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Dynamically adjusting Digital Educational Games towards Learning Objectives

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Abstract: Personalization techniques offer the possibility to tailor each learner's experience of a Digital Educational Game (DEG) to their specific needs. Such personalizations can adapt the challenge and difficulty of the DEG to the learner's cognitive ability, motivation and gaming abilities. In particular, complex story based DEGs have introduced micro adaptive approaches, in which the adaptivity is applied in specific learning situations that do not usually affect the overall story line of the game. For adaptivity to be applied across an entire story based DEG, macro level adaptivity, such as learning situation sequencing, needs to be addressed. Such adaptivity can provide the means to dynamically adjust a DEG towards learning objectives based on the learner's evolving needs, whilst monitoring and adapting to the learners motivation. For this the applied adaptations need to consider a holistic view by encompassing different dimensions within DEGs, such as learning, game play and narrative. This can be achieved by allowing the underlying storyline of a game to dynamically grow based on micro adaptive decisions made in specific learning situations with the goal to ensure an exciting and meaningful gaming experience for the learner. Finally any approach to adaptivity in DEG needs to assist reusability and general applicability in order to allow low cost and timely development. This paper introduces an approach to producing adaptive story based DEGs that incorporate best practice in reusable personalization techniques in e-Learning with adaptive storytelling for games. For this the concepts of micro and macro adaptivity are introduced as a means of addressing the challenges associated with applying personalization in story based DEGs. Furthermore the usage, implementation and evaluation of such dynamic personalizations is detailed. Finally the challenges of dynamic adjustment of DEGs towards learning objectives is illustrated based on two full-featured demonstrators that have been produced as part of the European Commission funded research project 80Days.

Keywords: Serious Games, Digital Educational Games (DEG), Non-invasive Adaptivity, Adaptive Storytelling.

1. Introduction

The challenge of combining traditional pedagogic methodologies with state of the art gaming technology has led to exciting new approaches. These approaches, generally known as Digital Educational Games (DEG), promote both the curricular based learning objectives and the intrinsic motivation of the learner (Prensky 2003). However it can be argued that many DEGs focus more on the overall gaming experience by primarily promoting motivational aspects and not the overall learning objectives. Moreover the learning objectives tend to be pre-set throughout the game not taking the learner's individual preferences and development into account (Rieber 1996). Recently two adaptive approaches addressing this shortcoming have been introduced and separately applied to DEG. The first approach, known as micro adaptivity, adapts Non Player Character (NPC) dialog in a specific learning situation to the skill level of the learner (Peirce et al. 2008) . The second approach, known as macro adaptivity, adapts the sequence of learning situations to the learners overall skill level and to gaming and story line constraints (Kickmeier-Rust et al. 2008). This paper introduces the integration of both approaches by allowing micro adaptive interventions inform macro adaptive decisions. The goal of this approach is to allow a more personal gaming experience by supporting both the motivation of the player and the learning objectives stated by a teacher/pedagogical expert, thus improving learning motivation with an overall dynamic and engaging storyline (Kickmeier-Rust & Albert 2010) (Kickmeier-Rust et al. 2008) (Peirce et al. 2008).

The remainder of this paper is structured as followed. It first outlines related work in the area of adaptivity and DEGs. After which the application of micro- and macro adaptivity in DEGs is illustrated. This is followed by illustrating of the overall architecture of the 80Days European Commission funded project in which the usage of adaptive techniques to adjust DEGs towards learning objectives is

applied. Finally an initial evaluation of a first fully featured demonstrator and conclusion chapter is provided.

