Personalized, Adaptive Digital Educational Games using Narrative Game-based Learning Objects

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Abstract. This paper introduces the concept of Narrative Game-based Learning Objects (NGLOB) for the personalization and adaptation of Story-based Digital Educational Games (DEG). In the context of the European research project 80Days, settled in the field of Technology-enhanced Learning, Section 1 characterizes the potential of DEG in general and motivates the need for and the use of personalized, adaptive DEG, as required by the heterogeneous types of players and learners. Based on a brief discussion on related work in Section 2, in Section 3 a first approach for an integrated solution for personalized, adaptive DEG combining learner modeling, player modeling and storytelling is presented. Section 4 describes a prototypical realization of the introduced concepts implemented in the context of the Bat Cave scenario, a second demonstrator of the 80Days[1] project. Finally, the main results are summarized and further research activities such as additional evaluation studies are outlined.

Key words: Digital Educational Games, Personalization, Adaptation, Technology-Enhanced Learning, Narrative Game-based Learning Objects.

1 Motivation

Until today, the concept of Digital Educational Games (DEG) is becoming more and more interesting for different user groups and purposes, ranging from educational games at school to provide an easy, playful access to computers and information technology or to teach different subjects such as computer science, history [1] or geography up to games with more challenging content for institutions of higher education, like teaching object-oriented programming via computer games [2]. Furthermore, a variety of industrial game-based learning applications for training and simulation exist. Examples for this include corporate simulation or planning games like learn2work (`http://learn2work.de`), BIMSonline

[1] 80Days - Around an Inspiring Virtual Learning World in Eighty Days. EU, FP7, IST, STREP, Challenge 4.1.2 Technology-enhanced Learning. www.eightydays.eu

(www.bims.ag), TOPSIM (www.topsim.com), or Virtual Team Trainer (www.vr-team-trainer.com).

From a research perspective, the main challenges are among others (such as assessment or usability) personalization and adaptation. Regarding educational games, the motivation to learn is proportional to the fun of the game. Thus, it is desirable to adapt such a game to the player's preferences. While some prefer action games, others prefer story-based adventures or Role-Play Games (RPGs). It is certainly not possible to create an own game for each type of player but it would be a great advance if an educational game was flexible and customizable enough to be able to adapt to the heterogeneous needs of different players preferences by using adaptive technologies. Hereby, adaptation and adaptivity should consider the selection of appropriate content and presentation forms to teach subjects and skills of a curriculum as well as the speed and order of learning units in order neither to bore nor overstrain students. Furthermore, what people like to play depends on various non-static factors, like skills, mood, etc, which can change during play. Consequently, the game ideally would keep track of these factors and adapt accordingly. Concerning motivational aspects, the game should contain an interesting, suspenseful, and entertaining story, and be challenging, but not too stressing. Providing a good and suspenseful story however, is often a restricting factor to the variability of a game.

Based on that analysis, in this paper we focus on the problems of personalization and adaptation of adventurelike (scene-based) DEGs in terms of gaming, learning and narration by use of Narrative Game-based Learning Objects (NGLOB) and present a first prototypical implementation of a tool for an author of a DEG, which provides a 'player' on the one hand and visualizes the underlying learner and player model of a test player and a narrative modeling of the game on the other hand which can be used as an evaluation tool.

2 State of the Art

For adaptation to the player's preferences, a player model is necessary. A lot of research in the field of player modeling has been done up to now. One of the first player models was designed by Bartle [3] in 1996. Houlette [4] introduced a player model which keeps track of several player traits to create a model which can be used to adapt the behavior of Non Player Characters (NPCs). In this context, Yannakakis and Maragoudakis [5] showed how to improve a player's experience during a Pacman game by an adaptation of the opponents' behavior according to the player's skill by use of an adaptive player modeling. Magerko et al. [6] designed a game for teaching microbiology concepts called S.C.R.U.B. which can be personalized according to a player type chosen at the beginning by answering a questionnaire. The chosen model however is static for the whole game and does not consider adaptation based on the learning context. Cowley et al. [7] propose a game adaptation mechanism based on a continuously updated factorial player modeling with varying factors for different game genres. In the context of storytelling, the system Passage [8] uses player modeling to adapt the game's story individually to the type of player. In Façade [9] the player can join an interactive story which adapts its agents' behavior according to the players's actions.

