AI Planning for Unique Learning Experiences: The Time Travel Exploratory Games Approach

Oksana Arnold[1] and Klaus P. Jantke[2]
[1]*Fachhochschule Erfurt, Germany*
[2]*ADICOM Software, Weimar, Germany*

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Abstract: All good human educators behave adaptively and treat their students individually different according to their needs and desires. And good educators take context conditions such as disturbances from outside into account. They react even to unforeseeable events. The more surprising a situation, the more important is the adaptivity. In technology-enhanced learning, there is abundant evidence for the necessity of adaptive learning technology. But how to prepare for the unforeseeable? This problem becomes even more intriguing in advanced approaches such as, by way of illustrattion, in learning environments that allow for unusual human learner experiences like virtual time travel. How might a learner behave when finding herself back in time in a foreign virtual world? The authors design digital games for environmental education that enable learners to find data from the past. The narrative is traveling back in time and exploring the past. Successful learners return with valuable findings. But sometimes they fail. Not everyone is familiar with time travel. Preparing the exploratory digital game – more precisely: *the time travel exploratory game* – for unforeseeable behavior is an involved planning task. For this purpose, advanced technologies of Artificial Intelligence for planning in dynamic environments such as complex industrial processes is adopted and adapted. This leads to storyboarding of learners' experiences.

1 INTRODUCTION

The authors aim at an approach to educational game design, in general, and to the design of games they call *Time Travel Exploratory Games*, in particular.

The basic idea, still very roughly circumscribed, is that a certain number of players, say all schoolmates of one class, play individually and undertake virtual journeys back in time. They explore the past and bring all their findings back to the present time. The phase of individual exploration is followed by a phase of collaboration. Players report about their individual time travel adventures and present each other their findings. They are guided to an assembly of a result that combines the varying individual findings – the whole is more than the sum of its parts.

The crux of game design is that – unforeseeably, but very likely – all players will have highly individual and mutually very different time travel experiences. They travel virtually to varying virtual locations and to different points in virtual time. Thus, players will act differently and will need varying amounts of time.

Players will face different obstacles and will find their (pre)historical assets in possibly different ways.

Despite these differences, the game should enable all players – recall they are learners – to be successful. Furthermore, there is the need for synchronization to allow for a phase of collaboration in which the team's common research result is created.

To meet all the aforementioned conditions and goals, the game design must not determine a certain flow of game play. Instead, it specifies a whole space of potential behaviors and experiences. What will happen during game play is not fully defined at design time, but will dynamically unfold during play time.

This resembles approaches in highly complex and dynamic environements (Arnold and Jantke, 1994a; Arnold and Jantke, 1994b; Arnold and Jantke, 1996) developed for the purpose of driving disturbed industrial processes back into a normal mode of operation (Arnold, 1996). Those are *AI approaches to planning*.

The cited approaches are adopted and adapted. What is called *a plan* in books like (Arnold, 1996) is now *a digital storyboard* that unfolds at play time.

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Figure 1: The permanently grounded aircraft IL-18 that is hosting “The Flying Classroom” project with the present game.

2 EMBEDDING APPLICATION & IMPLEMENTATION

“The Flying Classroom” is the name of a very recent edutainment project[1] that shall be equipped with a series of digital learning games.

The authors’ present contribution, on purpose, does *not* deal with the issues of implementation and application. Instead, the didactic design approach of dynamic planning and storyboarding is in focus.

The present section is only intended, so to speak, to embed the authors’ work into a wider context, to see it almost literally from a bird’s eye view, and to allow for an appraisal of its reach.

The Flying Classroom is located in a permanently grounded Russian-made aircraft of type IL-18 (fig. 1) of the former East-German airline Interflug.

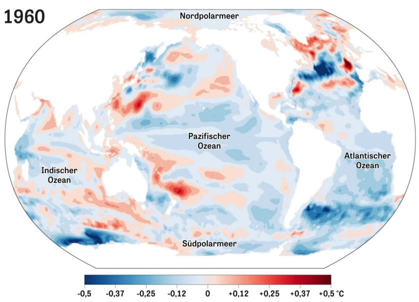

Figure 2: Ocean warming data from 1960 ©Cheng, 2020.