2. Related Work

The difficulty of integrating gaming and learning in an engaging and educationally meaningful way has been recognized by several research and commercial projects, such as ELEKTRA (Kickmeier-Rust et al. 2006), 80 Days and the commercial "Global Conflicts" computer game series (http://www.globalconflicts.eu). However one of the main challenges in the development of DEGs still is the difficulty of balancing game and learning experience. Moreover it can be argued that both experiences exclude each other e.g. focusing on motivational game play elements, such as fast-paced or action rich game elements may come with the price of sacrificing the underlying learning objectives. On the other hand by focusing on the learning objectives, the game play may tend to provide a dull gaming experience leading to a higher drop-out rate (Kickmeier-Rust et al. 2007). In order to find the right balance of both learning and gaming experience recently adaptive mechanisms have been introduces to DEG taking the individual preferences of the learner into account. The ELEKTRA project, as one example, successfully applies micro adaptive mechanisms, such as learning hints through the Non-Player Character (NPC) Galileo Galilei as a learning mentor. The adaptive hints are based on the individual skill level of the learner and are designed to be non-intrusive in order to not adversely interrupt or even break the game flow. To ensure the learner receives the right hint in the right situation a statistical model based on the competency-based Knowledge Space Theory (CbKST) is applied (Hockemeyer 2003). In this model all skills, e.g. knowing the location of Paris on a map, are represented in a graph like structure. Based on the interaction of the learner, e.g. clicking on a map after being asked where Paris is, all skills related to this specific interaction are updated resulting in a value between 0 and 1. The skill probabilities can then be used to identify an appropriate adaptive intervention, e.g. via a NPC dialog.

The 80Days project, as a second example, extends the micro adaptive approach of ELEKTRA by introducing a learning buddy called Feon (note Figure 1). The mostly dialogue based adaptive NPC interventions in ELEKTRA have been extended in 80Days with behavioral interactions, such as eye movement and body posture. It is envisaged that improved NPC interaction will lead to a higher level of para-social interaction, thus a higher level of trust between the player and the NPC, which can have a positive effect on the overall gaming and learning experience (Shapiro et al. 2006). The 80Days project also introduced and investigated macro adaptivity in DEGs, such as story pacing and story adaptivity (Kickmeier-Rust & Albert 2009). The objective of applying macro adaptivity in the DEG 80Days is twofold, with (1) providing a compelling and engaging story line that can dynamically adjust learning objectives as the story progresses and (2) providing a generalized approach to assist the design of macro adaptivity adaptive DEGs leading to a reduction in cost and effort. Finally the integration of both micro and macro adaptivity was studied addressing the question how micro adaptive interventions can inform macro adaptive decision. Both micro and macro adaptive approaches have been applied to different application areas and are strongly related to the research area of Adaptive Hypermedia (AH) (Brusilovsky 2001). In particular, adaptive e-Learning applications have produced impressive results by applying adaptive interventions to specific learning situations, e.g. a specific topic in an overall course (Conlan, O & Wade, V. 2004). The typical approach taken is to provide an individual learning experience based on a learner model that reflects the individual knowledge level and curricular of the learner. This allows the adaptive e-Learning application to ensure that only content suitable for the specific learner is displayed. In addition to the learner model, adaptive e-Learning applications usually apply a pedagogical model to ensure that the adaptive learning experience is driven by overall pedagogically sound learning objectives. In DEGs however overall learning objectives are usually integrated in the story line or narrative of the game and not represented by a separate adjustable pedagogical model. In order to adjust the DEG towards learning objectives, the 80Days project has introduced macro adaptivity which is related to research in adaptive storytelling. Applying adaptivity to DEG however is a costly and time consuming task. In order to support the development of adaptive DEGs, an additional tool called 'Bat Cave' was developed in the 80Days project. This tool, which is not discussed in this paper, allows the game designer to investigate the impact of micro and macro adaptive mechanism on the overall game. The following chapters describe micro and macro adaptivity and its implementation in DEGs.