For our approach, the use of a learner model is necessary, because an adaptive DEG must track the player's state of knowledge and adapt the learning content and its difficulty according to it. The Knowledge Space Theory (KST), as originally proposed by Doignon and Falmagne in 1985 [10] and adapted by Albert [11], is designated to be used for modeling and for the assessment of a learners knowledge. ALEKS (`http://www.aleks.com`) for example provides a commercial adaptive learning system based on Knowledge Spaces. Hereby, KST deduces the learners actual knowledge from his ability to solve problems associated to learning objects but not from his/her existing competences. Korossy [12] provided an extension called Competence based Knowledge Spaces (CbKST). Projects like ELEKTRA (`www.elektra-project.org`) already successfully utilized CbKST to provide adaptive interventions relying on a well defined cognition based logic [13].

However, none of the approaches mentioned above is able to provide both personalization and adaptation concerning learner modeling, player modeling and storytelling simultaneously. A promising approach directly utilizing the symbiosis and interplay of learning, storytelling and gaming is represented by the 80Days project funded by the European Commission, settled in the field of Technology-enhanced Learning. Here, key aspects of 80Days include (see Figure 1):

Fig. 1. Technology-enhanced Learning

– Storytelling: The use of stories and adaptive interactive storytelling methods and concepts as instrument for suspenseful knowledge transfer.
– Gaming: Provision of a playful learning environment. As slogan 'Learning by playing' might serve. Fun, motivation, exploration and interactivity do have the first priority.
– Learning: Here, most relevant is the knowledge transfer. Emphasis is set on assessment, learning success and effectiveness or methodic-didactic aspects. Mechanisms to motivate and engage users -such as a narrative context (storytelling) or gaming context (gaming)- are welcome, but are not dominant.

In major parts, these aspects and characteristics are complementary, for instance both storytelling and gaming concepts are used to increase the motivation of users in DEGs. On the other hand -especially with respect to a technical implementation and integration of the concepts- the so-called 'Narrative Paradox' [14] indicates a conflict between storytelling (focus on narratology; linear, non-interactive, plot-based approach) and gaming (ludology; interaction, non-linear gaming approach). 80Days tackles that challenge on different levels: On the one hand, the fundamental model is designed theoretically, on the other hand a technical solution in form of an implementation is provided.

NOTE: Our understanding of micro and macro adaptation is as used in the context of the 80Days project, which we will refer to in this paper. In contrast to the definition by Cronbach [15] in 1967, our interpretation is that micro adaptation is an adaptation inside a scene/situation of the game, i.e. shaping it. Macro adaptation on the other hand concerns the question of how to proceed with the game, i.e. which scene to choose next (cf. 'sequencing').

3 Conceptualization of Narrative Game-based Learning Objects

In a first step, the formalization of narrative, gaming and learning objects is briefly discussed in the respective contexts learning, gaming, and storytelling. Hereby, a major aspect during the conceptualization of NGLOB has been set on the integration of measurable, quantitative and qualitative elements and annotations of narrative, gaming and learning contexts.

3.1 Personalization and Adaptation in the Learning Context

Adapting DEGs while incorporating learning issues mainly consists of adapting the game's story structure (macro adaptation, sequencing), or to trigger appropriate pedagogical interventions (micro adaptation, personalized presentation of a scene). Therefore, it is necessary to track and to evaluate the learner's knowledge state to get a sound basis for the decisions to be made. Based on the gathered information the next scene presented to the player should be determined in a way such that the learner is neither unchallenged nor overwhelmed by the complexity of the contained tasks. It should rather be ensured that the learner's knowledge is steadily increased up to full knowledge mastery.

Based on CbKST, a set of skills $\mathcal{S}$, and a prerequisite relation R among these skills is defined by the author. The given relation is stored in the DEG's learning context. R provides a way to derive a competence structure $\mathcal{C}$ from the skills of $\mathcal{S}$. Let a Knowledge State $\mathcal{KS}$ be a set of skills $\in \mathcal{S}$ satisfying the condition

$$If\ (s, s' \in \mathcal{S}) \wedge sRs' \wedge (s' \in \mathcal{KS}), then\, (s \in \mathcal{KS})\,. \tag{1}$$

$\mathcal{C}$ then is the sum of all Knowledge States $\mathcal{KS}$. Using $\mathcal{C}$ the player's knowledge state can be determined and meaningful learning paths can be provided.

