, as shown below.

Like the nodes, the edges of a storyboard schematic have logical execution conditions. The result scene of Figure 4 has two outgoing edges with conditions that are complementary to each other. In the case of an undesired event, the edge to the episode time travel is activated. This episode has two outgoing edges, as well. They represent the designers' idea of enabling trainees to travel back in time to two earlier episodes.

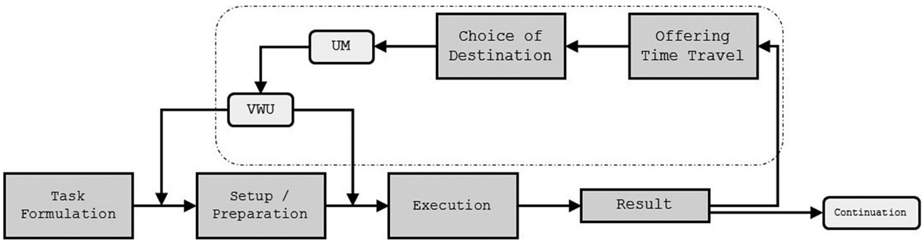

Fig. 5. Expansion of the time travel episode by another storyboard schematic

Storyboard schematics unfold over time by substitutions. According to [13], such a schematic expansion can be done automatically by an interpreter that reads data from the game system's internal knowledge base including the user model. The scene named UM in Figure 5 refers to the system's activity of updating the user model. The accident that just happened is recorded, as well as the trainee's choice of destination. The VWU updates the virtual world according to the trainee's selected destination.

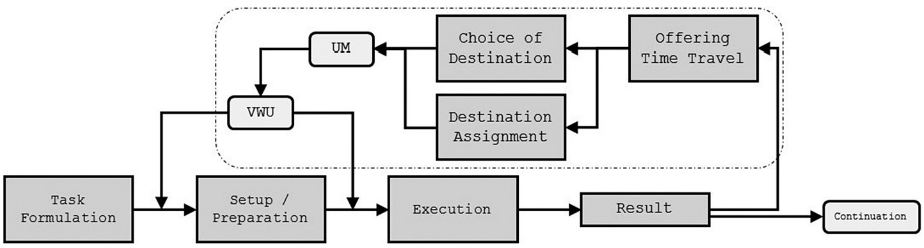

Fig. 6. An alternative expansion allowing for time travel adaptive to the trainee's behavior

If a trainee fails at the current task repeatedly, it may be helpful to replace the opportunity of selection of time travel by a system's optimal assignment (Figure 6).

4.2 Design patterns in storyboards

The pattern concept was established in science in a still rather informal way during the 70s of the last century [19]. Shortly afterward, [20] provides us with a formal approach including a collection of deep insights. Building on the seminal paper [20], [21] demonstrates that patterns of game playing behavior may serve as indicators of mastery in game-based learning. In [16], the author carried over ideas of the above cited references to patterns in storyboards. Those patterns may explicate game design concepts (so-called game mechanics) and pedagogical principles, or the dovetailing of games concepts and didactic concepts. Throughout the process of design, patterns may serve as guidelines and as quality control criteria.

Storyboards may reveal strengths and weaknesses of game design and may provide a posteriori explanation of a game's stranding (see the right schematic in Figure 7).

