Chapter

Time Travel Gamification of Learning and Training: From Theoretical Concepts to Practical Applications

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Abstract

Gamification is considered the systematic anticipation and design of affective experiences. It is not erroneously reduced to the usage of game-typical elements in another context. The human experiences in focus are varying forms of virtual time travel. In a time travel exploratory game, players return virtually to the past for gaining insights and, possibly, finding artifacts bring back to the present time. This works well for environmental education studying, by way of illustration, the worldwide ocean warming over several decades. Time travel prevention games go even further. Players who visit the past get an opportunity to impact their fate. This works well in application areas such as crime prevention and industrial accident prevention. Dynamic time travel prevention games are a recently developed game type in which the past changes dynamically to support the player's chances of successfully completing the mission. The authors present original concepts and technologies and demonstrate running applications.

Keywords: gamification, time travel games, time travel exploratory games, environmental education, time travel prevention games, industrial accident prevention, dynamic time travel games

1. Introduction

The Institution for Statutory Accident Insurance and Prevention for Raw Materials and Chemical Industry has more than 34,000 member enterprises in Germany with about 1.6 million insured persons. Learning and training that aims at accident prevention are of high societal significance.

Gamification is an approach to make conventional learning and training more attractive, even more effective. In particular, the authors present concepts of virtual time travel and implementations as well as applications.

2. Gameplay

The systematic transformation of learning and training into playful experiences requires an understanding of the phenomenon of play. Johan Huizinga's cultural-historical perspective [1] is worth consideration, but far from operationalization. Opinions are divided.

There are a few more concise conceptualizations in the topical literature such as considering *an activity taking place on the basis of formally defined rules and containing an evaluation of the efforts of the player. When playing a game, the rest of the world is ignored* [2]. However appealing at a first glance, this perfectly fits written exams in schools, vocational education, and higher education. It misses the point.

As Fabricatore puts it, *there is probably no universally accepted definition of gameplay* [3]. But there is an urgent need for a firm foundation of endeavors such as gamification in areas of societal significance.

Based on rich sources such as the books by Fritz [4] and Koster [5], the authors prefer a lucid approach adopted from [6, 7] and illustrated by means of **Figure 1**.

Those who engage in gameplay perform an act of framing as psychologists and communication scientists call it. That is basic to Juul's saying that the rest of the world is ignored (cited from reference [2] above). And it coincides with Bartle's saying that *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 [8]).

Engaged in playing a game, humans experience a balance of indetermination and self-determination [9]. This balance may depend on the knowledge and skills of the player and changes over time due to the experience of play. Indetermination may be based on a large variety of factors such as randomness, complexity—there is a deep relationship between randomness and complexity [10]—environmental conditions, and the presence of other human players. Apparently, because the balance is dynamic, the experience of play changes over time. What appeared incomprehensible in the beginning may become more and more interesting over time. What once has been exciting may become boring when getting under control.

The crux is that play brings with it learning—learning of the game mechanics, learning of patterns of play, learning of the relationship of stimulus and response, and the like. The player's efforts of gaining control to increase self-determination and to overcome indetermination unavoidably result in learning (for illustration, see [11]).

The authors' perspective at play visualized by means of **Figure 1** leads to some fundamental insights into the essentials of play such as the dovetailing of playing and learning. The perspective serves as a guideline for game design, in general, and for the gamification of learning and training, in particular. This will be demonstrated throughout the rest of the present contribution.

Figure 1.
Illustration of the concept of gameplay as introduced and discussed by the authors in [6, 7].

3. Gamification

The authors aim at the transformation of socially relevant learning and training into attractive and effective experiences of play, a case of educational gamification, a term coined in [12]. In this report, the authors cite a vision translated from [13] as follows. *Imagine—if successful—teaching, learning, and training offers that are addictive. Learners always want more and learn more, trainees cannot stop to train, and those who learn and train, form communities on the internet where they exchange their experiences and successes in acquiring knowledge and sharing skills, as well as inspiring others to participate. Imagine, textbook publishers producing educational materials of an addictive nature and where school becomes our children's favorite venue*.

The gamification of a publisher's textbook material is systematically investigated and technologically described in [14]. But this does not apply to the present chapter that has *Time Travel Gamification* in focus, a term coined here. There is apparent evidence for the need for disambiguation.

As Landers et al. put it, *definitions of gamification tend to vary by person, both in industry and within academia* ([15], p. 315).

Authors like Deterding et al. trivialize gamification as the use of elements of game design in non-game contexts ([16], p. 2, see also [17], p. 10). If they would be right, everyone were able to implement gamification and nobody would need any scientific background to do so. Chou [18] claims to go *beyond points, badges, and leaderboards*, but being a bit changeable, he later explains gamification as *the craft of deriving fun and engaging elements found typically in games* ([18], p. 8). Here they are again, Deterding's elements of game design.

Bogost [19] responds by calling gamification *bullshit* and naming those supporting gamification *bullshitters*.

At this point of the controversy, the authors take up a position. Due to the focus on learning and training, the term of educational gamification is adopted from [12], p. 5: *Educational Gamification means the transformation of given learning or training material and/or educational environment into a form that bears the potential of playful experiences that are likely to unfold when humans accept to engage*.

As briefly discussed in the preceding section, experiences of gameplay are highly individual and, in addition, depending on local and temporary conditions. According to Chou, gamification means *combining different game mechanics and techniques to form desired and joyful experiences for everyone* (cited from [18], p. 10).

There is no way "to form experiences for everyone". Instead, there are techniques of providing spaces of experience—called story spaces in [20]—such that there may dynamically unfold experiences of play that vary from one human player to the other, i.e. desired and joyful personalized experiences for everyone. Story space design is dynamic planning [21] based on dynamic approaches to storyboarding [22]. The storyboarding approach itself is adopted and adapted from dynamic plan generation in critical industrial application domains [23]. *Storyboarding is the organization of experience*, as Jantke and Knauf put it ([22], p. 25). To make the experience affective and effective, the design shall be adaptive to the learners' needs and desires [24–29] by means of Artificial Intelligence [12].

