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Dovetailing Pedagogy and Technology for Training with Time Travel

Hans-Holger Wache [1], Ronny Franke [2], Oksana Arnold [3], Klaus P. Jantke [4*]

[1] Institution for Statutory Accidents Insurance and Prevention for Raw Materials and Chemical Industry, Prevention Center Berlin, 10825 Berlin, Germany

[2] Fraunhofer Institute for Factory Operation and Automation IFF, 39106 Magdeburg, Germany

[3] Building Services Engineering and Computer Science, Erfurt University of Applied Sciences, 99085 Erfurt, Germany

[4] Research & Development, ADAMATIK GmbH, 99423 Weimar, Germany

ABSTRACT

In technology-enhanced education, there is always a mutual impact between pedagogy and technology. To maximize educational effectiveness while leveraging the appeal of contemporary technology, educators and developers have introduced time travel exploratory games. To meet the needs of occupational accident prevention—a task of societal relevance for the protection of human health and life, the avoidance of damage and major financial losses, and for the protection of the environment—these exploratory games have been enhanced into time travel prevention games. The phenomenon of time travel allows for, and even fosters, a deeper dovetailing of pedagogy and technology. During accident prevention training, participants who have caused a—fortunately, only virtual—disaster are offered the option of time travel. By returning to an earlier stage of the training, they have the opportunity to change the outcome and to achieve better results on their next attempt. This approach relies on insights into the role of human mental time travel in episodic knowledge representation. From a pedagogical perspective, educational game design means the anticipation and preparation of stories of success to be experienced during game-based training. Essential elements of these stories should be memorable and even worth retelling. From a technological perspective, a trainee's mental time travel is digitally implemented—technology makes daydreams come true. Within practical training modules, several original and innovative concepts have been developed, implemented, and applied, such as modifications of the past that make pedagogical concepts operational.

*CORRESPONDING AUTHOR:

Klaus P. Jantke, Research & Development, ADAMATIK GmbH, 99423 Weimar, Germany; Email: Klaus.p.jantke@adamatik.de

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1. Introduction

The authors' area of application is *occupational accident prevention training*, a field of societal relevance to preserve human health and lives, to avoid damage and large financial losses, and to protect the environment. The customers are more than 35,000 enterprises with more than 1,600,000 insured individuals. The present contribution expands the author's prior–and quite recent–work [1–10].

As Prensky put it in the heading of chapter 2 of his book [11], "learners have changed", which led him to the study of *digital game-based learning*. Aiming both at the practitioners' low-threshold access to and at the high effectiveness of prevention training, the present authors settled on technology-enhanced game-based learning as well.

McLuhan, though not yet facing the rise of the internet and the contemporary hype of artificial intelligence (AI), writes about "the pain and the misery that result from a new technology" [12]. Among the many interesting cases in history, McLuhan is investigating, there is one in the sixteenth century. The paintings of Hieronymus Bosch are considered a response to "the Gutenberg technology invasion of the old tactile world" [12]. No doubt, technology has an impact on human life including education. Vice versa, human needs and desires challenge technology.

The present authors are going to study the interplay of pedagogy and technology in the area of game-based learning. Aiming at a particularly rich interplay, their intention is to go beyond the limits of game-based learning that may be called conventional and that is dominating the literature from Prensky [11] to the most recent present [13].

McLuhan did already recognize "the human power of retracking a path of events or of following a process quite independently of the material that is being processed" [12], a phenomenon more recently named *mental time travel* [14], considered relevant to the evolution of the human mind [15], and seen as a form of human knowledge representation [16]. Particularly the latter makes it relevant to technology-enhanced education.

The authors introduced the concept, studied the potential, and coined the term *time travel exploratory games* [17, 18]. Even more appropriate to occupational accident prevention training is the subclass of *time travel prevention games*, notably a key term (in German: Schlüsselbegriff) of the conference and expo series entitled German Prevention Day [19]. Originally, the development of time travel prevention games aimed at a novel contribution to crime prevention [20, 21]. Time travel prevention games enable players/learners/trainees when facing problems to travel back in the history of play to turn the tide, so to speak. This technology goes beyond the limits of conventional game-based learning, consequently opening up new opportunities and bringing with it new challenges.