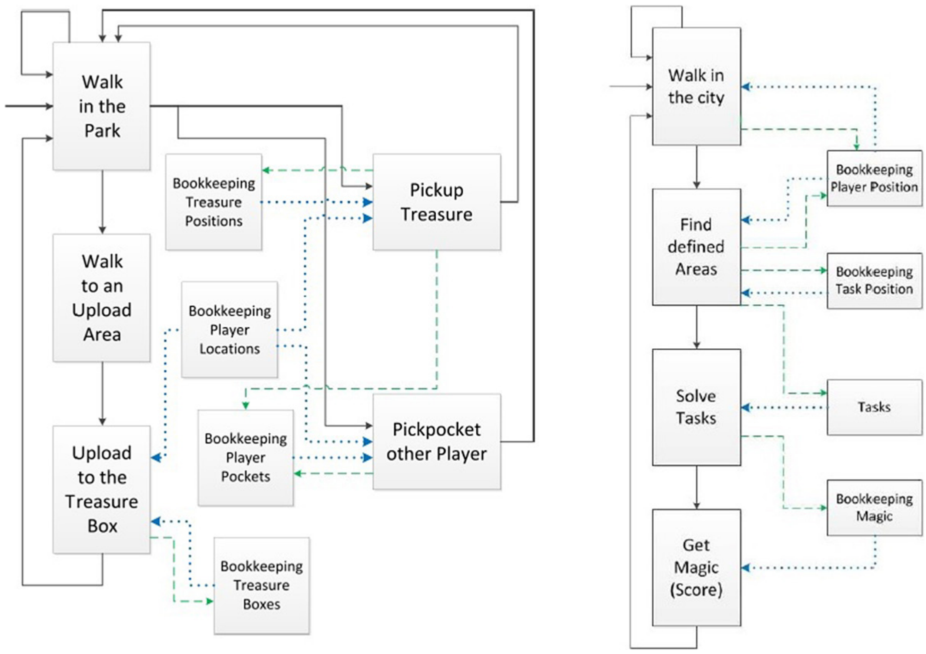

Fig. 7. Storyboards for a comparative quality analysis of two pervasive games [14]

The left storyboard in Figure 7 describes essentials of the game *Treasure* [22], and the right one surveys the interaction structure of the game *REXplorer* [23]. The solid lines in Figure 7 describe the flow of game play as usual. The dashed lines indicate the way in which player actions cause system activities. And the dotted lines explicate the way in which the players' earlier actions may have impact on the current experience of play. Readers may find more details about how to play the games in [22], [23], and [14].

Notice that some of the system's actions such as bookkeeping are not perceivable to the human player.

The storyboard schematic of the REXplorer game shows a certain simplicity of human-system interaction, whereas this interaction is more intriguing in the Treasure game. Playing Treasure still nowadays may be fun, whereas REXplorer failed badly.

Within the authors' area of research, development, and application, naturally, those patterns are of greatest interest that relate to time travel. By way of illustration, we are going to discuss just one example that we call *stations of the time tunnel*.

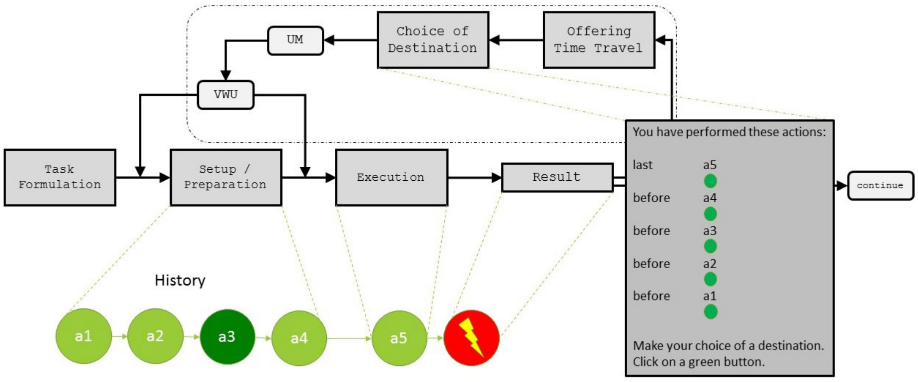

Fig. 8. Expansion of the choice of destination episode by offering a selective list

Assume that some game play took place that is represented by the history in Figure 8. There are six actions on display of which the trainee has performed five, and the last one emphasized by a lightning bolt is the system's animation of an accident. The darker circle of action a3 is intended to indicate that this is the inaccurate action causing the accident. A trainee who travels back in time gets offered an unrestricted list of destinations if this accident under consideration happened for the first time. The selective list on the right may be considered an instance of a general pattern.