Skills are presumed to be not observable atomic competences, or pieces of knowledge obtained by the learner. These are uncovered by associated tasks which each require a certain subset of skills to solve them. Additionally, an availability probability ap_i for each skill $skill_i$ in the set of all skills describes how far the skill can be assumed to be already gained by the learner. Using a

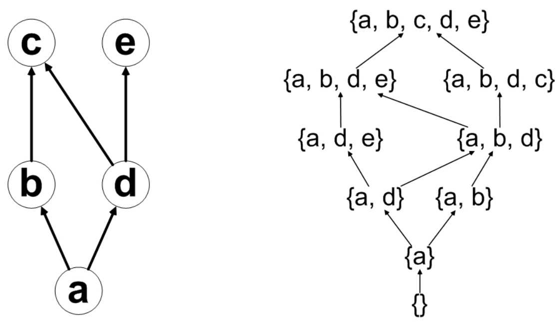

Fig. 2. Prerequisite Relation Graph (left) over skill set $\mathcal{S} = \{a, b, c, d, e\}$ for the Prerequisite Relation $R = \{(b, a), (d, a), (c, b), (c, d), (e, d)\}$ and the associated Competence Space (right).

probability instead of a binary solution like 'the learner has achieved skill x' or 'the learner does not have skill x' prevents wrong assumptions, as lucky guesses and careless errors made by the player can introduce noise on the measurement of certainty. The subset of skills that are gained up to a certain time are defined the actual Knowledge State $\mathcal{KS}_j$ of the player.

To support such a concept within a story-based DEG such as 80Days, each scene has to be assigned with a subset $\mathcal{P}$ of all skills that are assumed to be necessary to solve the tasks associated to the scenario. $\mathcal{P}$ is called the scene's Prerequisite Skills. Further, each scene is associated with a subset of skills that is meant to be improved by the covered learning objects. This set, the Associated Skills $\mathcal{A}$, describes the knowledge gain that can be expected if the scene's challenges are successfully mastered. After finishing a scene, the availability probability value ap of all skills in set $\mathcal{A}$ must be updated. To realize this, actions triggered by the user (e.g. right or wrong answers, clicking at the right position of an image) can be used to increase or decrease ap_i of a particular skill $skill_i$ or a set of skills. The amount of update is defined by the author and depends on the learner's performance (e.g. increase $skill_i$ much for a correct answer, increase it lower for a partially correct answer or decrease it for a wrong answer).

To determine the next meaningful scene for the player's learning progress, the parameters stated above are used to assign an appropriateness value av to each available scene. Scenes where the prerequisites $\mathcal{P}$ are not fully contained in the player's knowledge state $\mathcal{KS}_j$ receive a value of zero, because the scenes are not suitable for the learner up to that time. A skill $skill_i$ is assumed to be element of $\mathcal{KS}_j$ if its availability ap_i exceeds a certain threshold p_{min}. Among the remaining scenes, those are rated with higher values for av that deliver a reasonable set of additional skills in $\mathcal{A}$ when accomplished. Having assigned av to each scene, all scenes can now be ordered according to their quality to fit as the next scene in the learning context.

3.2 Personalization and Adaptation in the Gaming Context

Adaptation according to the gaming context means changing the game in a way fitting better to a determined player model. For that we use a model based on the player model proposed by Bartle [3], which contains four categories of players: Killers, achievers, socializers, and explorers. However, in our model, we do not sort a player into one of these categories. Instead, for a player P we assign a model $M_P = (p_k, p_a, p_s, p_e)$, which is a quadruple of normalized values ranging from $[0, 1]$, indicating, how much the player fits into each category.

The player model can be assigned by evaluating a questionnaire at the beginning of the game to find out the player's preferred style of play. However, as player interests and preferences depend on various factors such as mood, excitement, etc. this player model can change during play. The game needs to keep track of these changes by evaluating the player's decisions and putting them into a gaming context. Whenever a situation can be handled in more than one way by the player, the different options have to be put into a context by the author in advance. When the player chooses an option in the game, the player model gets adapted/updated. A simple example clarifies this: '*The player must retrieve an item from an NPC. He/she can either talk to it and try to persuade the NPC to give the item to the player or he/she can simply attack the NPC.*' Obviously, the first option is strongly related to the socializer type while the second one is a typical killer approach.