Varying approaches aim at transformations toward exciting playful experiences. In critical industrial application areas, failure is a crucial phenomenon to deal with. Following Litts and Ramirez, the authors see *failure as a process, not an endpoint* [30]. Papert compares the trainees' struggle with failure to a term of software engineering: debugging ([31], p. xiii). This is logically related to abductive reasoning [32, 33].

To deal with failure playfully, given a digital training environment, the authors suggest the implementation of abductive reasoning by means of virtual time travel, a novel approach to gamification called *time travel gamification*.

In other words, gamification of a training environment is performed by means of the introduction of time travel opportunities. Trainees get offered the chance to impact the fate—an exciting experience they can hardly gain in the industrial practice.

Imagine a training module structured according to the high-level storyboard graph on display in **Figure 2**. For more details of the underlying storyboard concept and of the storyboarding process, readers are directed, besides the key source [22], to a conceptualization called layered languages of ludology [34, 35], to dynamic plan generation [21, 36–42], to didactic knowledge in storyboards [43–48], and to large-scale applications in areas such as civil protection and disaster management [49, 50]. The details of the storyboarding technology are beyond the limits of this contribution.

To complete this short intermediate discussion, interested readers are directed to a possibly valuable practical approach—*storyboard interpretation technology* [51]. Sufficiently complete digital storyboards are computer programs that may be subject to automatic interpretation, i.e., to execution.

Smaller nodes of a storyboard graph describe *scenes*. Scenes have—possibly alternative—semantics in the domain given by other components of the storyboard. By way of illustration, the scene Task Formulation may be implemented by means of a video, an audio file, a PDF document, a text on the screen, or anything like this up to a face-to-face instruction by a trainer. The scene Exit Menu might offer just two buttons either for returning to the Data Analysis or for leaving the training session.

The larger nodes of a storyboard graph represent *episodes*. For every episode, there may exist alternative graphs of the storyboard for substitution. The substitution of a storyboard graph for a node has execution conditions, an issue that will be discussed in more detail below. If an execution condition contains variables that may hold dynamically changing values and if the substitution of nodes is postponed up to execution time, this is key to the dynamic emergence of varying training experiences, a decisive property inherited from the underlying approach to dynamic planning [23].

Gamification is the transformation of designs such as the one shown in **Figure 2** into the one in **Figure 3** toward the enabling of varying playful experiences.

The authors' present approach to time travel gamification consists of the extension of a given design by means of opportunities to travel back in time virtually. The didactic intention is to allow for another trial—perhaps several times—such that human trainees get a chance to arrive at better results, found in the Data Analysis episode, they may consider their own individual achievement.

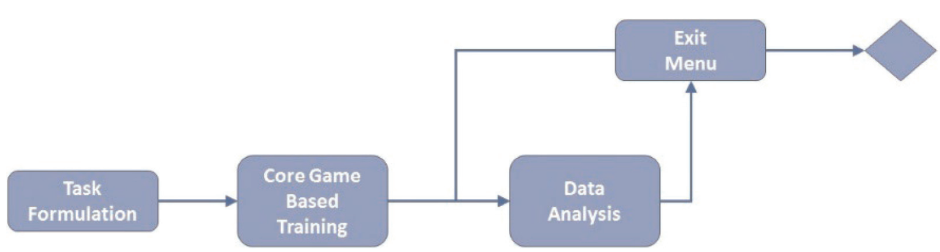

Figure 2.
Top-level design storyboard graph G1 specifying a training module including closing assessment.

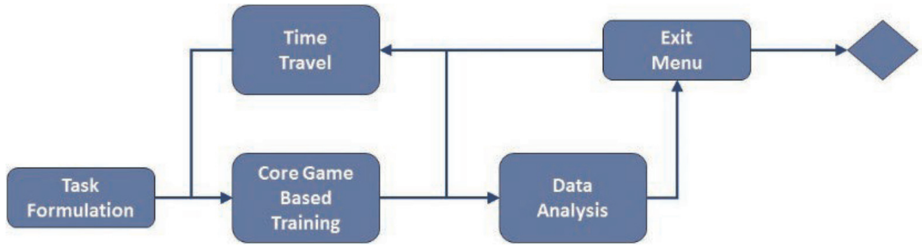

Figure 3.
Top-level design storyboard graph G1 specifying time travel gamification of a training module.

4. The time travel gamification methodology

The introduction of time travel does not primarily lead to any game elements such as points, badges, or leaderboards. It bears the potential of unprecedented experiences.

4.1 Syntactic embedding

Syntactically, time travel gamification shows in embedding novel scenes and episodes in conventional interaction design as exemplified by **Figure 3** compared to **Figure 2**. In the case of **Figure 3**, for instance, inserting a Time Travel episode requires changes in all implementations of the Exit Menu scene such that the novel episode becomes accessible from there. By way of illustration, **Figure 4** shows on the left a Tardis-like entrance to time travel. The present authors try to avoid overstating issues of syntax.

Similarly, the edges outgrowing newly introduced episodes and scenes need to point to some successor node such as core game-based training in **Figure 3**.

Under the hood, so to speak, the training system does a lot of bookkeeping to allow for adaptivity. User/learner/trainee/player profiles are essential to a digital system's ability to hypothesize the human user's needs and desires and to adapt accordingly. This artificial intelligence perspective is discussed in some detail in the paper [52]. The authors confine themselves to a detailed discussion of syntactic implicitness. From time to time—as in the following paragraphs—a few details are shining through.

Another more subtle issue of syntax relates to execution conditions. For the sake of adaptivity, it becomes important to process data of a trainee's repeated time travel. Those data are collected by means of the system's bookkeeping. They are only useful if execution conditions are syntactically modified to access the time travel history. It is an issue of didactics and game design on how to use the syntactic data semantically.

4.2 Time travel control

Time travel gamification has the gist of play in focus. Consequently, it comes with a high degree of self-determination that shows, among others, the freedom to select the destination of time travel. **Figure 4** shows on the right a variant of the authors´ time tunnel as implemented in some of the authors´ current applications.