Figure 1 The 80Days NPC Feon

Figure 2 An example of micro adaptive interventions in 80Days

3. Micro Adaptivity

The objective of micro adaptivity is to observe the behavior of the learner in virtual problem solving situations known as Learning Situations (LeS). An approved approach to represent and monitor the gained knowledge of a learner within a LeS is the competency-based Knowledge Space Theory (CbKST) (Kickmeier-Rust et al. 2007). This theory states that within a finite set of problems prerequisite relationships can be assumed between abstract cognitive skills and competencies necessary to master the pre-defined problems. One example of this relationship can be that knowing where Paris is located on a map implies the knowledge of knowing where France is. Even though knowing the location of Paris and France are two separate abstract cognitive skills, both can be defined in an abstract prerequisite relationship. For instance, knowing the location of France could be defined as a prerequisite to knowing the location of Paris. The resulting skill structure that is generated can then help a DEG to infer that a user already knows where France is if they have shown that they already know how to locate Paris. This helps to avoid the display of inappropriate or redundant adaptive hints to the learner.

All skills in a prerequisite structure are initialized with a value between 0 and 1, which is calculated automatically from the prerequisite relation. These initialized values are then updated based on specific player interactions within the DEG. In essence, specific skill probabilities increase when the user is progressing successfully and decrease when not. Thus, these changing probabilities can be used to infer the current skill state of the learner, and the accuracy will increase the more learning actions the learner performs within the DEG. Depending on the skill probabilities of the user, and their most pressing needs at that specific time, different cognitive, meta-cognitive or motivational hints (text, dialogues, videos etc.) can be selected to be displayed to the learner within the DEG. Micro adaptive approaches, such as introduced above, have been integrated successfully in the DEG project ELEKTRA (Kickmeier-Rust et al. 2006). In ELEKTRA the individual LeS are related to physics experiments involving light and magnetism, and the micro adaptive interventions are mostly realized as NPC dialogs. However these interventions are confined to specific LeS and the sequence in which the individual LeS are presented is constrained to the overall game narrative. From a pedagogical poit of view this can lead to a DEG which can provide an adaptive learning experience only within the specific LeS and not allowing a dynamic adjustment of the overall DEG towards the evolving needs and preferences of the learner. These limitations were addressed in the 80Days project, which focuses on teaching geographical content and environmental issues. By introducing macro adaptive approaches such as story pacing and story adaptivity, and combining them with the micro adaptive approaches outlined above, 80Days provides a versatile and holistic adaptive approach towards a more effective learning and gaming experience within DEGs.

4. Macro Adaptivity

Whereas micro adaptivity, as described in the last section, is concerned with managing small or localized adaptations within specific learning situations (LeS) to dynamically adjust the game towards

the learning objectives in the specific LeS, we refer to macro adaptivity as adaptivity based on the dynamic sequencing of situations or on story pacing, i.e. the temporal control over the unfolding of a story. This approach takes learning and motivational aspects of the DEG into account by monitoring the narrative of the DEG to uphold a suspenseful story arc, or by adjusting the game to match the gaming preferences of a player.

As a basic unit of storytelling-based DEGs such as 80Days, the concept of Narrative Game-Based Learning Objects (NGLOBs) has been introduced (Göbel et al. 2009). In general NGLOBs can be seen as learning situations which are annotated based on different dimensions, such as learning, narrative and game play. This allows an adaptive DEG to compute a sequence of NGLOBs which is best suited to the current state of the learner, reflecting both the currently available information about the learner and the current state of the game.

Three dimensions of metadata in NGLOBs can be defined as follows:

- *Learning Dimension*: This set of metadata is concerned with the learning objectives of the NGLOB, comprising the set of skills required to understand the content of the NGLOB as well as the set of skills that can be imparted in this scene. The actual effect of the scene on the user's skills during the NGLOB is inferred and tracked by the Skill Assessment Engine (see section 5).
- *Gaming Dimension*: For the gaming context description of a NGLOB, the concept of player modeling is used, with the metadata describing the suitability of a NGLOB for a certain type of player.
- *Narrative Dimension*: The metadata concerning narrative are related to the concept of story models such as the Hero's Journey (Campbell 1968) and consists of information which narrative functions the NGLOB can serve by being inserted into the story during a certain step of the story model.