Figure 1 presents a bird's eye view of the essential structure of a time travel prevention game. A decisive feature is that there is no need to teach with stories of disaster, an approach widespread in the topical literature on safety training [22–26]. From the viewpoint of interactive digital storytelling, the authors aim at the trainees' experience of stories of success [6–8]. Readers who would like to get a better understanding of and a better feeling for training with those digital games are directed to earlier publications that contain dedicated sections [1–9].

The present contribution aims at an investigation of the interplay of pedagogy and technology in the conditions of occupational accident prevention training with time travel prevention games. How does pedagogy challenge technology? And how does technology accelerate pedagogy? The working hypothesis is that–in the conditions of time travel games–novel effects occur and a deeper integration of pedagogy and technology becomes possible. Investigating the dichotomy of pedagogy and technology, Fawns identified what he calls an *entanglement of pedagogy* [10]. Beyond this entanglement, the authors' intention is to demonstrate a more intense *dovetailing of pedagogy and technology* by means of the development of novel concepts and their implementations in original time travel prevention games toward *unprecedented adaptivity*. This adaptivity, which may be seen as *personalized didactics* serves as proof of concept.

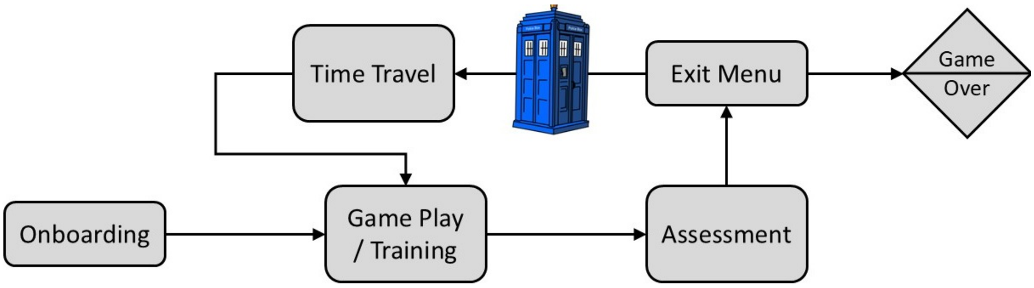

Figure 1. Top-level structure of a time travel prevention game.

2. Didactic and Game Design Challenging Technology

The design methodology of choice is digital storyboarding[27] that—from the viewpoint of dramaturgy—is understood as "the design of emotional experience. For digital games that are intended to tell a story, game design includes anticipation of the players' experiences, which will lead to excitement, fascination, thrill, perhaps to immersion and flow"[28], relevant to affective and, thus, effective training experiences. Storyboarding, shortly called "the organization of experience"[27] means anticipation and planning of future human activities in complex and dynamic conditions. At planning time, it is rarely known which plan will succeed at execution time. The authors adopt and adapt concepts, principles, algorithmics, and a mindset developed for dynamic plan generation applied to safety issues in the process industry[29]. Expanding on the conceptualization by Jantke and Knauf[27], this design methodology has proven in a variety of educational settings[30–42].

2.1. Essential Technicalities

The authors refrain from a detailed discussion of the technicalities of storyboarding adopted from the key source[29] and adapted subsequently[27] and, instead, focus the essentials sufficient for the present contribution. A storyboard is a finite hierarchically structured family of finite directed graphs, so-called pin graphs[43], as illustrated by means of **Figure 1**. Storyboard components such as nodes and edges are annotated by logical conditions that control the substitution of nodes by other storyboard graphs or their operational semantics, respectively, and the execution of edges leading from one scene to the next one. Parallelism is admissible constituting challenges to technology. Storyboards may be seen as graph grammars[44] and storyboard execution, i.e., playing the game, is graph rewriting[45].

Because the conditions that control rewriting depend on dynamic data of game play, the expressiveness of this type of graph grammars goes far beyond the limits of conventional graph grammar concepts[46]. The resulting experience evolves during game play and is not yet fully determined at planning time, i.e., at the time of didactic and game design. There does not exist any compiler that translates storyboards into game play. The generation of experiences of play is better described as storyboard interpretation[47].

2.2. Challenges

One of the authors' fundamental pedagogical positions is not to teach and train through the experience of disasters, but instead by means of stories of success[6, 8]. Stories experienced when training shall be remembered with pleasure and, thus, might even be worth telling. To avoid an end of game play with disastrous results, time travel is invoked that leads to a cyclic game design of the top-level storyboard graph as on display in **Figure 1**.

When a trainee decides to embark on a journey into the past, a time tunnel opens, illustrated here with cutouts from screenshots taken while running one of the authors' training modules.