During a training session, the episode of core game-based training is substituted by a lower-level storyboard graph, nodes of this graph may be substituted again, and so on until scenes determine what actions a player may execute. For executed scenes, the system uses iconic representations that represent destinations in the time tunnel. The

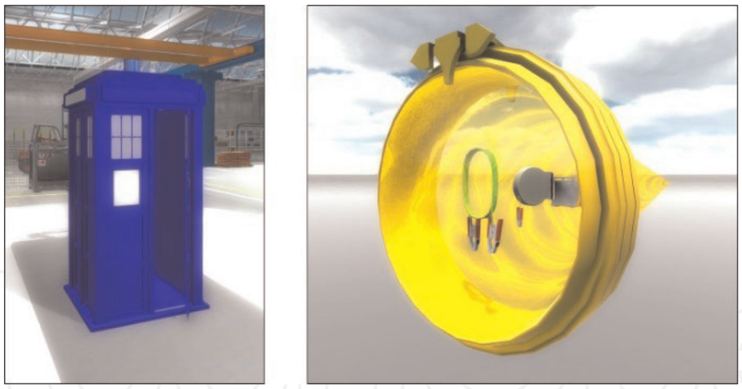

Figure 4.
Technicalities to control time travel: a Tardis-like entrance and a time tunnel with destinations.

player may fly through the time tunnel backward and forward in time, the latter—for the time being—only within the limits of the history of gameplay that took place. For time travel prevention games as in [21, 53], and for time travel exploratory games, a term coined recently in [52], journeys to the future are not yet considered. The selection of an object by clicking the button in the upper middle of the time tunnel brings the player backward in time to the related scene.

In case a player has difficulties in completing the training mission successfully and, therefore, goes repeatedly on a journey in time, this shows the necessity of guidance. The adaptivity of time travel is a key issue of time travel gamification. Consequently, time travel gamification is deeply interwoven with artificial intelligence design [52].

From the perspective of play (see **Figure 1**), the first approach to better adaptivity is to change the balance of self-determination and indetermination. The choice declines.

The first approach may be implemented by stepwise reduction of the stations in the time tunnel as demonstrated earlier by the authors (see [53], Figures 8 and 9). The ultimate strongest version is to direct the player to the decisive scene only. Apparently, it is an issue of learning psychology, game design, and media didactics whether or not and, if so, in what conditions to decide for such a strong guidance.

Similarly, one may reduce the number of possible interactions with a scene, in this way decreasing the likelihood of wrong decisions, a step toward dynamics of the past.

4.3 Dynamic modification of the game world

Dynamically changing the past of gameplay is a method introduced in [54] and demonstrated by means of an application for the training of accident prevention in the paint and coatings industry. Trainees when traveling back in time may arrive at scenes they have experienced before, but that appears somehow different this time.

The method is illustrated in the present contribution by means of two screenshots taken from the application demonstrated in the following Section 5.

There is an enormous space of opportunities to change the story [20] experienced during game-based training—a highly creative part of the time travel gamification methodology. Subsequent variations of AI support to the human trainee may be considered cascades, as the authors put it in the study [54].

Figure 5 shows on the left a scene as experienced for the first time. Among others, grounding cables and pumps are available. The trainee is expected to install the grounding before a pump is used. Furthermore, the wall-attached grounding shall be

Figure 5.
The past is no longer what it used to be—dynamic changes to increase the likelihood of success.

used first, because attaching the two-sided grounding cable to two containers may result in an equipotential bonding.

At a later visit on display in **Figure 5** on the right, the virtual past has changed. There appears a nonplayer character (NPC) talking to the trainee. The empty speech bubble is intended to indicate that even the NPC's utterances may be modified from a visit to visit aiming at increasingly better guidance of the trainee.

5. The time travel gamification in practice

No other industrial training experience is lasting as long as a self-induced accident, especially if it comes with an explosion and fire. Affective training is more effective. For good reasons, however, the authors prefer to experience accidents only virtually. The installation on display in **Figure 6** is a perfect place for learning from experience, in particular, if trainees get offered opportunities of time travel to impact the fate.

The authors adopt and adapt some training situations from [53] in the virtual installation on display in **Figure 6** developed at Fraunhofer IFF, Magdeburg, Germany. The implementation is in use at the Institution for Statutory Accident Insurance and Prevention including several industrial partners. The mission discussed in the present demonstration consists of the decanting of an inflammable fluid from a larger container into a slightly smaller barrel. Trainees are informed about their mission in the task formulation scene (see **Figures 2** and **3**).

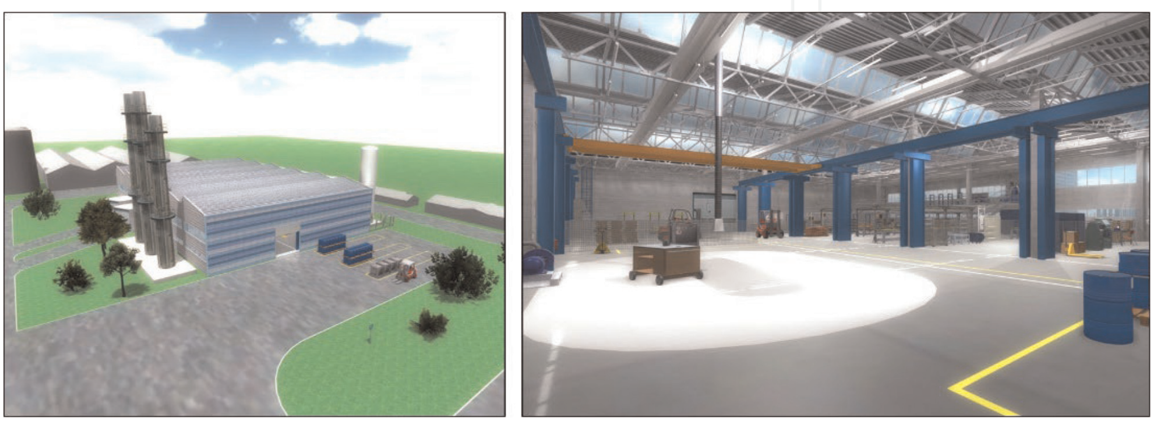

Figure 6.
A virtual installation for training accident prevention is subject to time travel gamification.