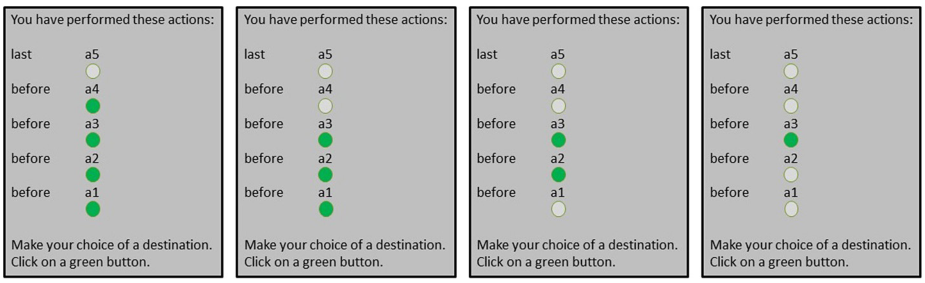

Fig. 9. More instances of restricting the choice of destination toward adaptive guidance, where only green buttons that, by iconic objects, represent time tunnel stations are clickable

Human trainees need to be finally successful. Frustration must be minimized. To be effective and sustainable, prevention training must result in the trainee's mastery of the problems and in the experience of a solution considered the trainee's achievement. For those trainees who fail repeatedly, this requires more and more guidance by more and more restrictive instances of stations of the time tunnel as on display in Figure 9.

To be a bit more precise when dealing with design patterns, let us have a closer look at Angluin's seminal paper [20] to make explicit what is relevant to our work.

The formal apparatus underlying [20] is simple and small. There is assumed any finite alphabet A and a potentially infinite set of variables X. To avoid confusions, one assumes that $X = \{x_1, x_2, x_3, \ldots\}$. It is useful to require that A and X are disjointed.

As a basis, [20] relies on formal language theory [25], on recursion theory [26], and on computational complexity theory [27]. Here, we can suppress almost all of these foundations.

Given the alphabet A, the term A* denotes the set of all finite strings build from letters of A including the empty word ε. When the empty word is excluded, all the non-empty strings form $A^+ = A^*\backslash\{\varepsilon\}$. Patterns that occur in [20] are finite strings that may contain both symbols of A and variables of X.

The meaning of a pattern p is straightforward. It describes—like any grammar—a set of formal expressions denoted by L(p). A string w belongs to L(p) exactly if there is a substitution that replaces every variable of X that occurs in p by a non-empty string. Formally, substitutions are mappings from X into A^+. By way of illustration, $L(x_1)$ equals A^+, $L(x_1x_2x_3)$ contains all strings from A^+ that are at least of length 3, and L(ab) = {ab}, because there isn't anything in ab that can be replaced by a substitution.

Design patterns in the process of storyboarding are an amalgamation, so to speak, of the simple pattern concept adopted from [20] and storyboard schematics as used here. To allow for a flexible and comprehensible design process in interdisciplinary teams, the storyboard schematics in use are typically small.

The simplest design concept defines a pattern as a pair consisting of a string pattern and a schematic, formally [p,G]. Again, the meaning is straightforward. The string pattern describes what took place in game play, and the schematic represents what shall be possible afterwards. Notice that the storyboard schematic may represent varying forthcoming experiences that unfold at the time of playing according to data such as the interaction history.

From Figure 8, one may derive an almost trivial example. We assume that the underlying alphabet contains expressions like a_1 a_2 a_3 a_4 a_5 that are all considered letters. To avoid confusion, every string is written here with space between the letters. The string $p_1 = a_1\ a_2\ a_3\ a_4\ a_5$ represents the history on display in Figure 8. This is a conventional pattern with no variables—a ground pattern. A further interesting and useful pattern is the following generalization: $p_2 = x_1\ a_3\ x_2$. It represents several interaction histories that may begin with anything represented by x_1 followed by the critical action a_3 and then continued by whatsoever interactions represented by x_2 until the accident takes place. The pattern named p_1 is a most specific one. The pattern p_2 is one of many possible generalizations of p_1. The most general pattern is x_1, which is rarely of much interest. Apparently, patterns may be too specific or too general.