The time tunnel has a personalized appearance that reflects the trainee's previous gameplay. Every scene experienced is represented by an icon in the tunnel. For example, the trainee's most recent action before a disastrous explosion with fire was the use of the exhaust suction device, which appears in the front on the left. Trainees can zoom in or out and select a past scene to travel to. The time tunnel contains three buttons at the top. With the left button, the trainee moves further into the past, progressing from the current front state to the next state behind it. Using the upper right button, one turns back coming closer to the present. These two outer buttons refer to the direction of a clock's arms as customary. A click on the button in the middle selects the central icon on display bringing the player to the past scene inside of the core game-based training episode where this object was used.

The basic technological requirement is that the system writes a log file of game play and generates corresponding sequences of icons in the time tunnel. For longer episodes of play, there are usually many possible orderings of icons. Potentially, every human trainee gets a personalized time tunnel for choosing the destination of every journey back into the history of game play.

It is a particular challenge to didactic and game design to deal with repeatedly occurring necessities of time travel. Technology is challenged accordingly.

For human trainees encountering difficulties, adaptive support is essential—an issue central to the authors´ pedagogy[1–10]. Time travel ideas are deeply interwoven with learner and trainee centricity[10].

By way of illustration, the training module underlying **Figures 2–4** deals with inflammable liquids. Disasters such as an explosion with fire may be self-induced in case an inappropriate pump is selected for decanting.

Figure 2. Traversing a time tunnel after 7 scenes of game play and the trainee's decision to try again.

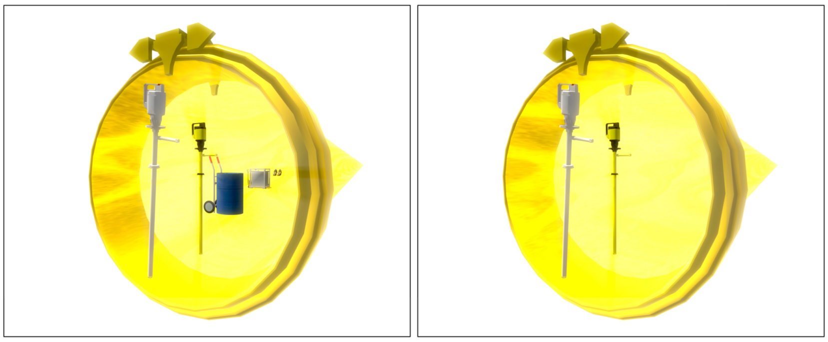

Figure 3. Administration of the time tunnel – target-oriented reduction of the destinations offered.

If a trainee fails repeatedly due to the same mistake, it is an elementary pedagogical principle to direct the trainee's attention to the decisive issues. Technology shall allow for an administration of the game's time tunnel such that irrelevant destinations disappear as displayed in **Figure 3**. The cutout of a screenshot from the authors' training module on the right illustrates a situation in which the system suppress irrelevant destinations of time travel. The scene in which the trainee selects a pump remains in focus.

Taking away the cause of a fault is the very last measure of pedagogy. At least, it is a goal of pedagogy to raise the human trainee's awareness of the situation. Technology is challenged to implement those ultimate measures. By way of illustration, **Figure 4** presents one of the technological solutions implemented in the authors' corresponding training module. The inappropriate pump is awakening to life and running away.

The effect of such an extreme solution is that (i) the trainee does not overlook the event, (ii) it is unforgettable, and (iii) it gives cause for reflection. Last but not least, in dependence on a trainee's social embedding, (iv) the experience may be worth telling. This helps to enhance the experience and to communicate the lessons learned. Telling interesting or even wondrous stories experienced may attract further trainees.