To decide, which scene to choose next from the current scene according to the player model, a gaming context C_N is assigned to each NGLOB to indicate how good the scene fits for each player type. This can easily be done by assigning an appropriateness vector A as a list of tuples ($playerFeature$, $appropriatenessFactor$) to each scene S_i. The length of this vector depends on the number of modeled features. Of course, we use the same model as for the player modeling. The scenes are then ordered according to an evaluation metric which calculates an appropriateness value av for each scene making use of the player model and the appropriateness vector A. The one with the highest value is the best candidate for the next scene according to the current player model. One such metric could be as follows: Let n be the number of features of the player model. Appropriateness value av_i of scene S_i for player model M_P is:

$$av_i = \frac{1}{n} \sum_{j \in \{features\}} (1 - |a_{i,j} - p_j|) \tag{2}$$

Here, the factor $\frac{1}{n}$ is a normalization to the interval $[0, 1]$. Inside the sum, for each of the player types the difference between the model value m_j and the appropriateness value of scene i $a_{i,j}$ is calculated as $(|a_{i,j} - m_j|)$ and subtracted from 1. By this, the matching of model value and scene value is normalized between 0 (no match) and 1 (total match). Table 1 provides an example of a player model and four scenes. In the last row the appropriateness of each scene is shown. Note that of all scenes, Scene 2 is closest to the example player model. Consequently, the calculated appropriateness value of Scene 2 is the highest one.

Table 1. Appropriateness of four example scenes to the player model

	Player Model	*Scene* 1	*Scene* 2	*Scene* 3	*Scene* 4
Killer	0.80	0.00	0.90	0.20	0.40
Achiever	0.00	0.60	0.10	0.00	0.40
Socializer	0.00	0.80	0.00	0.00	0.60
Explorer	0.40	0.00	0.40	0.80	0.60
Appropriateness Value *av*		0.40	**0.95**	0.75	0.60

3.3 Personalization and Adaptation in the Storytelling Context

From a storytelling perspective, the major challenge is to overcome the Narrative Paradox (see also Section 2) providing both a) a motivating, thrilling and suspenseful narrative environment based on well-proven story structures and patterns such as the Hero's Journey [16, 17] and b) an adaptive, interactive environment, enabling the user to interact and (at least in parts) take control of the story structure during play. Hereby, the system needs to take into account player/user/learner characteristics as well as overall (learning/knowledge transfer vs. gaming) strategies defined by an author (pedagogue vs. game designer), which implicitly decreases the level of influence by the user/player/learner.
Louchart and Aylett [18], Göbel [19] or Champagnat [20] investigated a lot of research tackling the Narrative Paradox and the use of appropriate and flexible storytelling methodologies in that context. As a result and being used within 80Days, Göbel et al. [19] suggest the use of a combined approach based on the Hero's Journey as underlying, well-proven (mostly linear) story model and emergent, non-linear parts: The middle part of the Hero's Journey with the dramatic step 'The Road of Trials' is very flexible and provides the possibility to integrate as many story units as needed and to combine those units in any order. Because of that, this story part is especially suitable for an adaptation and personalization. As the scenes can be ordered in various ways, it is possible to provide an individual learning and gaming to the players. Furthermore, the replayability is increased if a new game can run completely different.

Concerning adaptation and personalization, this approach implies a two-fold strategy: First, on a micro adaptive level, different variants of specific situations/scenes (dramaturgic steps in the model of the Hero's Journey) should be authored (in advance) respectively automatically created (during run-time) according to the characteristics and peculiarities of users/learners. Second, on a macro adaptation level, the order/sequence of story units within the flexible part of the 'Road of Trials' is determined during run-time based on user/learner/player activities, underlying models and strategies.

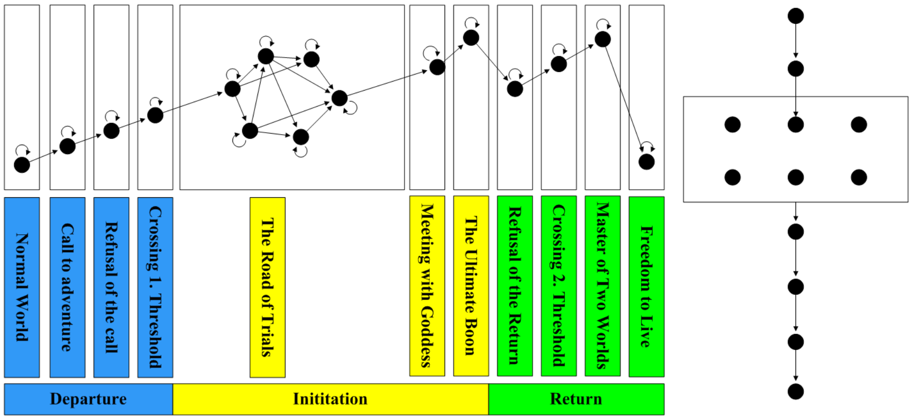

Fig. 3. Hero's Journey story model (left) - linear and modular story units (right).