[1]This article from the main Thuringian newspapers is at the time of running the CSEDU 2021 conference less than half a year old: https://www.thueringer-allgemeine.de/regionen/erfurt/vorfreude-auf-das-fliegende-klassenzimmer-in-erfurt-id231055542.html

Classes of pupils may visit the aircraft. According to their age and grade of school, they get offered to play a digital game inside the aircraft. The framing story of every game is a virtual journey in the IL-18’s *Flying Classroom*.

Every game has its particular learning content. The present contribution reports about the first of these games. The content is the ocean warming which is a very intriguing issue due to the ocean currents and the exchange of heat between ocean and atmosphere (Rhein et al., 2013).

Investigating the ocean warming requires observations over a longer span of time and taking the ocean world-wide into account. This is very demanding and requires a literally global approach.

Virtually flying around the world takes care of the problem of world-wide observations. But what about the problem of observations over a longer period of time? This problem is resolved by *virtual time travel*.

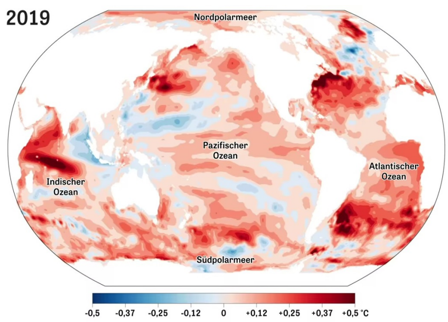

Figure 3: Ocean warming data from 2019 ©Cheng, 2020.

Players on a virtual journey back in time may take thermal pictures like those in the figures 2 and 3.

Finally, players discuss their individual findings and assemble a video illustrating the ocean warming over a period of 40 years.

3 TIME TRAVEL GAMES

Time Travel is known in commercial games since DAY OF THE TENTACLE, 1993, and SHADOWS OF DESTINY, 2001. Naïve variants of time travel occur in games such as BRAID, 2008.

Furthermore, the first introduction of *save points* in games, pioneered in THE LEGEND OF ZELDA, 1986, may be seen as rudimentary time travel.

3.1 Time Travel Prevention Games

To the present authors' very best knowledge, the term *Time Travel Prevention Games* has been coined on the German Prevention Day, Frankfurt/M., Germany, 2015. It is listet there as a keyword[2].

In a sense, SHADOWS OF DESTINY is a prototypical time travel prevention game.

In a time travel prevention game, players confronted with undesired events may get the opportunity of travelling back in time to change the past such that the undesired event may be avoided the next time.

Concepts of time travel prevention games have been developed and studied for varying purposes such as crime prevention (Winter and Jantke, 2014).

They have enormous potential for health care and for the training of accident prevention.

3.2 Time Travel Exploratory Games

The term *Time Travel Exploratory Games* is coined in the present publication.

In such a game, the purpose of time travel is not to change the past, but to explore it. To some extent, the exploration is an important aspect of time travel prevention games as well. Players need to explore the virtual past for finding a way to change it as desired. But in time travel exploratory games, exploration is primary.

What players may bring with them when returning to the present are experience, insights, and artefacts. So, first of all, time travel exploration games are – by nature – learning games.

In dependence on the subject of the study, it may be more or less desirable or even necessary, to visit different locations in different periods of time.

The necessity of explorations comprehensive in space and time suggests the engagement of multiple players. By nature, time travel exploratory games tend to be effective multiplayer games.

Time travel exploratory games are useful for competitive and collaborative learning and both at once.

4 ENVIRONMENTAL EDUCATION

4.1 Environmental Education in General

All big themes of environmental education are related to changes of the world such as the ozone depletion, the deforestation of rainforest, and the glacier melt. Other serious problems range from the decline in the insect population to the impending extinction of the Javan rhinoceros.

Environmental education depends on data that change over time and on the comparison of these data.

First, the interpretation of findings is intriguing and especially young learners very much depend on visualization.

Second, the study of large amounts of data may easily become boring.

In the light of these difficulties, the two authors propose time travel exploratory games as an approach to environmental education.

Finding data through an adventurous process of time travel to and exploration in the virtual past leads to a certain bonding. Players value their individual findings and show more interest in comparison and interpretation. Hence, they look at visualizations of their own findings with a particular interest.

Larger amounts of data result from the individual explorations of members of a larger team like a class. At this point, it is time to change the didactic method.

Individual competitive exploration is followed by the collaborative creation of the team‘s overall result. The following four chapters 5 6, 7, and 8 step by step present the educational and game design. The authors see this as a guideline for applications of their storyboarding approach.