During the execution of a game, models related to these three dimensions are created and updated. All model updates are based on player actions. Examples of such models are the learner model and the player model. In a second step these models can be used as input for constructing sequences of NGLOBs. For example, after the execution of a certain NGLOB has finished, the next NGLOB to be entered is searched in the following fashion: from the set of available NGLOBs, that NGLOB that is most suited to continue the game in an optimal and effective (concerning learning) way is chosen. The basis for this choice is the evaluation of the NGLOB based on the three dimensions described above. For example, two NGLOBs might differ in their appropriateness for certain player types. The scene for which the player model annotation matches the current state of the player model best will be chosen in this case. This process can be seen as finding an optimal sequence of NGLOBs, based on metrics found in the dimensions NGLOBs are based on.

Concerning the Learning Dimension, an NGLOB is chosen according to the pedagogical model, with the optimal choice of the next NGLOB maximizing the skills of the player. Similarly for the Gaming Dimension a choice is made based on the player model, with the NGLOB that has the gameplay best suited to the current model being favored. Finally, choices influenced by storytelling are dependent on several properties. On the one hand, a continuing choice should uphold the suspense of the story and the story arc that is constructed. Choices can also be influenced by Story Pacing (Göbel et al. 2006), for example, if there are time constraints placed on the game (e.g. it must be finished in the course of a normal school lesson), NGLOBs that are not central to the game's narrative could be omitted.

Since these choices by themselves can lead to conflicts (according to different metrics, different scenes are optimal), mechanisms for resolving these conflicts have to be introduced. These could be in the form of weighting factors, which give each metric different weight in the final decision. An example could be a context in which the learning aspect of the game is to be stressed, therefore assigning it the largest weighting factor and in effect always choosing a sequence of NGLOBs optimal for learning, disregarding the aspects of narrative and game play.

The concept of NGLOBs has been influenced by the use of Learning Objects (LOB) in e-Learning applications focusing on re-usability and meta-data for automatic processing. However, due to the inherent differences between e-Learning applications and DEGs, several key restrictions and differences can be pointed out. The guiding principle of LOBs in e-Learning is the concept of re-use

and the simple development of courses by composing already available LOBs within Learning Content Management Systems (LCMS). Extending this approach towards DEGs mostly running on a computer or game console and using 2D or 3D game engines can prove to be a difficult undertaking, since DEGs usually function differently than LCMS and do not apply the principle of composing larger units (courses) from smaller units (LOBs). Digital games tend to be conceptually broken down into levels in which all control is handled by the game play mechanics, triggers, flags, and other control mechanisms. Due to this difference and the high amount of cohesiveness between game units and the rest of the game, NGLOBs are not intended to be re-used between different games although limited re-use between games sharing a common platform/engine can be possible.

5. Adjusting DEGs towards Learning Objectives

Micro and macro approaches are suited for certain aspects of a game. Micro adaptivity for instance is applied locally to make short-term adjustments to the perceived game play, which is based on the moment-to-moment interaction between the player and the game system. However due to this confined scope, micro-adaptivity is not suited to assist the learner to achieve the overall learning objectives over a longer gaming period. Macro adaptivity, on the other hand, has a far wider scope due to dividing larger game-play units (scenes) into meaningful and personalized sequences. Using this approach, the player can be led towards an optimal set of learning objectives by finding the best suited sequence. However, due to the global approach of macro adaptivity, it cannot achieve the same responsiveness as micro-adaptivity, since the effects of a macro adaptive adjustment only take effect after a player has completed a certain scene. As the scene will be composed of several interactions with the player, which can trigger micro adaptive adjustments, these adjustments will be more responsive to the player than the macro adaptive adjustment. However combining both approaches allows a DEG to dynamically adjust the DEG towards the overall learning objectives based on the learner's progress and based on the progress of the overall story. It is believed that this will increase both the learning and gaming experience.