In the process of designing effective and affective experiences of play, designers consider likely patterns of game play that are of a moderate generality. Already the choice of patterns is a critical design step. For a certain selected pattern like p_1, e.g., the next design step means to negotiate the specification of subsequent experiences. The design storyboards are schematics on largely varying levels of granularity.

In case of Figure 8, the schematic designed in response, so to speak, to p_1 is a description of game play with stations of the time tunnel that relate to actions in p_1.

5 The application of time travel

This section aims at a demonstration of how the concepts and technologies introduced in the preceding sections work in practice.

Fig. 10. The virtual installation serving as an environment for accident prevention training

The virtual world illustrated by means of (only) four screenshots in Figure 10 is an implementation developed at Fraunhofer IFF and deployed by industrial co-operation partners, as well as within the fourth author's BG RCI prevention center on varying hardware and software platforms including mobile 3D kiosk terminals.

The last screenshot in the lower right position of Figure 10 displays a workplace. Subsequently, we will discuss a training session at this workplace dealing with the task of decanting a flammable liquid from a larger source container to a barrel. This will be accompanied by session screen shots to convey something like a touch and feel of training with a time travel prevention game.

The training game is experienced in a first-person perspective, very much like a conventional first person shooter. The only difference lies in the trainee's weapons and in the tasks to be performed. As Richard Bartle, one of the fathers in spirit of Dungeons and Dragons put it, "at the persona level of immersion, the virtual world is just another place you might visit, like Sydney or Rome. Your avatar is simply the clothing you wear when you go there. There is no more vehicle, no more separate character. It's just you, in the world" (cited after [24]).

During the execution of the Task Formulation episode, trainees get detailed advice describing the task to be performed. The system performs the actions of this episode.

When the Task Formulation episode is completed, the game system initiates the next episode by a scene placing the trainee in a working environment such as the virtual location displayed in Figure 10.

Next, it is the trainee's turn to interact with the environment. Usually, the episode offers varying alternatives. A trainee selects one, then possibly another one and so on.

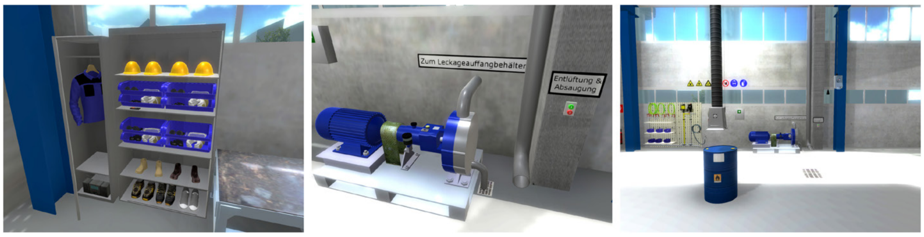

Fig. 11. Three of a trainee's actions represented by subsequent screenshots

The first screenshot on the left in Figure 11 shows the personal protective equipment. After dressing, the trainee has several opportunities. One is to turn on the de-aeration as on display in the middle. In Figure 11, the third screenshot illustrates that the trainee has provided the target barrel for the fluid to be filled in.

We continue the case study by way of illustration providing six more screenshots in Figure 12 and Figure 13 subsequently. The explanation can be kept short.