The left screenshot of **Figure 6** shows the virtual factory in its virtual environment. On the right, there is the inside workplace where the trainee shall perform the task explained by means of the task formulation scene implementation.

It follows the core game-based training episode that is implemented by several scenes of activities such as putting on protective clothing and turning on deaeration.

The scenes that occur in the main training episode are partially ordered. Some of them have a certain dependence on others—by way of illustration, getting dressed comes first—whereas some other scenes are mutually independent of each other. By way of illustration, there is no required ordering between turning on the de-aeration and attaching the two grounding cables. But for grounding, a required order exists.

The designer team of domain experts, IT specialists, learning psychologists, and possibly other experts negotiate those dependencies. The result is reflected in some storyboard graphs specifying potential implementations of the main episode [21].

Throughout this section, subsequent figures illustrate the actions of a trainee that took place within a training session. Recall that actions have iconic representations that occur in the time tunnel, in case traveling back in time becomes necessary. Subsequently, all this will be illustrated by means of screenshots from a training session that begins with the dressing scene (see left screenshot of **Figure 8**) and ends with an undesired accident visualized by the rightmost screenshot of **Figure 11**. Unfortunately, a book chapter presentation like the present one does not allow for a visualization of the dynamics of the human-system interaction.

In case an undesired event terminates the main training episode, a trainee has to decide how to respond. Time travel gamification is intended to reduce frustration, encourage continuation, and guide the trainee to a satisfying completion of mission that is experienced as the trainee's own achievement.

5.1 A straight forward training session

The designer team negotiates the issue and decides on the intended balance of self-determination and indetermination (see **Figure 1**). Potential substitutions of the core game-based training episode specify the dichotomy of freedom and guidance.

The simple storyboard graph on display in **Figure 7** exemplifies the design idea that getting dressed professionally first is not put at the human trainee's disposition. Trivialities like that are not subject to game-based training. This may serve just as an example, an illustration, of how storyboarding is used to adjust the focus of training.

Notice that the scene of the storyboard graph in **Figure 7** is indicated iconically. Seen from the perspective of time travel, scenes are considered atomic. Journeys may lead back to a scene as a whole, but not into a scene. This is underlying the iconic representations in the time tunnel (**Figure 4**).

Figure 8 reports the first trainee activities by means of 3 subsequent screenshots.

After putting on the personal protective equipment, the trainee dealt with a carriage blocking the workspace and, next, turned on the deaeration.

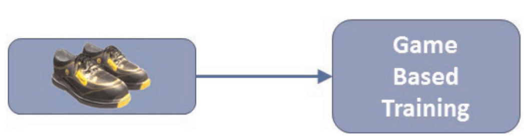

Figure 7.
*Next-level storyboard graph for expanding the core game-based training episode (**Figures 2 and 3**).*

Figure 8.
Preparatory scenes of training to get ready for the critical decanting of a certain inflammable fluid.

Notice that the carriage on display in the central screenshot of **Figure 8** carries a radio and a cellphone both containing rechargeable batteries. Those objects must be removed from a workplace; a sub-activity when dealing with the carriage scene.

There is a larger number of scenes—actions to be executed by the trainee—that have to occur in expansions of the game-based training episode shown in **Figure 7**. They are iconically visualized in **Table 1**.

In fact, **Table 1** represents a storyboard graph that exclusively consists of scenes. Whereas graph representations as in **Figures 2, 3**, and 7 might be more appropriate to human comprehension, a relational presentation such as in **Table 1** does perfectly meet a digital system's needs.

Conceptually, every finite directed graph consists of a set of nodes N and a set of edges E, where E is a binary relation over N, i.e. $E \subseteq N \times N$.

Following Jantke and Knauf [22], storyboard graphs are additionally annotated by a variety of logical formulas. Formulas that are attached to a whole graph determine conditions in which the graph may be used for expansion of an episode. By way of

										
	0	1	1	1	1	1	c_2	c_3	c_3	c_4
	1	0	1	1	1	1	c_2	c_3	c_3	c_4
	1	1	0	1	1	1	c_2	c_3	c_3	c_4
	1	1	1	0	1	1	c_2	c_3	c_3	c_4
	1	1	1	1	0	1	1	c_3	c_3	c_4
	1	1	1	1	1	0	1	c_3	c_3	c_4
	1	1	1	1	c_1	c_1	0	1	c_3	c_4
	1	1	1	1	0	0	0	0	c_3	c_4
	1	1	1	1	0	0	1	1	0	c_4

Table 1.
Edges between scenes for expansion of the core game-based training episode of ***Figures 2*** *and* ***3****.*

illustration, this type of execution conditions is used to prevent graphs from multiple substitution, in case an episode—due to virtual time travel—is visited repeatedly. Designer teams negotiate and specify the regulations of graph substitution based on their respective concepts of didactics, game design, learning psychology, and the like.

Furthermore, edges may carry annotations as well. If an edge from a node n_1 to a node n_2 is annotated by a logical formula c, the formula c determines in which conditions node n_1 may be immediately followed by node n_2.

The first graph in tabular form represents largely unconstrained opportunities of trainee activities. Trainees can even repeatedly return for playing a scene differently. Notice that this graph does not obey the design requirement exemplified in **Figure 7**.

Readers may easily recognize that the graph represented by means of **Table 1** consists of 10 nodes and 76 edges. Note that 0 describes the logical value *false*, thus, indicating that the corresponding edge does not exist. A graph representation as in **Figures 2, 3**, and **7** with 76 edges might appear a bit cumbersome.

Notice that a graph for substitution of **Figure 7**'s game-based training episode results from the one in **Table 1** by elimination of the first row and the first column.

As said before, the above graph is the most unconstrained one that may occur in an early training phase—its logical execution condition is controlling in which conditions it may be substituted for the core game-based training episode in **Figures 2** and **3**.

The value 1 in a cell of the graph description table represents the logical value *true* indicating the scene denoted by the icon in the leftmost column may be always followed by the scene denoted by the icon in the uppermost row.

There are four nontrivial annotations to edges denoted by c_1, c_2, c_3, and c_4, resp., decorating 28 of the edges. The formulas describe minimal technological conditions.