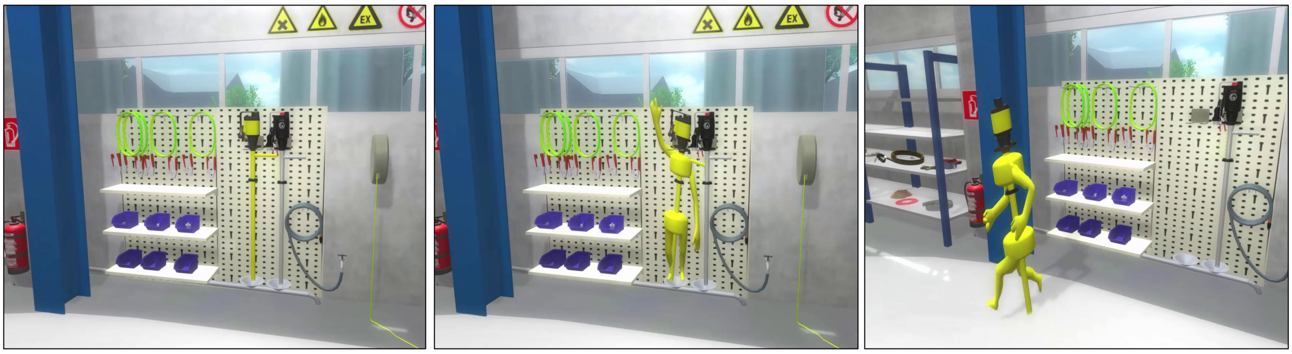

Figure 4. The ultimate system action to prevent a trainee from making a mistake.

3. Technology Empowering Pedagogy

The possibly surprising experience of game play exemplified in **Figure 4** above is an instance of a more general pattern of technological modification. Pattern concepts arose in the scientific discourse first in architecture [48] and are nowadays present everywhere in information and communication technologies. Particular design patterns are very recently introduced and investigated for the purpose of educational time travel [49] expanding on prior work on pedagogical patterns and didactic memes [50] where, interestingly, storyboard concepts as discussed in the section before play a key role as well. Patterns of game playing behavior are useful in technology-enhanced assessment and serve as indicators of mastery [51].

There will follow a section dedicated to an innovative pattern concept originally investigated in the present paper. The present section focuses on the particular technology of modifications of past states briefly referred to as mops [9, 10].

3.1. The Invention of Mops Technologies

Educational time travel offers to human players/learners/trainees the opportunity to be more successful the next time. But if a human trainee fails repeatedly, the game intelligence needs to take over by changing what is called the story space [52]. By modifications of past states (mops, for short), the game system provides adaptive guidance. It changes the possibility and/or necessity of game events, an issue that may be well-expressed in terms of modal logic [53], a perspective successfully applied to educational time travel investigations, implementations, and applications [4, 5].

A mop is an action of the game system denoted by μ in **Figure 5**. It may either be passed or executed in dependence on conditions specified in the process of didactic and game design. In case of execution, there may be alternative operational interpretations available, selected in dependence on dynamic data (see **Figure 6**). If executed, the mop μ takes place immediately before the trainee who arrived in the past can take action. The past is no longer what it used to be.

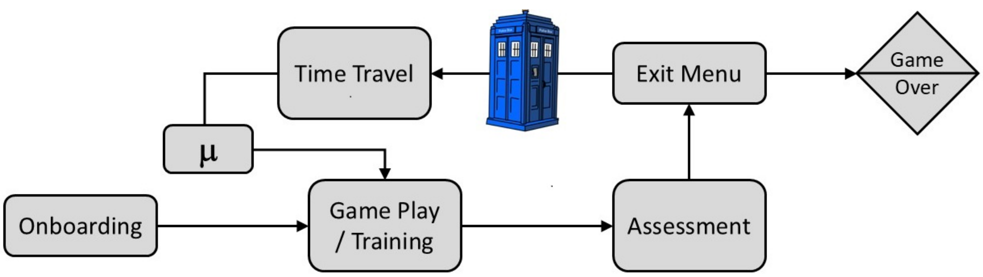

Figure 5. Extension of the top-level structure of a time travel prevention game by modifications of past states.

A modification of a past state as illustrated in **Figure 4** turns the modality of a player action from possible to impossible.

The introduction of the technological mops concept is illustrated by another case in **Figure 6** which shows screenshots from a training application developed for the paint and coatings industry. One of the problems that occur during a training session is the pollution of workplaces due to handling fluids with a high vapor pressure. Transportation of these fluids in buckets is impermissible. After a trainee fails repeatedly, a mop takes the buckets away. The buckets may be simply gone, they may slowly resolve (screenshot in the middle) or they may even fly away in front of the trainee's eyes (on the right).

Figure 6. Three alternative implementations of a modification of a past state—the disappearance of buckets.

3.2. Challenges

Innovative technologies allow for novel effects and, thus, for unprecedented experiences of playing a training game. The question is how to deploy the possible implementations for purposes of education.

