

# Using CbKST for Learning Path Recommendation in Game-based Learning

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**Abstract:** This paper presents a novel approach how learning paths consisting of game units can be created and adapted to learners based on their behavior during the game play. Non-invasive assessment procedures interpret the behavior and calculate information about the competences of the learners. A user model holds probabilistic information on the competence profile. Based on this competence profile game units/stories are recommended fitting to the actual competence state of the learner. This approach is part of the EC-funded TARGET project which provides the technical infrastructure regarding the 3D virtual game environment. The innovative part of this paper is the adaptive learning strategy and how it can be included in a game-based environment. The user perspective is demonstrated on a concrete scenario where the learner has to solve a task in the game-based environment.

**Keywords:** Digital Educational Game, Adaptive Learning Paths, Competence-based Knowledge Space Theory, Simplified Updating Rule

## Introduction

An important research area in Technology-enhanced learning (TEL) focuses on adaptivity and personalization. Several approaches have been elaborated that demonstrate how a system and its content can be adapted to the learner's knowledge level. To allow individually tailored educational software solutions, it is necessary to keep track of an individual learner's knowledge state at a specific moment in time [6]. In Adaptive systems relevant information is typically described in user models, domain models, and adaptivity models [3].

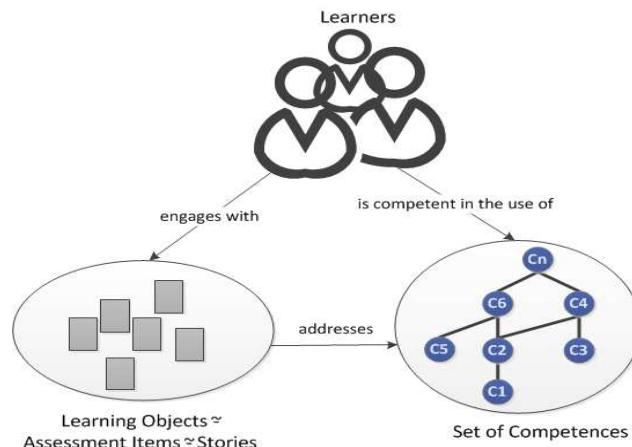
One research area in TEL is Game-Based Learning (GBL) and Digital Educational Games (DEG). They provide powerful opportunities for the learner regarding motivation and flow experience. It has also shown that these factors in game-based settings have positive influence on learning effectiveness and learning outcomes [9]. The European research project ELEKTRA (<http://www.elektra-project.org/>) firstly explored and presented the micro-adaptivity approach. This methodology allows assessing a learner non-invasively and continuously without interrupting the learner's potential game flow experience. Assessment data is retrieved from the user's behavior while being engaged in the game [8]. This approach was revisited and implemented in subsequent projects. In 80Days (<http://www.eightydays.eu/>) for instance, information was derived from specific actions indicated by the manipulation of objects [9].

This paper presents an approach how learning paths consisting of game units can be created and further adapted to learners based on their behavior during the game play. Non-invasive assessment procedures interpret the learner's observable behavior and infer information about the competence level, which is stored in the user model. Based on the

user model, stories are recommended fitting to the actual competence state. This learning cycle is done until a learner achieves a desired competence state. This approach is part of the EC-funded TARGET project [10] which provides the technical infrastructure regarding the 3D game environment. The innovative part presented in this paper is the adaptive learning strategy (LS) and how it is embedded in a game-based environment.

## 1. Conceptual Framework

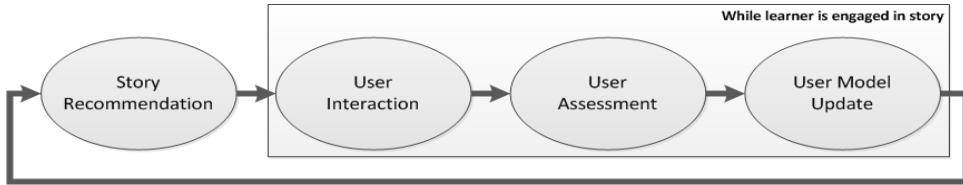
In a DEG like TARGET, learning happens during the game play. Therefore, the game is structured into game units that teach competences and thus act as learning objects (LOs). Traditionally, LOs are designed as multimedia documents containing texts, images, animations, and other 2D elements. In our case these units are designed as immersive 3D environments where learners can move around and interact. Since there are also tasks to solve in a defined and contextualized situation, they are seen as stories. For the completion of a story, a certain level of proficiency is required but might also enhance throughout the confrontation with comprised challenges. Hence, stories or LOs do not only teach subjects, but also test the knowledge of the learners by observing the learners' performance when interacting in a story (see Figure 1).