Condition c_1 says that the object of the next scene to be visited, either the barrel or the container, must not yet be connected to the wall-mounted grounding cable. Formula c_2 says that, at least, one of the object's container and barrel must be in place. And c_3 is the requirement that both the container and the barrel are already in place. By way of illustration, this is an obviously necessary precondition for the installation of the two-sided grounding cable. Condition c_4 describes the requirement that all preparations are complete and the process of decanting may be started.

The icon heading the last rightmost column is showing the switch to turn on the pump for completing the mission. This scene has no successor scene in this graph.

So far, the trainee has experienced three scenes as illustrated in **Figure 8** which are the first scenes iconically represented in **Table 1**. The trainee has many choices to continue as determined by the third row of **Table 1**.

Training proceeds as on display in **Figure 9**. First, the trainee brings the barrel to the workplace. Next, the container is provided. Third, illustrated by the rightmost screenshot of **Figure 9**, the trainee inspects the available grounding cables and selects

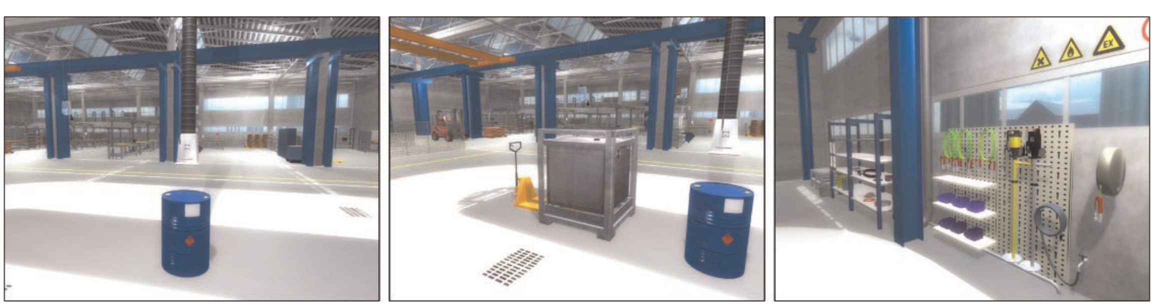

Figure 9.
Further preparatory scenes of training to get ready for the critical decanting of a certain inflammable fluid.

the wall-mounted cable. As visible in the leftmost screenshot of **Figure 10**, this cable is attached followed by the two-sided grounding cable collecting container and barrel.

Condition c_3 is satisfied. This allows for the installation of a pump as determined in the last but one column in **Table 1**. The second and the third screenshots report that the trainee has installed a pump in the container and connected the pump's hosepipe to the barrel. Furthermore, the de-aeration iconically represented by the green button has turned on and the exhaust system is in place over the barrel.

The graph relationally represented in **Table 1** determines that the only remaining scene—the one iconically represented by the switch on top of the last table column—is the execution of the decanting process. Turning on the pump by pushing the button shown in the central screenshot of **Figure 11**, results in an explosion and fire.

5.2 Time travel gamification exemplified

The training activities surveyed and illustrated in the preceding subsection lead to an undesired event, an effect that is not uncommon in the training of complex tasks in risky conditions. From the viewpoint of learning psychology, events like that are valuable. Self-induced accidents are effective and bear the potential of effective learning and of sustainable insights and patterns of behavior. Moreover, they may be considered worth telling and, thus, contribute to the dissemination of the authors´ efforts in training for accident prevention in the industry.

But how to respond in the context of training? How to continue such a session? Time travel gamification is the authors´ answer to transform an undesired event into just the initially motivating experience within the framework of an adventurous experience of play that leads human trainees to mastery using their own resources. As shown in the light of **Figure 1**, self-determination shall overcome indetermination.

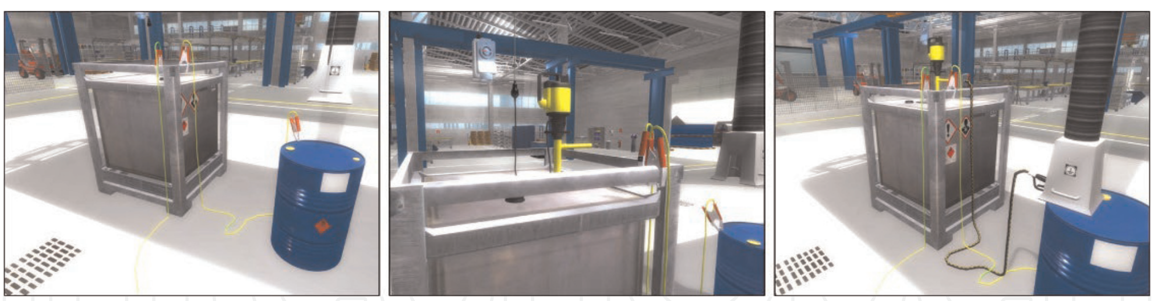

Figure 10.
A pump is installed, grounding cables are attached, and a pipe leads to the barrel.

Figure 11.
The issue of pump installation in the container showing the counter, the switch, and the effect.

Digital storyboarding as reported in [21, 41–50, 52–54] is the design technology to span story spaces [20] of potential experiences desirable from a didactic perspective.

According to [22] expanding on [23], a storyboard is a finite hierarchically structured family of finite directed graphs, a bit more precisely, of pin graphs [55]. Lower-level storyboard graphs are prepared expansions for episodes in higher-level graphs. Among others, they represent patterns of game design and didactics [7, 47]. The modeling of educational theory by means of storyboarding is exemplified in [48]. In this section, the authors confine themselves to the present application case study.

First of all, time travel gamification means extending a storyboard by graphs such as the one on display in **Figure 3**. Trainees get opportunities to revisit scenes of the past—based on the system's bookkeeping of game-playing history—and to do better this time. But the avoidance of inaccuracies is not guaranteed by repetition of actions.

The diagonal structure of **Table 2** reflects a certain partition of the set of scenes.

The scene of putting on the personal protective equipment must come first because there is no edge in the graph that leads to this scene. This is followed by the three scenes dealing with the carriage, the leakage pump, and the de-aeration switch. These three scenes may be visited in any order and they may be revisited repeatedly. They form, so to speak, an elementary preparation episode.