Technology allows for the implementation of variants of events that are partially ordered with respect to certain properties such as the surprise effect as visualized by means of **Figure 6**. In extreme cases, a change may be overlooked. It is an opposite extreme if pumps are running and buckets are flying. Modifications of past states that restrict the trainee's option to interact may be partially ordered by the degree of story space reduction.

Whatever modifications of past states technology is offering to pedagogy, the alternatives raise the question of the didactic motivation of applying a mop and for the conditions in which the one or the other variant of a mop is chosen. Technology is bringing in novel issues of didactic and game design.

By way of illustration, in which condition is the observability of a modification of a past state pedagogically relevant? In cases where it is considered relevant, what are the variables that determine the choice of variants?

To complement the investigation of modifications that restrict the story space, the authors are exemplifying a case of story space extension. To adapt to the needs of a trainee who repeatedly selected the inappropriate pump for decanting an inflammable fluid, the game system may extend the available options of interaction as visualized by means of **Figure 7**.

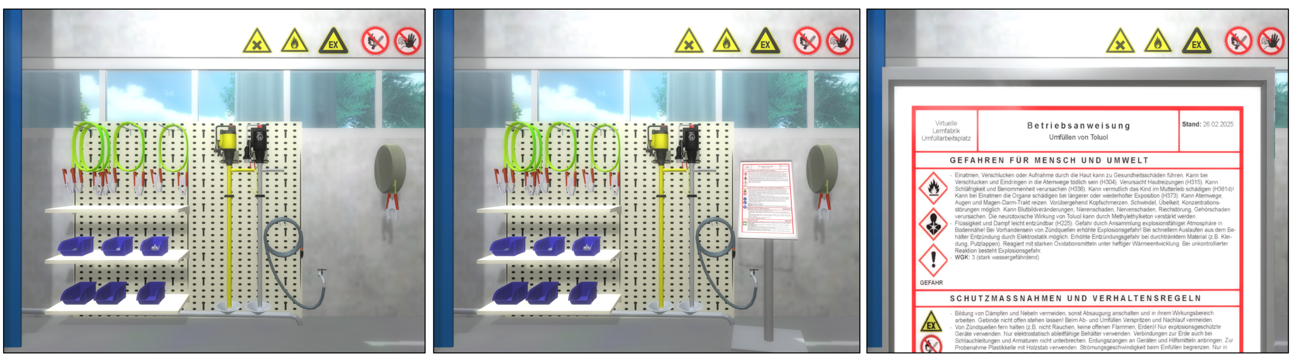

Figure 7. A modification of a past state that extends the story space by a new object allowing for a novel interaction.

Originally, the workplace appears unchanged (left screenshot of **Figure 7**). A mops inserts a put-up hinge (center) with a poster that turns out to be clickable. This way, the trainee's amount of options is extended. A click on the poster enlarges the text (right screenshot). The poster explains the differences between the two pumps available. This should prompt the trainee to select the right pump. It is a principle of didactics to support learners in finding their own solution.

However, this only works if the player decides to choose the novel opportunity, clicks on the poster for reading.

Technology has further measures to make the modification of the past clear and to emphasize its importance as illustrated by means of the screenshots in **Figure 8**. On the left, the pin-up hinge appears flashing up, in the center it comes within a cloud, and on the right the appearance is somehow magic. The usefulness in accident prevention training shows in the ultimate success of the human trainee.

Figure 8. Three alternative implementations of how a novel opportunity may bob up.

4. Prospective Experience Patterns

Patterns of prospective experience or, slightly shorter, prospective experience patterns (abbr.: Pep) constitute an innovative far-reaching concept introduced for didactic and game design. Pedagogy and technology are challenged at once.

The intention is that during game-based training, when such a pattern applies, it determines forthcoming experiences. It is a challenge to pedagogy to specify under which conditions and for what purpose to deploy what pep and, in particular, how to draw advantage from time travel. It is a challenge to technology to control future game play with pep accordingly.

4.1. Notions and Notations in a Nutshell

To speak about prospective experience patterns, there is a need for notions and notations of states in focus and of game play to come. The terms will be π and $\Pi_\pi(G)$, respectively. A stepwise introduction follows, stripped down to the core essentials.