4.2 Ocean Warming in Particular

The article (Chen et al., 2020) is a highly topical and alarming knowledge source demonstrating the gravity of the situation. The quite intriguing interference of cyclones and ocean warming is discussed in depth and

[2] https://www.praeventionstag.de/nano.cms/vortraege/begriff/Time-Travel-Prevention-Games?sb=Time+Travel+Prevention+Games

detail by (Trenberth et al., 2018). The ocean warming invigorates tropical cyclones. On the other hand, the strong winds of tropical cyclones keep the ocean cooler by causing stronger evaporation.

To begin with, environmental education shall inform the learners about the phenomenon of ocean warming making it intelligible both in its gravity and in its diversity. The complexity of the problem shall become discernible resulting in an appreciation for collaborative studies and big data management.

5 TIME TRAVEL GAMES FOR EXPLORATORY STUDIES OF OCEAN WARMING INCL. COLLABORATIVE LEARNING

The key idea as already introduced above consists in a multiplayer digital game installed inside an aircraft. A group of players engage in game play in which

- players undertake independently of each other a virtual journey back in time,
- explore the past virtually,
- find artefacts that carry information about ocean warming,
- bring these artefacts back into the present time,
- compare, discuss, and interpret their individual findings,
- and collaborate toward a common presentation of the aggregate of their findings.

This leads to a design of interaction, experience, game play, and learning as summarized by the graph on display in figure 4.

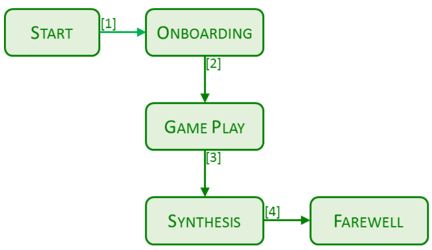

Figure 4: Top level storyboard graph.

In a storyboard graph like the one in figure 4, the nodes are called *episodes*. Other nodes called *scenes* will be introduced later. Episodes are placeholders for more detailled descriptions of anticipated experience. In slightly more technical terms, the episode nodes determine places for graph substitution. Replacement of episodes by other graphs of the storyboard takes place at execution time. The discussion of these technicalities is postponed.

Edges from one node to the other specify the flow of interaction. Every edge is annotated by a logical condition of execution. In this way, it is determined in which conditions game play may proceed from one episode to the other. The logical conditions seen as formulas contain variables. These variables refer to environmental data – game play may depend on the day time and even on the outside wheather conditions – and on data from the user/learner/player model including the interaction history.

For simplicity, one may assume that the conditions [1], . . . , [4] in figure 4 have constantly the value *true*.

The design of interaction, game play, and learning proceeds via a step by step introduction of storyboard graphs admissible for the expansion of episodes. This is the collaborative process of storyboarding that may proceed bottom-up, top-down, or even both at once. Storyboarding means *the organization of experience* (see (Jantke and Knauf, 2005). p. 25).

This usually results in alternative concepts of graph expansion, i.e. varying proposals of what to substitute for a particular episode node. Every graph

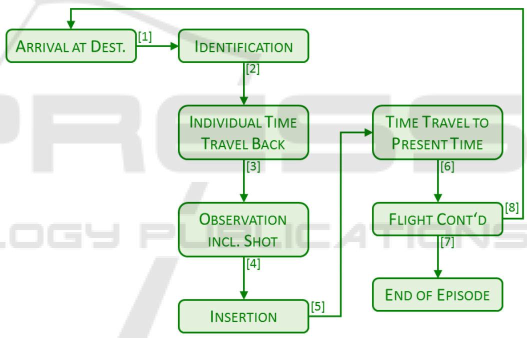

Figure 5: Storyboard graph to expand GAME PLAY.

is annotated by its substitution condition. This allows for the design of alternatives that will be invoked in different conditions.

By way of illustration, the episode node named in figure 4 may be substituted by the graph on display in figure 5.

Let us briefly describe the intentions behind the graph to be substituted. First, the flying classroom aircraft virtually arrives at some destination, say the great barrier reef. Second, players get some visual information and identify their current location. Third, they get the opportunity of individual time travel back in time. When they arrive in the past, fourth, players explore the environment and using the virtual infrared camera take a picture. Fifth, this picture is inserted into the infrared ocean map they have. Sixth, all the players return individually to the present time and, seventh, the virtual journey continues to another location.

The complanate nodes of the graph in figure 5 are *scenes*. Those have a some fixed semantics in the game mechanics such as a scripted scene, a video, or an audio file with a spoken text.