The elementary preparation is followed by bringing the container and the barrel into the right working position. The corresponding novel execution condition c_5 says that the elementary preparation must be complete. Condition c_3 is the same as before saying that both the container and the barrel must be in place, whereas the negation written as $\neg c_3$ says that one of them is still missing. The wall-mounted grounding is usable as soon as c_3 is valid. The other scenes follow deterministically.

										
	0	1	1	1	0	0	0	0	0	0
	0	0	1	1	c_5	c_5	0	0	0	0
	0	1	0	1	c_5	c_5	0	0	0	0
	0	1	1	0	c_5	c_5	0	0	0	0
	0	0	0	0	0	$\neg c_3$	c_3	0	0	0
	0	0	0	0	$\neg c_3$	0	c_3	0	0	0
	0	0	0	0	0	0	0	1	0	0
	0	0	0	0	0	0	0	0	1	0
	0	0	0	0	0	0	0	0	0	1

Table 2.
Alternative graph implementing some concepts of didactics and game design for later expansion of the core game-based training episode when being revisited due to the chance of time travel.

Table 2 defines a storyboard graph more constrained than the graph in **Table 1**. The team of designers, in response to varying trainee behaviors, may come up with further alternative graphs aiming at a guidance to ultimately successful experiences. In this contribution, the authors refrain from an attempt of completeness. Instead, the graph of **Table 2** will be rewritten, visualized differently, and discussed in some detail.

The graph of **Table 2** presents an alternative characterized by a unique initial scene and a unique final one. Those distinguished nodes of a graph are called *pins* [56] expanding on [55]. Graphs like the one represented by **Table 2** and visualized differently by means of **Figure 12** are, so to speak, prototypical pin graphs.

From the viewpoints of ludology, of learning psychology, and of topical didactics, the goal is to support the emergence of varying experiences. This is made possible by means of the dynamics of plan generation as developed in [23] and adopted by [22]. Graph expansion occurs at execution time. The anticipation of varying experiences and the design of graphs prepared for substitution that—by means of time travel—make desired experiences likely is what the authors call *time travel gamification*.

By way of illustration, the core game-based training episode in **Figure 3** may be substituted differently when arriving there on repeated occasions. An expansion by means of the graph of **Table 2** leads to a closer look at time travel opportunities based on the structure that becomes more intuitively visible in **Figure 12**.

Figure 13 displays a design decision from the time travel gamification process that consists in offering to the human trainee 4 destinations in the time tunnel (**Figure 4**). The icon shown in the time tunnel represents the first scene of the related episode that occurred in the history of gameplay.

Note that the dotted arrows in **Figure 13** (and in **Figures 14** and **15**) are intended to represent the embedding of the excerpt on display into the graph of **Figure 3**.

For combinatorial reasons, there exist 14 different slightly more constrained variants of the (excerpt of the) graph in **Figure 13**. It is a design decision within the process of time travel gamification which of these graphs to include in the storyboard and what execution condition to attach to a graph.

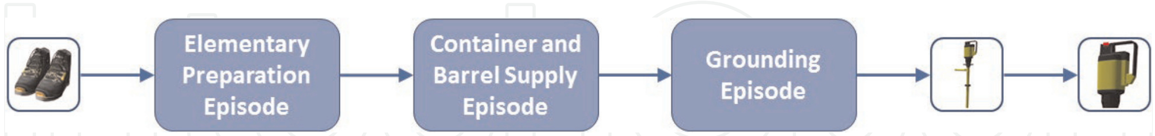

Figure 12.
*The prototypical pin graph of **Table 2** for expansion of the core game-based training episode.*

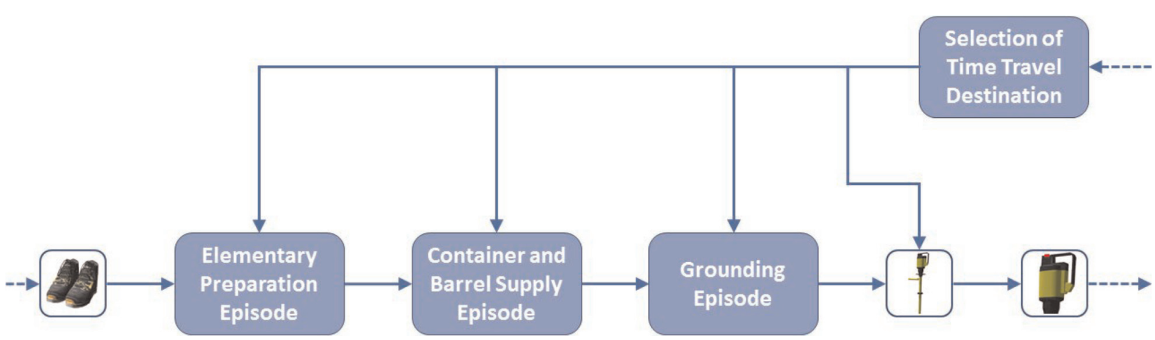

Figure 13.
*Excerpt of a storyboard after an expansion of the time travel episode as on display in **Figure 3**.*

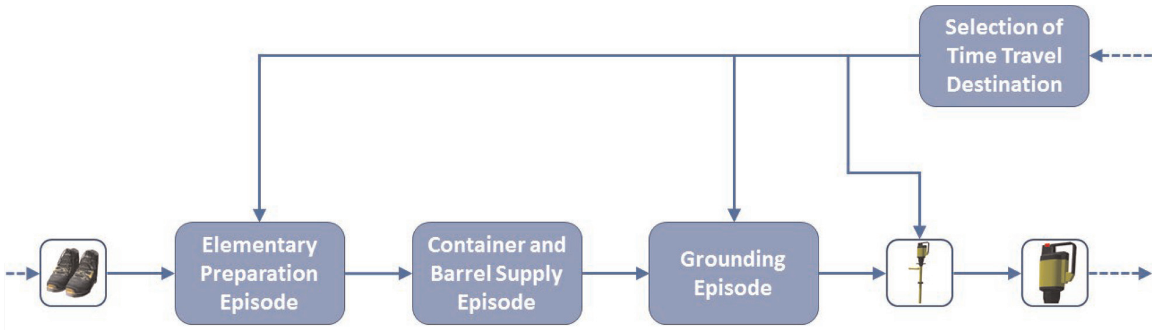

Figure 14.
*An excerpt alternative to the one in **Figure 13**; the present one being slightly more restrictive.*