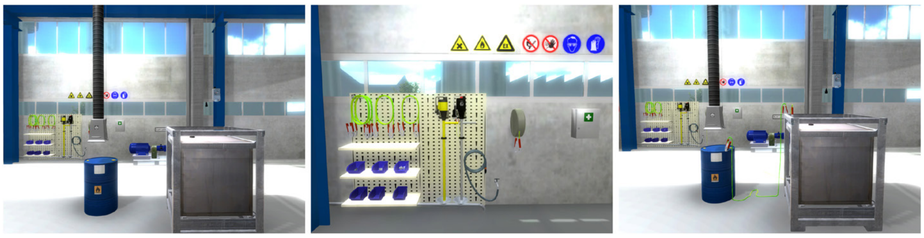

Fig. 12. On the left, the source container has been supplied. In the middle, the trainee inspects the available equipment, and, on the right, the trainee has attached the grounding cables

Fig. 13. From left to right, the pump is inserted into the source container, the counter is set up, the pump nozzle is connected to the target container, the suction device is in place

With the trainee's actions illustrated by means of Figure 12 and Figure 13, preparations are completed and the decanter installation is fully set up. The trainee is now ready to turn the pump on and finish the job.

Fig. 14. A sudden end of training or, alternatively, an opportunity to turn back the wheel of time

In the training session case study under consideration documented by screenshots in Figure 11, Figure 12, and Figure 13, the trainee selected and installed an illegitimate pump. According to the data recorded by the digital training game system, the result episode executed by the system (see also the action with the lightning bolt in Figure 8) appears as an animated explosion. The trainee may quit the session by pressing the white button. But there is the offer to engage in a time travel to avert the fate—a chance that is quite rare in real life.

Fig. 15. A slightly more adaptive end, giving the trainee some advice about what went wrong

For trainees who fail repeatedly, adaptive behavior of the system has varying forms (Figure 8 and Figure 9). In Figure 15 on the right, the trainee is informed that the illegitimate pump was causing the disaster. This corresponds to the rightmost instance in Figure 9.

Storyboarding is the appropriate technology to design adaptive experiences and to negotiate alternatives in the interdisciplinary team of designers.

6 Summary & outlook

To the authors' very best knowledge, what they are presenting in this publication is the first *time travel prevention game* for training of industrial accident prevention worldwide. However pleasant to be able to say and to write that, the open questions and the remaining work seems overwhelming.

First of all, when coming closer to the end of the current pandemic, training must be restarted and will allow for a systematic evaluation.

Second, there is much more content that can be integrated into the currently existing VR game world to allow both for a larger variety of trainee experiences and for a wider spectrum of accidents to experience virtually and, thus, to prevent practically.

Further research on adaptivity and implementations in this regard appears both academically and practically attractive to the authors. The more adaptive the game play is, the more efficient will it be, and the more affective and sustainable can it be to trainees.

Fig. 16. Iconic objects reflecting trainee actions of a time travel prevention game session and symbolizing a ground pattern that may be generalized toward the design of adaptivity

The objects on display, from left to right, are electrostatic discharge shoes, the switch of aeration, a leakage pump, a filled container, an empty barrel, a drum pump, a grounding cable for the container, and a grounding cable for the barrel.

When time travel becomes possible respectively necessary, the objects may occur in the time tunnel as already sketched in Figure 3. The aim at adaptivity can make it advisable to reduce the *stations of the time tunnel*, a didactic pattern concept shortly introduced in this paper (see Figure 8 and Figure 9).

Assume that we encode the eight objects above by action names in the alphabet A; shall we take a ground pattern as a basis of design? Or shall we replace some symbols of A by variables from X to arrive at a more expressive pattern? When we think about stepwise restrictions of time travel destinations as exemplified in Figure 9, how many versions shall we try? The numbers of different answers to those questions are growing exponentially in the length of the basic ground pattern.

Even worse, the objects on display in Figure 16 may occur in slightly different orders. The barrel might be brought to the workplace prior to the container, the grounding cables might be attached before the pump has been selected, and there is no required order in which the grounding cables have to be used.

The world of didactic design, in general—and of didactic and game design aiming at effective, affective, and sustainable accident prevention training, in particular—is very rich and full of secrets to be uncovered.

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