M is a finite set denoting actions and events. The set of all finite strings over M is denoted by M* including the empty string ε. Defined on M*, there exists the binary operator of concatenation that does not need any operator symbol. For any $z_1, z_2 \in M^*$, one simply writes z_1z_2 to denote the concatenation of these two strings. Concatenation may be extended to sets of strings as follows. For $K, L \subseteq M^*$ it holds $KL = \{ z_1z_2 \mid z_1 \in K \wedge z_2 \in L \}$. Furthermore, there is the binary relation $\leq$ on M* expressing that the left string is an initial segment of the right one, i.e., $z_1 \leq z_2$ holds exactly if there is some $z \in M^*$ satisfying $z_1 z = z_2$. Notice that z may be equal to ε. The irreflexive part of $\leq$ is denoted by $<$.

Given a particular game G, the subset of strings in M* that denote complete game play from the beginning to an end is named $\Pi(G)$, where the letter Π shall resemble the word play. Game play proceeds through play states $\varepsilon < \pi_1 < \pi_2 < \ldots$ with $\pi_n \in M^*$. The game mechanics determines what may take place after a play state π denoted by $\Pi_\pi(G) \subseteq M^*$.

From the viewpoint of didactic and game design, the relationship between π and $\Pi_\pi(G)$ is decisive. $\Pi_\pi(G)$ abstractly represents the experience of play forthcoming after π. There exist patterns of a thoughtful design of affective and effective experience of game play—prospective experience patterns.

Two concluding remarks of the present subsection are deemed important, one about the pattern-instance relation and one about a widespread misconception.

A pattern is something general, a principle, a fundamental idea and the like, whereas instances are forms in which patterns occur in concrete conditions. A pattern may have many instances, usually infinitely many. And an instance may belong to more than one pattern. When dealing with patterns and instances in practice, what we are usually facing is not the pattern, but its instances. This establishes the pattern inference problem; given any set of instances, does there exist a common pattern underlying these instances? And if so, how to find such a pattern effectively? Usually, this is a problem of high algorithmic complexity [54].

Finally, there is a widespread misbelief that patterns are visible in their instances. The authors admit that there exist exceptional cases in which patterns are literally visible in their instances [55]. In general, however, there does exist background knowledge that is not embedded in a string. By way of illustration, think of string properties that depend on arithmetic. Peano arithmetic is rarely embedded in a string. There may be knowledge that assigns numbers to substrings such as, e.g., the approximate number of inhabitants assigned to a string which is the name of a location. There is context. The context determines a formula's validity. When dealing with game-based learning, context is in the game mechanics.

4.2. Bottleneck Patterns

To focus the present investigation, the authors confine themselves to only a very few prospective experience patterns; those related to bottlenecks of game play. In commercial digital games such as point and click adventures, the introduction of bottlenecks is a preferred technology to adhere players to a predefined story. They play from one bottleneck to the other.

For purposes of didactic and game design, the authors are interested in the human's experience of a bottleneck that—aiming at the success of training—is widened for them.

First of all, the concept of a bottleneck is introduced using the terminology of the preceding subsection. A bottleneck is the following property of a play state π, where B is a fixed set of letters or strings satisfying $B \subseteq M$ or $B \subseteq M^*$, resp.

$$\Pi_\pi(G) \subseteq M^*BM^* \tag{1}$$

For the reader's convenience, we are 'reading' the formula (1). After playing π, there may follow some unrestricted sequence of actions. But at some point, it necessarily follows an action from B or an action sequence from B, resp.

Apparently, formula (1) defines a property of π, because π is the only free variable that occurs in the logical statement.

The preceding formula (1) defines a string property that is considered a pattern. Whether or not a particular play state, i.e., a string of M^*, satisfies the formula (1) is determined by the context that comes in via the conceptualization of $\Pi_\pi(G)$. The authors' interest goes beyond the limits of just a bottleneck.

The idea of didactic and game design aims at an interplay that (i) enables players who passed a bottleneck to go on a journey in time for a game state preceding the bottleneck and that (ii) relies on game intelligence deployed for widening this particular bottleneck. As a result, the experience of game play may change fundamentally.

Using the terminology introduced within the preceding subsection, time travel from a current play state $\pi' \in M^*$ back to an earlier play state $\pi < \pi'$ means a sequence of particular actions and events $\tau \in M^*$ such that it holds

$$\Pi_{\pi'\tau}(G) = \Pi_\pi(G) \tag{2}$$

This is setting the stage for widening a bottleneck passed during the game play formally represented by the string π'. Widening a bottleneck is introduced as a particular modification of the past (see **Figure 5**).