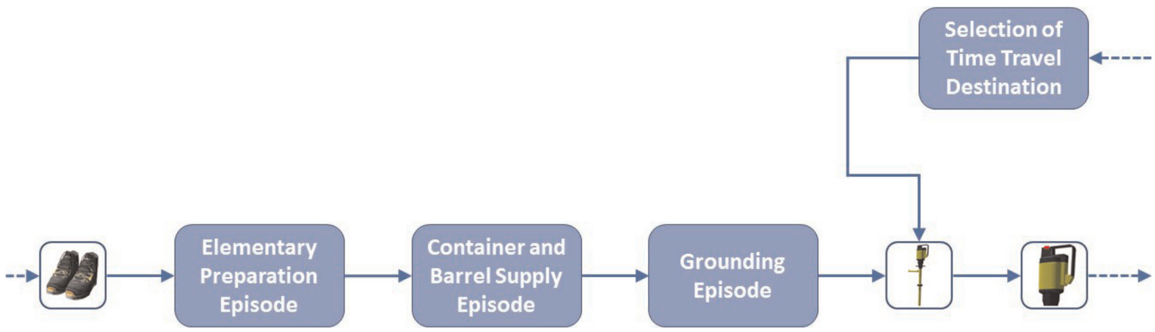

Figure 15.
Most restrictive time travel offer directing the trainee's attention to the cause of the accident.

An inspection of the training session surveyed in Section 5.1 reveals the cause of the accident illustrated by means the rightmost screenshot of **Figure 11**—the usage of an illegitimate pump. In case a trainee repeats this failure several times, a strict guidance by means of a very restricted time travel offer as on display in **Figure 15** may be the only way out.

Furthermore, the authors have developed the concept of dynamic time travel prevention games [54] in which even the virtual past is no longer what it used to be. The right screenshot of **Figure 5** illustrates a dynamically changing scene in which an NPC assists the trainee in selecting the right pump and, thus, completing the mission (**Figure 16**).

The ultimate goal of time travel gamification is the trainee's individual success.

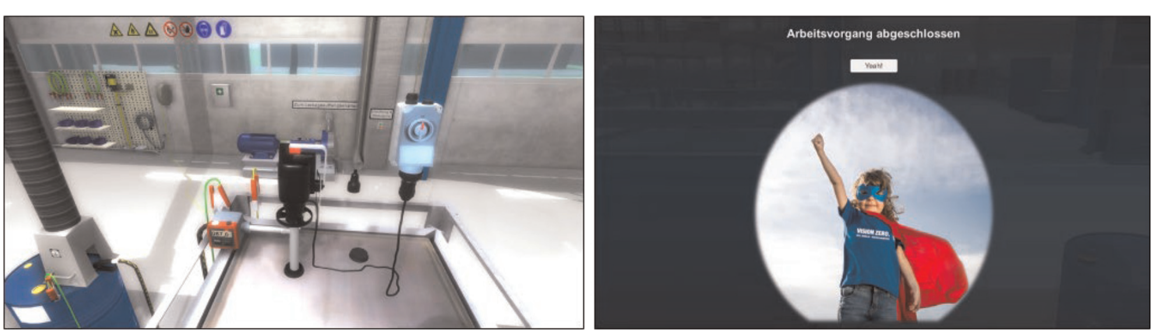

Figure 16.
The correct installation of all details including the selection of the right pump leads to success; illustration on the right © Shutterstock/sunny studio.

5.3 Technicalities of time travel gamification

The authors´ present chapter on time travel gamification is intended to be an introductory one spanning the spectrum of issues discussed from theory to practice dealing with original theoretical concepts and with practical industrial applications. Clearly, there are a large number of technicalities that are mostly kept under the hood. The present subsection, for the sake of honesty and correctness, addresses just a few.

According to [22, 23, 36], storyboards are finite hierarchically structured families of finite directed pin graphs. Computerized graph manipulation is tedious [36, 55, 56]. In the authors´ approach, the key technicalities are graph rewriting by means of node expansion underlying what the author calls storyboard interpretation technology [51]. The power of the approach, inherited from [23], lies in reasoning at execution time. When training begins, there does not yet exist the full graph of opportunities to come. Instead, this graph unfolds, so to speak, during gameplay and, thus, emerges in dependence on the trainee's individual behavior. Thus, experiences are personalized.

Intuitively, there is a top-level graph G_1 in the storyboard F such as in **Figure 3**. The interaction begins at an entry pin of this top-level graph G_1. When interpretation arrives at a scene, its operational semantics is used according to the currently valid execution conditions. Notice that issues of conflict have to be resolved. This holds as well when in a graph G episode e is reached. A graph $G_k \in F$ with a valid execution condition replaces this episode node e. A formal notation of expansion is $G[e{\downarrow}G_k]$. In this way, the current graph is rewritten to $G' = G[e{\downarrow}G_k]$. This establishes a rewrite relation $\Rightarrow_F$ in dependence on the storyboard F. At the end of gameplay, the initial graph G_1 is transformed into a graph G^m describing what ultimately took place. Formally, $G_1 \Rightarrow {}^*_F\, G^m$ where $\Rightarrow^*_F$ denotes the reflexive, transitive closure of $\Rightarrow_F$.

Originally, this is an approach to plan generation based on usually incomplete information in complex environments [23, 36]. Planning algorithms that implement graph rewriting are carried over to storyboarding (see [21], page 7, **Figure 4**).

Kirsten demonstrates formally that this dynamic plan generation approach is more expressive than alternative formalisms [57]. Essentially, the approach exceeds the limits of context-free formal languages (see [58] or any other standard reference). To circumscribe this formal result very loosely, with the planning approach of [23] one can generate a considerably larger variety of plans than with other approaches. Carried over to storyboarding, with the approach inherited from [23] demonstrated in [21, 49–54], one can generate a particularly rich space of potential experiences varying from trainee to trainee and depending on dynamic conditions of gameplay.