**Figure 1: Relation between stories, competences and learners**

In order to formally structure the stories with respect to knowledge and competences, the conceptual framework is based on the Competence-based Knowledge Space Theory (CbKST) [5][7]. This framework allows for representing knowledge of knowledge domains and learners and provides algorithms to test the knowledge of learners in terms of competences. The learning path is adapted according to these competences. The basic idea is to define a domain model by defining competences and to build a structure on them (a competence can be a prerequisite for another one). These competences are assigned to learners (a learner can demonstrate a competence), to learning objects (a learning object teaches competences), and to assessment items (an item can test whether a learner can demonstrate a particular competence). Each story is assigned with the competences that are required for solving the tasks of that story and hence for story completion. Competences and their relationships to stories form the domain model. Competences may or may not concern with one another but if they do, this is displayed in the domain model using pre-requisite relationships. In addition to the domain model there is also a user model that describes a learner's individual progress and state in terms of obtained competences. Figure 1 outlines the relationships between stories, competences, and learners.

Figure 2 illustrates the learning cycle: In the initialization phase the learner is invited to set learning objectives in terms of competences (Target Competence Profile, TCP) and to provide pre-knowledge in terms of competences through self-assessment (User Competence Profile, UCP). Based on the competence profile a story is selected that addresses the competences that the learner should learn next. The learner plays this story by interacting with the game and by trying to solve the task in the given situation. The interactions are observed and used to identify if the learner shows the respective competences. The result of this non-invasive assessment goes into and updates the user model. When the learner has finished a story, the system recommends the next story based on the user profile taking into account the results of stories a learner previously engaged with.



**Figure 2: Learning Cycle**

## 2. Adaptation Model

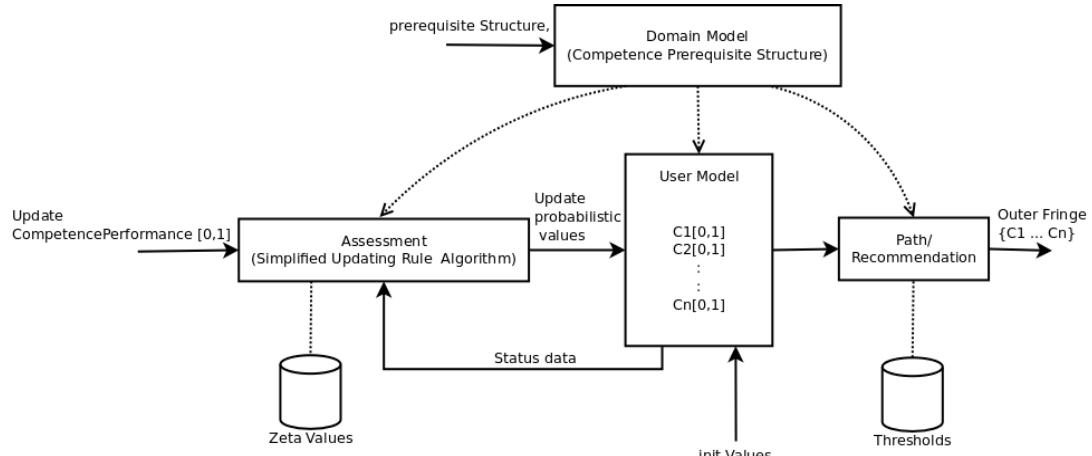
Adaptation in our case means to adapt the story path to the learner's competence state. Stories are recommended to the learner according to currently shown competences.

Assessment items are usually provided to the learner before or after she has consumed a set of LOs. However, as it often happens in serious games, both teaching and testing are within a single learning unit or game scenario. This offers the great opportunity to assess the learner's ability while she or he is being engaged with the game. It allows assessing the learner without destroying a potential flow experience [4]. Therefore, a non-invasive or implicit assessment procedure was introduced. The approach is based on the non-invasive assessment procedure that is already implemented in the TARGET project. Basically, it grounds on the interpretation of the learner's actions and interactions within the virtual environment [2]. These observations result in values (ranging between 0 and 1) for the set of competences assigned to the current story. For example, if a learner is playing story A and the competences x, y, and z are assigned to this story, then the result could be [0.1, 0.7, 0.8] meaning that the learner performed well in respect to competences y and z and poorly as to competence x. We call these values competence performance values.