Given a bottleneck B according to formula (1), widening the bottleneck means an extended set of actions $B \subset W \subseteq M$ or action strings $B \subset W \subseteq M^*$, resp., introduced by a modification named $\omega \in M$ satisfying the following pattern formula.

$$(M^*WM^* \setminus M^*BM^*) \cap \Pi_{\pi'\tau\omega}(G) \neq \varnothing \tag{3}$$

Apparently, formula (3) is a property of the play state $\pi' \in M^*$ in which via formula (2) the past play state $\pi \in M^*$ is contained implicitly. From the perspective of the play states, the formula describes what may happen in future game play. Thus, it is a prospective experience pattern.

For the readers' convenience, the authors circumscribe formula (3) briefly. The set difference in parentheses contains all the strings that are new due to the proper set inclusion $B \subset W$. The intersection represented by $\cap$ yields the set of all those sequences of play that are beyond the limits of $\Pi_{\pi}(G)$. As formula (3) explicitly states, this crucial set is not empty, i.e., there occur new opportunities of play due to widening the bottleneck.

4.3. Challenges to Pedagogy and Technology

Prospective experience patterns are challenging pedagogy and technology at once. Time travel plays a crucial role in drawing advantage of a widening of a bottleneck that has been passed before.

In the authors' training module for the paint and coatings industry cited earlier in the present contribution (see **Figure 6**), there exists a bottleneck that must be passed unavoidably: the selection of a container for the transportation of liquid from the dispensers to a basket mill. There is no way to complete the mission without this selection. The validity of the related pattern formula (1) is obvious. Unfortunately, a trainee may repeatedly make the serious mistake of choosing buckets.

During the design process, when a team of domain experts, educators, learning psychologists, VR developers, and possibly others identify a bottleneck of game play, this gives cause for the negotiation of possibly widening the bottleneck. The biggest challenge to creativity concerns the extension of B, more precisely, the embedding $W \supset B$. What shall be new, and how should it appear? This is really a challenge to the dovetailing of pedagogy and technology that becomes evident in the debate of the designer team.

An instance of widening a bottleneck implemented in the authors' training module for the paint and coatings industry is illustrated by means of **Figure 9**. As said before, the bottleneck consists in the necessity to select a container for liquids. When a trainee arrives by time travel repeatedly at the scene of the past, a modification widening the bottleneck is invoked. An NPC occurs offering a key to open a cabinet. Further actions of choice, i.e., trainee actions in $W \setminus B$, are available.

Figure 9. Returning to the past and facing a bottleneck widened by the game intelligence to support the human trainee.

5. Results

Initially, the authors' working hypothesis was that in conditions of time travel games certain novel effects occur in time-travel games, and that a deeper integration—termed "dovetailing" by the authors—of pedagogy and technology becomes possible. This hypothesis was fully confirmed, not only in theory but also in practice, as implemented in time-travel prevention game modules. Examples of this implementation are demonstrated through screenshots and excerpts displayed in **Figures 2–4** and **6–9**. As a side effect of their investigations, the authors developed a pattern concept referred to as "prospective experience patterns," which are examined here for the very first time. By nature, prospective experience patterns belong to both didactic and game design, as they essentially describe how future interactions depend on past gameplay.

From the authors' point of view, this contribution is primarily conceptual. Nevertheless, to provide a complete overview, it is worth noting that the innovative modules for occupational accident prevention training are developed at the Fraunhofer IFF on the basis of the development platform Unity and run on desktop computers and on virtual reality headsets used by employees of member enterprises of the Institution for Statutory Accident Insurance and Prevention for the Raw Materials and Chemical Industry in Germany.

6. Conclusions

The key motivation for the introduction of time travel prevention games [19] was to enable learners/trainees/players to impact the fate aiming at an ultimate success from the human's own strength. Humans are empowered to change the past. The authors' novel concept of modifications of past states–mops, for short–extends this ability to the digital game system. The system is technologically enabled to change the space of forthcoming human experiences by restricting the options of game play or by extending them [9]. The dovetailing with pedagogy is investigated in this contribution for the first time. Due to the original feature of virtual time travel in prevention training, this dovetailing of pedagogy and technology goes beyond the limits of conventional game-based learning.

Fawns is speaking about, as he put it, the entanglement of pedagogy [10]. The authors' present approach demonstrates dovetailing based on the extraordinary conditions of time travel beyond just entanglement.

