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Micro Adaptive, Non-Invasive Knowledge Assessment in Educational Games

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Abstract

Most existing educational games cannot compete with their non-educational counterparts in terms of visual and narrative quality, gameplay, or adaptability. Amongst the most advanced approaches is ELEKTRA, a European project that developed a framework for intelligent educational personalization, enabling games to adapt learning and gaming activities to individual learning progress and pedagogical strategies. In this context, a crucial aspect is an individualized assessment of knowledge and learning progress. The ELEKTRA methodology enables an integrated and individualized assessment by monitoring and interpreting the learner's behavior within the game in a non-invasive way. The present paper summarizes the theoretical background from the perspective of cognitive science.

1. Introduction

Immersive digital educational games (DEGs) offer a highly promising approach to make learning a more pleasant, engaging, satisfying, inspiring, and probably more effective task. As a consequence, it is not surprising that there is an increasing interest in research on game-based learning and serious games per se. Many of the potential advantages of DEGs (e.g., interactivity, feedback, situated learning) are considered being important for successful and effective learning [1] and games serve the demands of the "digital natives" [2]. Since the 1990s research and development has increasingly addressed learning aspects of playing recreational games and also the realization of computer games for primarily educational purposes. Still, DEGs have major disadvantages, for example, difficulties in providing an appropriate balance between gaming and learning activities or between challenge and ability, in aligning the game with national curricula, or the extensive costs of developing high quality games [3]. Thus, DEGs most often cannot compete with their commercial counterparts in terms of gaming experience, immersive and interactive environments, narrative, or motivation to play. Moreover, most educational games do not rely on sound instructional models, leading to a separation of learning from gaming; often such games provide gaming actions only as reward for learning. In the cold light of the day, most existing DEGs do not differ significantly from other multimedia learning objects or applications.

2. ELEKTRA

The ELEKTRA project (www.elektra-project.org), funded by the European Commission, which ended in February 2008 and had the ambitious mission to fully utilize the advantages of computer games for primarily educational purposes and to address significant drawbacks of DEGs. ELEKTRA developed a sound methodology for designing educational games and a comprehensive game demonstrator based on a state-of-the-art 3D adventure game teaching physics according to European curricula (Figure 1). Furthermore, ELEKTRA addressed important research questions concerning game design, didactic design, or educational interventions.

In the focus of research and development was adaptively generating an appropriate balance of challenges and the learner's abilities and learning progress. As attempted by conventional adaptive approaches to technology-enhanced education, a learner must not be frustrated by to difficult subject matter but also not bored by to simple challenges. Only if such balance can be achieved on an individual basis, immersion and flow experience can rise, enthralling and captivating the learner. The foundation of such adaptation is a sound assessment of knowledge and learning performance. In contrast to conventional

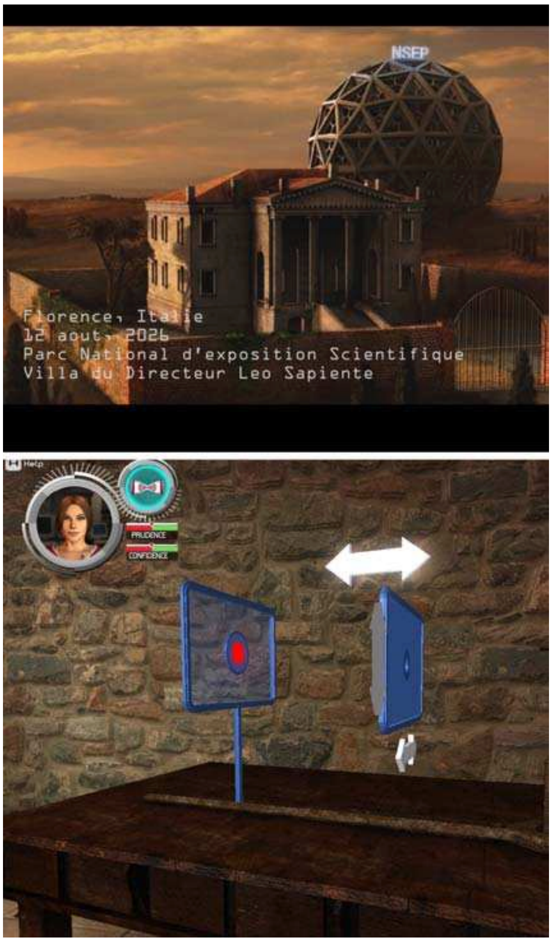

Figure 1. Screenshots from the ELEKTRA game

adaptive tutoring and knowledge testing, within a DEG assessment is restricted by the game's narrative, the gameplay, and the game flow. Typical and often used quiz-like methods (e.g., test items or multiple choice questions) fail to adapt to individual learners and, most likely, they break the game's flow and therefore immersion. The ELEKTRA approach attempts to realize *micro adaptivity*, that is, a continuous assessment by non-invasively interpreting the learner's behavior in the game and a subsequent adaptation and interventions within learning situations (LeS).