There is a branching point at the scene FLIGHT CONT'D. The number of time travels may be limited in advance or depend on the duration of game play so far. This is controlled by the conditions [7] and [8].

After the end of this exploratory episode it follows the episode SYNTHESIS of collaborative learning.

6 DYNAMIC PLANNING AND DIGITAL STORYBOARDING

Given any digital storyboard as a finite collection of directed graphs as on display in the figures 4 and 5, what players/learners will experience in the course of interaction is largely unforeseeable due to the graph expansion at execution time and due to the dynamically changing validity of branching conditions.

There is a similarity to the treatment of seriously disturbed complex technical processes. For example, think of a chemical reactor in which occurs an unexpectedly high pressure. This may be caused by an incorrect percentage of certain chemical ingrediens. But if the disturbance is unexpected, nobody knows exactly about the situation inside the reactor. There are larger numbers of measures to undertake, but the effects are not fully foreseeable. In dependence on the dynamic data, the process of driving the system back into a normal mode of operation unfolds during interaction. It is not planned in advance. Domain experts know about possible effects of all the measures they have. And they know about conditions of execution.

The measures in such a technical setting resemble the graphs as illustrated in the preceding section 5.

Based on this similarity, the authors' approach is to adopt and adapt the AI planning concepts from (Arnold, 1996) and to transform them into concepts of storyboarding time travel exploratory games.

6.1 Essentials of AI Dynamic Planning

Because the technicalities such as precise syntax and implementation details remain, so to speak, under the hood, an intuitive and widely informal presentation is appropriate.

As introduced above, *directed graphs* are the key concept for representing anticipated (inter)action. There is, more precisely, the concept of *pin graphs*. Every such graph has entrance nodes and exit nodes. In the technical planning domain, the set of all nodes of a pin graph is partitioned into two classes. Some of the nodes are called compound nodes. All the other nodes are called atomic nodes. Atomic nodes have a meaning in the technical domain such as a human intervention or a program to be executed. Compound nodes may be subject to later substitution.

A *plan* is a finite hierarchically structured family $\mathcal{F} = \{\mathcal{G}_i\}_{i \in I}$ of pin graphs, where I is any index set. For simplicity, one may imagine I to contain positive natural numbers, perferably without gaps inbetween, i.e. $I = \{1,2,3,\ldots,k\}$. k is the exact number of pin graphs in the plan $\mathcal{F}$. In practice, it is advantageous to use more expressive names instead of numbers.

One graph describes on the most general level and with most rough granularity the overall plan. This is the top-level graph that may be named $\mathcal{G}_1$ in case the index set consists of positive natural numbers.

By way of illustration, recall our graph on display in figure 4. This is a top-level graph, as we put it above, *on the most general level and with most rough granularity*.

Inside every graph, logical conditions are used to annotate edges. These conditions determine whether or not an edge may be used to step forward from one node to another at execution time.

Inside every graph, compound nodes get assigned graphs (for simplicity, just the indices of graphs) to determine which graph may be taken as a substitute for the node. Recursive substitutions are admissible.

Outside every graph, so to speak, there exists an annotation by a logical condition of deployment.

The regulations of graph substitution establish the hierarchical structure of the plan $\mathcal{F}$.

Planning is the process – team-based, possibly distributed over space and time, alternatively bottom-up or top-down or both at one – of constructing all the graphs of $\mathcal{F}$ including the internal annotations of the edges that determine the conditions of the usage of edges as well as the external substitution conditions that control graph substitution for compount nodes. Last but not least, planning means to assign to every atomic node an operational semantics in the domain.

The unrivaled modularity of the approach bears its unprecedented flexibility (Arnold, 1996).

The logical conditions contain variables of which, in the technical domain, many are numerical. At the time of planning, most values at some future points of time are unknown.

When some disturbance occurred, plan execution begins with $\mathcal{G}_1$. The atomic nodes are executed, dynamically emerging knowledge enables decisions, substitutions take place, the plan unfolds.

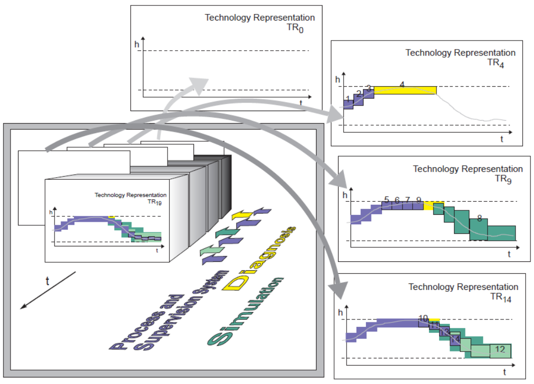

Figure 6: Dynamic knowledge relevant to plan execution.