For several details and their practical relevance, interested readers are directed to [51] where the term storyboard interpretation technology is coined. Intuitively, this may be considered a technology of graph rewriting at progressing execution time.

Within this contribution, just one technical issue shall be discussed in more detail. For the sake of easy access, earlier examples and illustrations are revisited.

Graph rewriting as above works well even with cyclic storyboard graphs. But in the process of time travel gamification, certain cycles are of key relevance. Cycles representing phenomena of time travel do not aim at the repetition of actions that are the same as before, but at modifications that bear the potential of changes. Those graphs need a particular treatment that requires an extension of rewriting beyond the limits of the original approach [23, 36]. Time travel gamification provides feedback to the theory. To this end, earlier notions and notations are revisited [59].

From the perspective of the rewrite process, the goal is to remember the earlier steps of rewriting. From the perspective of technicalities, the methodology is a certain dotted notation (see [59], Section 3.2, definition 4 and **Figure 5**). From the perspective of experience design, the key is to enable the nonmonotonicity of story evolution [20]. That is the gist of time travel to impact the fate.

From a logical perspective, modalities such as possibility and necessity [60–62] play a fundamental role. Trainees who rely on time travel to fix problems of the present time depend on opportunities to change the past. Varying variants of the past are like Kripke models of modal logic. For the basics, readers are directed to [60, 61]. Furthermore, [62] provides a considerably large number of insightful discussions. Varying pasts of gameplay are possible, so to speak, to happen in the future of play. Loosely speaking, varying pasts seen as Kripke models are different parallel worlds that are visited one after the other during gameplay trying to change for the better. Subsequently, a few notational technicalities will be supplemented for clarification. In this way, the rewrite relation $\Rightarrow_F$ will be slightly modified.

When a node e is substituted by some graph G_k, all the nodes in $G[e \hookleftarrow G_k]$ that result from the inserted graph G_k are renamed. If n is such a node in G_k, [59] renames the new node to *e.n*. Apparently, this dotted notation helps to remember which expansion introduced this novel node to the resulting graph. In time travel gamification, the authors go even further. If episode e is reached for the first time, inserted nodes n of a storyboard graph G_k are renamed to *e.1.n*. If due to time travel, episode e is reached for the second time, a node n newly inserted is renamed to *e.2.n*, and so on. This dotted notation indicates on which occasion a node has been inserted.

Alternative pasts of play are represented by subgraphs that are mutually different. They form universes that reside literally in parallel within the history of interaction.

A firm background and technicalities like those sketched above back up sayings such as *the past is no longer what it used to be* and, to repeat a formulation from above, *varying pasts are possible to happen in the future*. The foundations provide meaning.

Notice that Papert's debugging aspect—seen as a technicality in the small—cited above according to [31] leads to a perspective from which the overall training process is seen as a sequence of actions and interactions, like the execution of a program. Traveling back in time allows for *patching the past*. Patching may be considered insufficient due to its potential renunciation of a global understanding [63]. This is an issue of bounded rationality separating "the beliefs that people have and the choices they make from the optimal beliefs and choices" (see [64], p. 449). The digital system must guide human trainees to ultimate success contributing to sustainable training effects—the artificial intelligence perspective at time travel [52]. The cognitive science issue of *fast and frugal heuristics* [65, 66] is related but exceeds the limits of the present contribution.

A few closing remarks are intended to illustrate the interplay of technicalities. Modalities of possibility and necessity as mentioned above—by way of illustration, the

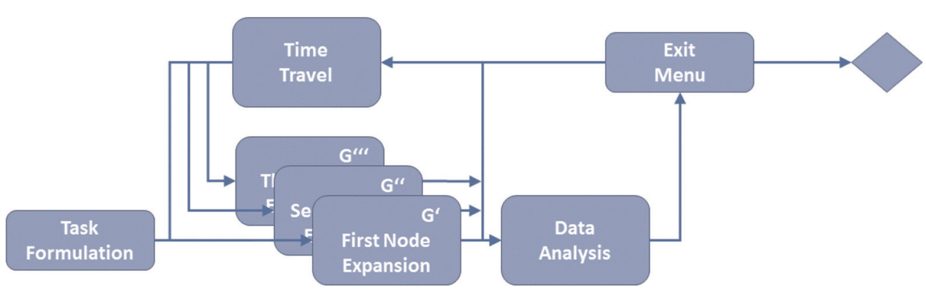

Figure 17.
Variants of the past occur subsequently establishing models of the world existing in parallel.

possibility of an accident—are controlled by incidences within storyboard graphs specified in incidence matrices like those on display in **Tables 1** and **2**. The storyboard, as a whole, specifies the space of conceivable experiences of which some unfold throughout gameplay whereas others do not. As illustrated by means of **Figure 17**, some are "conceivable but not actual" ([67], see also [62], p. 19). Designers negotiate logical conditions that occur in the incidence matrices to make desirable states likely.

6. Conclusions

Industrial accident prevention training draws benefits from time travel gamification that leads to practically applicable time travel prevention games [13, 21, 53, 54]. Similarly, environmental education benefits from time travel exploratory games [52].

However pleasant the state of science, technology, and applications might appear, this should not blind us to deficiencies and open problems. To mention just one manifest issue, the authors did not yet undertake any effort to travel into the future—virtually, in training games, an aspect already briefly investigated in [53], Section 3. Time travel gamification that includes the design of journeys to the future depends on ideas, concepts, and technicalities beyond those investigated in this contribution. By way of illustration, how to represent destinations in a tool such as our time tunnel? A scenery not seen before can hardly be represented iconically by objects to come. Further open problems arise when thinking of and discussing the design of the future. In the authors' present approach, the past serves as a blueprint for variants of the past that may deviate from earlier variants in cascades as the authors put it in [54] and as discussed in Section 4.3. The crux of time travel to the future is that this future is less constrained—a challenge to further work on time travel gamification.

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Last but not least, they gratefully acknowledge the fruitful cooperation with Oksana Arnold that has found expression in publications such as [21, 52–54]. She is, so to speak, the mother in spirit of dynamic plan generation [23] underlying the approach to storyboarding that is powering didactic and game design.

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