This section illustrates the integration and application of both micro and macro adaptivity in DEGs exemplified with the 80 Days project. Note Figure 3 for an overview of the architecture.

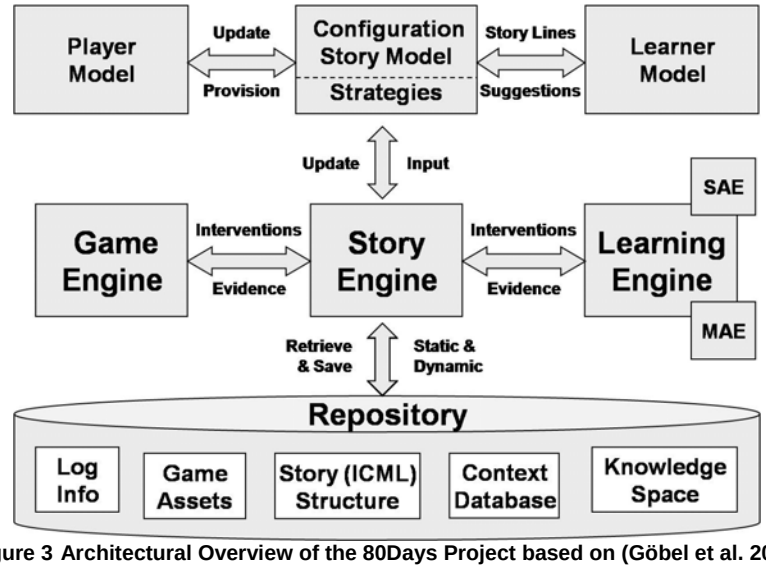

Figure 3 Architectural Overview of the 80Days Project based on (Göbel et al. 2009)

Learning Engine

Applying adaptive interventions in DEGs faces two main challenges: (1) All adaptive interventions need to be of non-intrusive nature in order to not aversively interfere with the game flow or narrative of the game and (2) all micro adaptive interventions need to be in line with macro adaptive decisions which overarch the individual Learning Situations (LeS). Within ELEKTRA and 80Days an adaptive Learning Engine (LE) was implemented with the additional of a Skill Assessment Engine (SAE) based on the CbKST illustrated above (Peirce et al. 2008). The main objective of the SAE is to provide an accurate picture of the current skill state of the learner for the adaptive LE to recommend cognitive and non-intrusive adaptive interventions to the game or any corresponding game management interface. In addition to the cognitive interventions provided by the SAE an additional CbKST based

Motivational Assessment Engine (MAE) was introduced in the 80Days project. The main difference of both approaches is that the skill space of the MAE only consists of two skills defined as Attention and Confidence which is used to provide specific motivational interventions in the case the learner seems to be losing motivation. Similar to the SAE a motivational intervention can be in form of a verbal or non-verbal interaction of the NPC, such as providing a motivational expression. The Learning Engine used in 80 Days is based on the rule based Adaptive Learning in Games through Non-Invasion (ALIGN) system architecture introduced and evaluated in the ELEKTRA project (Peirce et al. 2008). However ALIGN focuses mainly on micro adaptive approaches in DEGs by interfacing directly with the game engine. This allows ALIGN to directly react to game evidence in order to provide suitable non-invasive adaptive recommendations. In 80Days the ALIGN architecture was extended by providing adaptive motivational recommendations and by interfacing with the Story Engine and not the Game Engine. The Story Engine ensures that all adaptive recommendations do not adversely affect any game play elements such as story line or narrative. The emphasis of the Story Engine is on macro adaptive approaches thus it focuses on macro adaptive recommendations, such as story pacing and adaptive sequencing.

Configurable Story Model
In order to present NGLOBs in a machine-readable format the XML-based description language ICML, initially defined in previous projects (Göbel et al. 2009), was updated and extended to allow the annotation of game units with the necessary information for narrative, learning and gaming contexts. For the creation of ICML files, the authoring environment StoryTec (Göbel et al. 2008) is used, resulting in files loaded into the Story Engine component (both researched and developed at TU Darmstadt).