3.4 Definition of NGLOB

Starting with the storytelling perspective, Narrative Objects (NOBs) represent the smallest, atomic units of Story-based DEG. For the formalization of NOBs and narrative contexts, the idea is -as far as applicable- to map and annotate NOB corresponding to the steps and dramaturgic functions of underlying story models such as the Hero's Journey. With respect to learning issues, the idea is to formalize the learning and learner context and to provide machine-readable information about associated and prerequisite skills of a learning object (LOB) respectively learning situation based on the CbKST. Thus, for sequencing purposes - presumed an open, modular, emergent (narrative) environment is available without hardcoded transitions as in pure linear approaches - it is possible to decide whether a learning situation is appropriate for a specific learner (the learner does have the prerequisite skills) or not (the learner would be overstrained). Concerning the gaming context, the interaction concept in form of interaction templates (e.g. drag-and-drop, multiple-choice and puzzle templates in classic courseware or an explorative 3D environment) provides useful attributive information. Second, similar to the learning context, the idea is to build a correlation between gaming situations/GOB and the users (i.e. players in the gaming context) and underlying player models. Hence, all gaming situations are set into context with player types and annotated with appropriateness factors.

In sum, the model for a NGLOB is built by a composition of context information resulting in a triple vector C_N x C_G x C_L. The narrative context C_N provides a list of tuples ($storymodelStep$, $appropriatenessFactor$), whereby $storymodelStep$ is encoded by the initials of a story model (for instance 'SM_HJ' for Hero's Journey) plus a number for the step/part of that model. The parameter $appropriatenessFactor$ indicates how much the scene fits to the according $storymodelStep$ and is normalized in the range [0,1]. The gaming context C_G primarily tackles the appropriateness of individual GOB and gaming situations for different players and player types. Analogously to the narrative context C_N, the gaming context C_G also provides a list of tuples (*playerFeature*, *appropriatenessFactor*). Here, 'PM_BA_x' describes the player type based on the classification of Bartle [3]. For example, 'PM_BA_E, 0.9' indicates that the GOB is very appropriate for the player type 'Explorer' according to Bartle. The model for the learning context C_L provides a vector composed of two parts listing all Associated ('*Axyz*') and Prerequisite ('*Pxyz*') Skills for a specific learning situation/LOB, whereas 'xyz' is a unique identifier. Apart from that quantifiable part described above, the model for NGLOB contains further descriptive elements such as short texts/abstracts summarizing the synopsis of narrative, gaming and learning functions of a specific NGLOB. In Figure 4 an example for such an NGLOB is provided:

$$\left(\left\langle \begin{array}{l} (SM\_HJ\_1, 0.1)\,, \\ (SM\_HJ\_4, 0.2)\,, \\ (SM\_HJ\_8, 0.1) \end{array} \right\rangle , \left\langle \begin{array}{l} (PM\_BA\_K, 0.2)\,, \\ (PM\_BA\_S, 0.4)\,, \\ (PM\_BA\_E, 0.9) \end{array} \right\rangle , \left(\begin{array}{l} \langle A101, A102 \rangle \\ \langle P210, P217 \rangle \end{array} \right) \right)$$

Fig. 4. Quantifiable part of the model for Narrative, Game-based Learning Objects.

4 Prototypical Realization within the 80Days Bat Cave Demonstrator

The 'Bat Cave' scenario as second demonstrator in the course of the 80Days project is a demonstrator with twofold goals. On the one hand it is used as a player (instead of a game engine) for playing a game. On the other hand, it is able to explicitly visualize the underlying learning, gaming and storytelling mechanisms. Contrary to demonstrator 1, which addresses students from 12 - 14 years of age, the second demonstrator's main purpose is to visualize underlying methods and concepts and therefore it has no special group it aims at.