3. Knowledge Assessment on a Micro Level

The foundation of micro adaptive knowledge assessment and subsequent non-invasive interventions is interpreting the learner's (problem solution) behavior within learning and assessment situations in the game.

To realize such non-invasive assessment of knowledge, ELEKTRA grounds on the formal framework of *Competence-based Knowledge Space Theory* (CbKST) [4]. Originating from conventional adaptive and personalized tutoring, this set-theoretic framework allows assumptions about the structure of skills of a domain of knowledge and to link the latent skills with observable behavior. It provides an internal cognition-based logic that is quite similar to the logic of ontologies: well-defined entities (the competencies) are in a well-defined relationship (a so-called prerequisite relation).

The domain model, the set of meaningful competence states, and the learning paths are combined with a model of tasks and problems within a LeS, the so-called *problem space*. For each object in a LeS (e.g., the blind in Figure 1) we assume a set of properties (e.g., location, alignment, or angle) the object can have. Thus, the *problem state* is the combination of all objects' states in a given LeS.

The mapping of competence structures and problem spaces enables a continuous and non-invasive interpretation of the learner's behavior in terms of present and absent competencies within a LeS. This interpretation is probabilistic; for example, if a learner does not turn on a torch, we can assume - with a certain probability - that this learner does not "know that a task requires a light source".

4. Non-invasive adaptation

ELEKTRA's methodology allows providing individualized game situations on the basis of the same pool of game assets. For example, a high performer will be provided with fewer but more complex situations than an underachiever. Moreover, based on the presence or absence of certain skills, specific objects can be presented and tasks can be adjusted to the learner's needs. In the same way, the same learning situation can be presented repeatedly if necessary, for example with an increasing level of difficulty.

In addition to tailoring an entire LeS, the learner can be educationally supported by interventions (e.g., hints) when necessary. The conditions under which a certain adaptive intervention is given are to be developed on the basis of pedagogical rules; however, these rules will apply the micro adaptivity framework and utilize the learner model obtained through the assessment within the framework. Main types of interventions are:

- A *skill activation adaptive intervention;*
- A *skill acquisition adaptive intervention;*
- *Motivational adaptive interventions*;

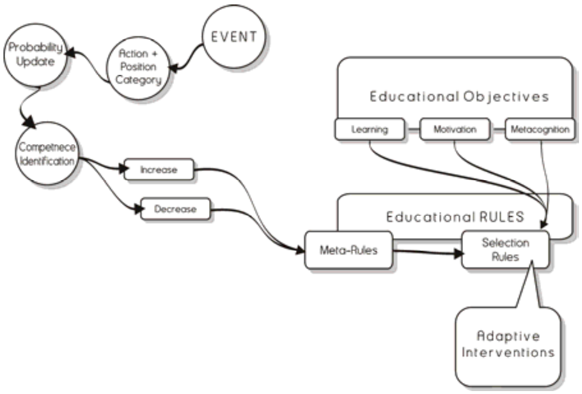

Figure 2. Process diagram of micro adaptivity

As summarized in Figure 2, the overall micro adaptive assessment and intervention process is imitated by any action the learner performs in the game (e.g., by switching on a torch). The situation after an event is analyzed in terms of the given problem solution state and, subsequently, the probability distribution over all competence states is adjusted to the problem solution state. This analysis, of course, must occur in real time. By the probability change of specific competencies involved in a situation (e.g., knowing that the torch's light is necessary), the most relevant/critical competencies can be detected. Depending on an increase (what actually is desired) or a decrease of the probability of specific competencies, pedagogical/ didactic meta-rules are utilized to select a specific interventions and feedback (e.g., "if the probability of a competence v involved in a LeS decreases below a threshold w, and the probability of a competence x is above a value y, then trigger an educational hint z').

5. Conclusions

The aim of micro adaptivity is to enable an assessment of competencies and learning progress during the game, which does not compromise the game flow and therefore does not negatively impact intrinsic motivation. The probabilistic assessment on the basis of interpreting the learner's behavior and actions within the game is supplemented with "harder" test items, for example the accomplishment of a certain task in order to reach a new level of the game. On the basis of this assessment, non-invasive adaptive interventions can be triggered in order to support the learning process.

Based on sound psychological models for problem solving and for competence structures, we have developed a framework for micro adaptivity within complex learning objects.

In the context of the ELEKTRA project, several empirical investigations and evaluation studies have been conducted (e.g., [5]), particularly concerning the educational effectiveness of adaptive features in assessment and interventions. Generally, analyses revealed that adaptive features result in better learning performance and also superior gaming experience than non-adaptive control groups.

However, micro adaptivity is still in an early stage of research and development. The underlying framework uses some simplifying assumptions like the identity of properties and position categories and actions. Based on the experiences in the ELEKTRA project, the framework will be generalized within and beyond the domain of game-based learning. Future work will also address the integration of meta-cognitive aspects such as confidence ratings into the assessment procedure In future projects also the realization of adaptive storytelling is envisaged in order to enable educational game technology even a broader range of individualization and adaptation to specific learners.

6. Acknowledgements

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