6.2 Digital Storyboarding as a Form of AI-based Dynamic Planning

Many industrial processes are highly complex and disturbed industrial processes may easily become very dangerous. However, every human being is much more complex than any chemical installation. Consequently, every effort to design adaptivity for the purpose of meeting human needs and desires shall be, at least, as powerful as the best AI approaches that adapt to technical necessities.

The AI planning approach of (Arnold, 1996) is carried over to planning human learners' experiences, especially to the design of time travel exploratory games.

A *storyboard* is a finite hierarchically structured family of pin graphs. Internally and externally, resp., the graphs are annotated in the same way as described in the preceding section 6.1.

Nodes of a graph that are *scenes* have an operational semantics in the time travel exploratory game. By way of illustration, see the scene of the graph in figure 5 that is named ARRIVAL AT DEST. This scene may be implemented by an audio file in which the virtual aircraft captain announces the arrival – virtually – at a certain destination. Further implementations are possible such as a video showing the aircraft captain during his announcement or just a textual information on the screen.

Every storyboard has exactly one graph on the top level 1 like the graph on display in figure 4. Graphs that may be substituted for an episode of the graph on level 1 are said to be on level 2. In general, given a particular graph $\mathcal{G}_j$ and n being the highest level on which a graph $\mathcal{G}_i$ exists containing an episode that may be substituted by $\mathcal{G}_j$, this graph is said to be on level $n+1$. The lower the level, i.e., the larger the level number, the finer the granularity of interaction design.

This corresponds to *layered languages of ludology* as introduced, studied, and applied a good decade ago in (Jantke, 2006) and (Lenerz, 2009).

In a sense, *digital storyboards are operational*. They may be seen as computer programs of the interactive media specified. A complete digital storyboard of a time travel exploratory game defines the game's implementation. The crux is that the program can not be compiled to executable code, because dynamic data decisive for the evaluation of logical conditions in the storyboard are not available prior to execution.

Alternatively, the storyboard may be interpreted at play time (Fujima et al., 2013). In dependence on the dynamics, interpretation unfolds the one or the other experience of game play and learning. Interpretation is adaptive to human needs and to varying context.

7 DIDACTIC AND GAME DESIGN

Dovetailed didactic design and game design take place as digital storyboarding. The result is a highly modular digital document describing not only one anticipated flow of human-system interaction, but a potentially infinite space of human game play and learning experiences.

The digital storyboard as a collection of annotated graphs has both a rather appealing and intuitively comprehensible appearance and the syntactic details of a computer program ready for interpretation.

Storyboard graphs are intentionally small to keep the overview and to be able to discuss the smallest details of pedagogy and of ludology.

Interdisciplinary designer teams of experts such as educators, ludologists, AR and VR specialists and others may maintain even contradictory alternatives. Decisions may be postponed during the design phase and some may even be taken as late as at execution time, i.e., when the digital game is running, when fun, excitement, and learning interfere.

Higher level design decisions are represented in higher level graphs. By way of illustration, the order of the episodes GAME PLAY and SYNTHESIS in the top level graph of figure 4 reflects the basic decision that exploration precedes collaboration.

On a slightly lower level, one has to specify how to individually travel back in time; an expansion of the corresponding episode in figure 5. Several of the ideas are reflected by the storyboard graph on display. All nodes of this graph are scenes to be implemented.

According to the overarching game design idea that individual explorations are followed by a phase of collaboration in which different players bring in their mutually different (!) findings, there is developed the following game mechanics. Players are encouraged

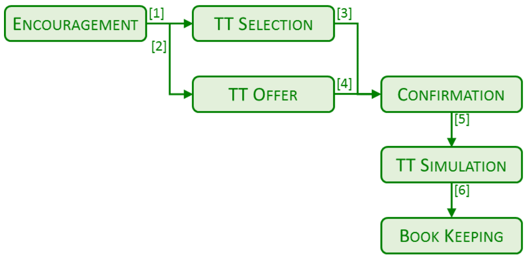

Figure 7: Individual time travel back in time.

to go on a journey back in time. If this is a player's first time travel (condition [1]), there appears a list of target time periods to selct one. We have 240 alternatives resulting from 60 years times 4 quartes of data. On the occasion of a later time travel (condition [2]), players are guide to the target time selected earlier.