Using a novel authoring tool like Storytec [19], developed at TU Darmstadt, a game author can easily create a scene-based educational game which runs in the Bat Cave demonstrator. With Storytec the author can annotate NGLOBs with narrative, gaming and learning attributes, thus decorating the scenes of the created game with little effort. Using Bat Cave, the author can play his own game for test issues and is able to see the underlying player and learner modeling and the narrative context which lead to the scenes chosen. This is a powerful support for an author to debug and enhance a DEG.

In Figure 5, a screenshot of Bat Cave can be seen. The GUI is divided into a left part, the part where the actual game is played, and a right part where the background information is displayed. Here, one can see (from top to bottom) different story variables, a history of chosen scenes displaying the course of the game, the different steps of the story model (here the 'Hero's Journey') showing the current scene in the story context, the current player model following Bartle,

Fig. 5. Screenshot of the Bat Cave demonstrator

the Prerequisite and Associated Skills for the current scene, the Knowledge Space and a list of the total skills achieved by the learner so far. Hence, the right part provides a detailed view on the learner and the player model and also keeps track of the story progress, thus making transparent the decisions made by the game based on the underlying learner model, player model, and narrative context.

As shown above, from the different contexts learning, gaming, and storytelling different proposals for the next scene to choose can be made which often will differ. We do not intend to provide a final solution to resolve that complex issue. In contrast, our approach is an author support for creation of an adaptive and personalizable DEG. By use of NGLOBs, an author is supported in the creation of reusable scenes which according to his/her focus are ordered automatically (in the non-linear parts of the game like the 'Road of Trials' which represents the greater part of a game's story). Subsequently, based on the early work on Story Pacing proposed by Göbel [21] our simple approach to this problem in the Bat Cave demonstrator is to assign weights to the three contexts learning, gaming and storytelling, thus defining which context has priority. This weighting can be defined by the author, or even be put into the player's hands. For every context, each scene gets assigned an appropriateness value av_i, $i \in \{1, .., \#Scenes\}$ in the interval $[0, 1]$ in discrete steps of 0.1 indicating how good the scene would fit as next scene according to the context. Additionally, for every context a weighting value w is assigned. The scene with the highest sum will be chosen as next scene (if no unique best solution does exist, one of the best solutions is chosen randomly).

Table 2. No weighting

	Le.	*Ga.*	*St.*	*Sum*
w	1.0	1.0	1.0	
Scene 1	0.9	0.2	0.2	1.3
Scene 2	0.5	0.5	0.1	1.1
Scene 3	0.1	0.8	0.5	**1.4**

Table 3. With weighting

	Le.	*Ga.*	*St.*	*Sum*
w	2.0	2.0	1.0	
Scene 1	1.8	0.4	0.2	**2.4**
Scene 2	1.0	1.0	0.1	2.1
Scene 3	0.2	1.6	0.5	2.3

Table 4. Absolute priorities

	Le.	*Ga.*	*St.*	*Sum*
w	0.0	0.0	**1.0**	
Scene 1	0.0	0.0	0.2	0.2
Scene 2	0.0	0.0	0.1	0.1
Scene 3	0.0	0.0	0.5	**0.5**

In Table 2 the unweighted (all $w = 1$) values for the scenes to fit best as next scene can be seen. If the contexts are assigned with different priorities, the optimal next scene can change as shown in Table 3. It is even possible to give one context an absolute priority over the others as shown in Table 4. However, in the linear parts of the story, we propose that the author hard-codes the transitions between scenes to provide a meaningful story. Consequently, in the linear story parts, there are no conflicts. Additionally, our model includes so-called 'story bridges', special independent scenes which can be inserted in order to provide a complex, suspenseful story, whenever a scene containing a required learning context needs a dramaturgic 'bridge' to soften an abrupt story jump before the scene can be played.

5 Conclusion and Outlook

Based on preliminary, long-term research in the field of Story-based edutainment applications, this paper introduces the conceptualization of NGLOB as basis for personalized, adaptive Story-based DEG. The main result represents a conceptual model for NGLOB composed of a narrative, a gaming and a learning context. The model has been prototypically implemented and serves as an underlying theoretical framework for the Bat Cave scenario as second demonstrator of the 80Days project, settled in the field of Technology-enhanced Learning. First evaluation studies of demonstrator 1 already have shown the principle potential of an adaptive, Story-based DEG: The users did not only appreciate the motivating, suspenseful and playful form of knowledge transfer, but also the possibility to actively influence the DEG during play. In the course of 80Days' Bat Cave demonstrator, further research will be investigated in evaluation studies to test and measure the benefits of the new concepts described in this paper.

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