Story Engine
ICML files, defining the game's structure and story as well as high-level interactions, are loaded at runtime into a reusable component referred to as the Story Engine. This component uses an interface to connect to the Game Engine to execute the game and to control high-level commands, such as loading a certain level, or triggering a speech act by a virtual character. In addition, the handling of events triggered by the user is controlled. Examples of such events can be the reaching a certain portion of a level or choosing a certain dialogue in a conversations with NPCs. Internally, the Story Engine tracks the evolution of the game's story according to a certain Story Model as well as the Player Model as indicated by the actions of the player. Additionally, the Story Engine has an interface to the Learning Engine for handling the updates of skills according to learning-related game evidence, and for forwarding micro-adaptive interventions or macro adaptive recommendation issued by the Learning Engine.

Overall integration
The interface between the Learning Engine and the Story Engine is based on a TCP/IP interface which supports bidirectional sending and receiving of game evidence and adaptive recommendations in milliseconds. In addition the Story Engine informs the Learning Engine if it rejects any of its adaptive recommendations, because of an overall macro adaptive decision such as story pacing or story line. The TCP/IP interface also provides means to request the skill state of the individual learner or if needed the probability of a specific skill. The interfacing of Story Engine and Game Engine relies on function calls allowing a seamless integration of the Story Engine with both the Game Engine and the Learning Engine.

6. Evaluation

The first fully featured 80Days demonstrator was played and evaluated by 71 secondary school students (35 Austrian and 36 English). Due to the consideration of cultural differences both data sets were not merged. Three categories were evaluated: Learning efficacy, usability and user experience. Overall the results in all three categories indicated the game to be beneficial towards the learning effect. In addition the usability of the game scored as satisfactory allowing the interpretation that the non-intrusive nature of micro and macro adaptive interventions did not result in usability shortcomings. These results were assessed based on evidence by the statistical differences in scores related to pre and post assessments of learning questionnaires on domain specific items. In the case of 80Days these items were related to geographical and environmental issues. The following points summarize the evaluation findings.

- There is a clear indication throughout the evaluated group that the game promoted knowledge gain in the subject area.
- Several students expressed their appreciation about the educational value of the game play.
- The level of cognitive load or frustration was generally low.
- The motivation to continue playing can be indicated as high with most students wanting to play the next level.
- The NPC Feon communicating the micro adaptive interventions was successfully accepted by the students.

Currently a second survey is ongoing focusing more specific on the effect of micro adaptive interventions such as cognitive hints related to the skill assessment of the learner and motivational hints related to the motivational assessment of the learner. Furthermore macro adaptive interventions such as story pacing needs to be evaluated in further detail. It has to be noted that the concluding evaluation of the ELEKTRA project, with a similar approach in relation to specific micro adaptive interventions, has indicated that applying micro adaptivity in DEGs though NPC dialogs has a positive effect on the overall learning experience of the learner (Peirce et al. 2008).

7. Conclusion and further work

This paper has introduced the integration of micro and macro adaptivity in DEGs exemplified by the European Commission funded 80Days project. For this several elements such as Story, Learning and Game engine need to be integrated in a seamless manner for adaptive non-invasive adaptive interventions to assist the learning outcome of the game. This approach presents opportunities to adapt the game to the evolving needs and learning objectives of each individual learner. In order to evaluate the learning effectiveness an initial evaluation has been conducted and introduced.

Future work will need to address among others the possibility of integrating more story adaptive based approaches. However even though initial design elements such as story bridges and NGLOBs have been introduced, their applicability outside of highly integrated games such as 80Days needs to be investigated. Furthermore the next evaluation will be focused evaluation on cognitive and motivational aspects allowing a more precise evaluation of the micro and macro adaptive interventions.

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