8 GAME DESIGN PATTERNS AND DIDACTIC PATTERNS

The pattern concept became explicit in science and technology by Christopher Alexander's related work in architecture (Alexander, 1979).

At almost the same time, Dana Angluin developed a very precise and lucid approach to patterns and their instances (Angluin, 1980). Trendsetting is Angluin's insight that there might be patterns in science and technology, but what we can perceive are only their instances. This leads directly to the pattern inference problem. Seeing a few or, perhaps, a large amount of instances, what is the pattern behind? This problem is usually an intriguing one.

In some areas, the pattern concept is rather vague and the borderline between patterns and instances gets blurred (Pedagogical Patterns Advisory Board, 2012).

Surprisingly, despite the appealing title of the book (Björk and Holopainen, 2004), this work does not contribute much to a dovetailed didactic and game design, as many of the concepts discussed are far from being patterns.

That patterns are a key concept of game-based learning is illustrated by (Jantke, 2012) where the occurrences of patterns – more correctly, of instances of patterns – may be interpreted as indicators of mastery. Thus, patterns and instances are key to assessment.

8.1 From Patterns to Instances

Let us see the pattern inference problem the other way around. When a pattern is designed, this determines all its possible instances.

Human players and learners do not experience the abstract concepts behind some game design, but what really happens. In other words, what designers really want are the instances, not the patterns.

The usage of design patterns means the usage of general principles that are likely to result in concrete interactions – the instances – that, hopefully, have an intended impact.

Among the *game design patterns* there are those that appear boring, at a first glance, but are relevant to the game mechanics. Many of these features are not recognized by the player, because their instances run in the background. This is mentioned here, because those patterns must not be overlooked. For brevity, we discuss just one: *book keeping*.

Whenever players make important decisions of game play, there is the necessity to record this for the purpose of later adaptivity. Data are send to the server and form the game play history as well as the human player profile. The corresponding scene is named Book Keeping (see figure 7).

One important insights is, that patterns appear as structural properties of storyboard graphs. What does not show structurally, that is not used semantically. This explicates the advantage of this design approach.

Finally, there will be discussed a design pattern that is interesting, because it may be seen as a didactic pattern and a game design pattern as well: *self-reliant interaction*.

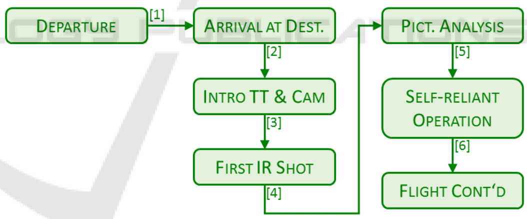

Figure 8: Onboarding incl. time travel.

Onboarding is a terminus technicus of the digital games area. It denotes an early phase of game play (see figure 4) in which players learn how to play and what to do without the need to read any manual or anything like this. The usage of onboarding is a game design pattern.

The players get an introduction into time travel and how to use the virtual IR camera. They make their first IR shot and get help in interpreting the value of their finding. After that, they are encouraged to try it again self-reliantly (see figure 8).

This is the basis for future self-determined interaction during the exploratory phase of game play, hence, a didactic pattern of *self-determination*.

8.2 From Instances to Patterns

When a time travel exploratory game is in use, one may easily record game playing. Conceptually, recorded game play is a string of (inter)actions that took place. In those string, one may find instances of what happened (Jantke, 2012).

A systematic analysis will reveal which of the game design and didactic patterns have resulted in anticipated human experience.

For a very rough illustration, it might happen that during graph expansion a particular storyboard graph is never invoked. Phenomena like that are studied in (Knauf et al., 2010).

To say it in terms of the pattern inference problem, observing game playing behavior that takes place, identifying potential instances of potential patterns, and learning the patterns behind gives feedback about the effectivity of the principles incorporated.

9 SUMMARY & CONCLUSIONS

After coining the term *time travel exploratory games*, it is the authors' foremost intention to advocate digital storyboarding as a methodology of truly dovetailed pedagogical and game design – team-based, possibly distributed over space and time, alternatively bottom-up or top-down or both at once. It clarifies details of didactics (Jantke, 2013) and works for large-scale applications (Arnold et al., 2013).

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