The overall approach has a firm background of formal methods that include graph grammars and graph rewriting, formal language theory, and logics up to modal and, in particular, deontic logic. There is a mutual interplay of these three underlying fields. A deeper elaboration of the theory exceeds the possibilities of a publication of limited scope.

Before the authors direct the reader's attention to issues of future research, a few short comments is intended to position the present work within a broader and more current research context based on papers published in Summer 2025.

There exists the fundamental pedagogical principle that technology follows didactics [56]. Basically, the authors agree. But the time travel technology brings with it challenges to the pedagogy that broadens our horizons. Didactics may follow. Interestingly, recent surveys about *personalization of professional training* and about *innovations in higher education*, resp., do not mention the potential of virtual time travel [57, 58]. Apparently, education based on time travel prevention games is a bit ahead of the state of the art. One may express it, perhaps, a bit oversimplistically and naïvely, but hopefully illustrative: What is the didactic potential of a pump that can run away and of a couple of buckets that may soar into the air?

A few aspects are not yet investigated systematically. Among them is the interplay of restricting and extending modifications of the past at once, i.e., in a single mops, or subsequently. This means challenging pedagogy, obviously the question of who is following. When, why, and how to combine restrictions and extensions?

Going into some more detail, are there higher-level patterns for dealing with restrictions and extensions? It is not hard to imagine that a restriction that takes away the option to execute a certain action is later on compensated by enabling this particular action again. Once more, the question to pedagogy is when and why to do so.

Furthermore, there is some generalization left for future research. Readers are encouraged to consult once more **Figure 5**. According to the present conceptualization, a modification of a past state denoted by μ is a scene in terms of the original storyboard concept [27]. When this point is reached at storyboard interpretation time, i.e., when playing, the game system executes the operational semantics of μ, possibly choosing from a set of alternatives according to dynamic data such as the history of game play. For running implementation examples, readers may revisit **Figure 8**.

The authors allow themselves a digression. It is quite interesting to experience that conceptualizations such as the underlying concept of storyboards and storyboarding support the explication of essentials. This also applies to concepts from formal language theory when applied to investigating patterns in game-playing behavior [49]. This has been exemplified within the present contribution by means of the equations (1), (2), and (3). Formalization with the resulting clarity pays off.

The authors believe it is promising to systematically develop further variations of prospective experience patterns. Because these patterns are of varying strength, the idea of a partial ordering naturally suggests itself, forming the mathematical concept of a lattice. The lattice of prospective experience patterns is an unexplored area. As sketched in the last subsection of this contribution, this area challenges both pedagogy and technology simultaneously. Questions arise concerning the pedagogical interpretation of algebraic relations and the development of appropriate technologies for efficient implementation. From a methodological perspective, a lattice of patterns functions as an algebraically structured catalogue. Boolean operations performed on the lattice should carry pedagogical meaning and a technological interpretation, both of which represent unexplored challenges.

Let us return to the generalization of the scene μ. From a formal language point of view, μ appears like some letter. Accordingly, a generalization means to substitute for the letter some finite string. In terms of the storyboarding technology, there might be a sequence of scenes to be experienced one after the other. Recall that we are dealing with modifications executed by the game system. In case the actions are not observable, this makes no difference for the human experience. Alternatively, assuming all actions are recognizable, the trainee arrives at the destination of the time-travel journey and observes a sequence of ongoing changes. By way of illustration: first, the pollution of the workplace becomes visible as gray clouds billowing out; next, the gray clouds transform into a colorful heatmap that more precisely illustrates pollutant concentration; finally, the player feels being lifted to float above the workplace, seeing the disaster from a bird's-eye view.

The generalization of the mops concept resembles a sub-story or, if interactions are enabled, an embedded minigame whose deployment presents a novel pedagogical challenge. Technology and pedagogy, literally engaged in an interplay, continuously inform and shape each other.

Author Contributions

Industrial and domain knowledge, topical didactics, pedagogy in the industry, H.-H.W.; conceptualization, formal methods, O.A. and K.P.J.; software, VR technologies, implementation, R.F.; exploratory time travel games, O.A.; time travel prevention games, K.P.J.; dynamic plan generation, AI planning, O.A.; storyboarding concepts, K.P.J.; pattern concepts, modal logic, K.P.J.; educational game design, H.-H.W., R.F. and K.P.J.; special effects of game play, R.F.; industrial accident prevention training, administration of the learning process, H.-H.W. and R.F.; writing, K.P.J. and O.A. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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