In Figure 3 one can find a more detailed view on the structure of the learning strategy's (LS) logic. Starting at the top of the illustration, the Domain Model encompasses all identified competences of the domain and their (pre-requisite) relations to each other. This model does not change during the learning cycle. On the other hand, the user model located in the center of the illustration keeps track of the competences a learner demonstrates. It is initialized with the values of the user competence profile, the target competence profile and relevant parts of the competence domain. All competences of the TCP and those that are pre-requisite relations to them are relevant for the user model.

Each competence within scope has assigned a probabilistic value that indicates the probability of the learner being competent in the use of it. The Assessment part receives competence performance values in a continuous range from 0 to 1 for single competences. Incoming values are applied through an algorithm called Simplified Updating Rule [1]. As the algorithm can only handle binary updates, solely values smaller than 0.35 for negative assumptions and values higher than 0.65 for positive assumption are taken into account. After the classification of the input, the algorithm can be applied on the affected competence

and its related competences in the user model. For example, if a competence x is a prerequisite for competence y then we can assume that a learner that shows competence y also shows competence x. If the assessment procedure delivers a probability value for competence x, we can also make the assumption that the same learner demonstrates competence y to a certain extent and thus we can increase also the probability value for competence y. According to this consideration all related probability values are modified each time the assessment procedure delivers data for the competences assigned to a story.



**Figure 3: The Core Logic of the Learning Strategy Component**

The recommendation strategy is based on the competence profile (of the user model). This strategy is done in a two-step process: First the competences that the learners should obtain next are determined. Then, an according story is selected. To that end, the Path/Recommendation module accesses the user model and selects a small set of competences whose probabilistic values differ from a defined threshold the least. If the value of a competence is very high, it is likely that the learner already demonstrates this competence. So this competence will not be selected. If the value is very low, it is likely that the learner is not competent in this area yet. This competence is also not selected, because it is assumed to be too difficult for the learner at this stage of the learning process. Therefore, a competence should be selected that has a probability value of about 0.5, because such a competence is expected to be of medium difficulty for the learner. In the second step a story is selected that addresses the picked competences. Then the learner continues with this new story and a new assessment is happening. This cycle is conducted until all competence values are above a certain threshold value.

### 3. The Learner's Perspective

The learner's active part in the personalization process takes place during the initialization phase, when the learning plan is created. In the TARGET project, a tool called Competence Analyzer is provided as an input device to assign selected competences to the User Competence Profile (UCP) or the Target Competence Profile (TCP). When the learner finishes, the UCP should include all competences the learner demonstrates at this point in time. The TCP should include all competences the learner would like to achieve during the execution of the resulting learning plan. Based on these profiles the first story recommendation can be provided and presented to the learner. Within the virtual environment the learner is represented as an avatar and has to interact (non-verbally and verbally) with so called non-playable characters (NPCs) to master story-dependent tasks. Stories are tailored to contribute to a learner's competence development. The story

description encompassing tasks, characters, and background information is presented to the learner at the very beginning. After reading the initial story manual the learner enters a scene of the Game scenario. The player learns and is being assessed till the end of the game is reached, which happens either when the story tasks have been mastered successfully or the playing time has expired. In any case, the learner gets the chance to reflect on a diagram that presents her or his performance of the story competences throughout the last game play. A next story is offered to the learner.

#### 4. Conclusion and Outlook

Focus of this paper lies on the CbKST based modeling of user competences to support the adaptive guidance through competence based learning and assessment in a DEG. A brief insight into the implementation and the application of the algorithm was provided. Evaluations of the overall TARGET platform have started. Initial feedback from users indicates that recommended stories are experienced slightly above the medium difficulty level. Further studies will provide information about the appropriateness of selected competences addressed in these stories. Subjects of adjustment could be the thresholds related to competence probabilistic that lead to the competence selection and also the number of competences addressed by one story, in order to improve the adaptation.

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