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# A NOVEL APPROACH AND SOFTWARE COMPONENT FOR SUPPORTING COMPETENCE-BASED LEARNING WITH SERIOUS GAMES

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## Abstract

Digital educational games constitute a major opportunity for acquiring knowledge and competences in a different way than traditional classroom- and technology-based methods. This paper presents a novel approach for a game component that structures the game play in an adaptive way. This approach consists of a combination of three learning theories and techniques. First, Competence-based Knowledge Space Theory is used to structure a knowledge domain into competences and game situations. Second, the Leitner system of flashcards is used to establish structured and timed repetition of competences to be acquired. Third, the Ebbinghaus forgetting curve is taken into account to model forgetting learned competences. This approach has been implemented as a game component in line with the games component architecture of the RAGE project. The design and development of this component followed the requirements of the French games company Kiupe that includes it in its environment of games and mini-games.

Keywords: Serious game, game component, competence, flashcard, forgetting curve.

## 1 INTRODUCTION

Digital games constitute a major opportunity for acquiring knowledge and competences in a different way than traditional classroom- and technology-based methods. Well-designed computer games provide key advantages for facilitating learning, such as enhancing motivation and stimulating a flow experience during the learning process [15]. In addition to typical game features, serious games also need a clear strategy on which and how knowledge and competences are conveyed [1].

This challenge is acknowledged and addressed by the RAGE (Realising an Applied Gaming Eco-System, <http://rageproject.eu/>) project and its modular approach [6]. In order to support the young emerging applied-game industry, the RAGE project developed (a) an interoperability framework for game components [13], (b) set of advanced game components matching the definition of this interoperability framework, and (c) an ecosystem where these game components are made available to the public [11].

In the course of previous work we have developed several software components that focus on the educational benefit of applied games [10]. First, the Player Profiling Component allows a pre-game adaption at the beginning of the game; this enables the game developer to tailor the game to a player's characteristics. Second, the Competence-Based Component controls the skill or competence development during gameplay; competence assessment and game path adaptation based on this assessment are the key features of this component. Third, the Cognitive Intervention Component provides learning support based on the in-game activities of the player; this leads to interventions targeting the reflection process based on psycho-pedagogical considerations. Finally, the Motivation-based Component handles the player's motivation by assessing and modifying it throughout the game. Those four software components represent a modular approach for multi-dimensional learning support in digital educational games.

This paper describes a novel approach for dealing with knowledge and competences in serious games. The novel approach to support competence-based learning in serious games is based on a combination of three existing learning theories and techniques. The first of them is Competence-based Knowledge Space Theory (CbKST), which is a set-theoretic psychological-mathematical framework for structuring knowledge domains and representing competences of learners. It is used to personalise assessment and learning paths in adaptive learning systems. The second theory incorporated in our approach is the forgetting curve researched by Hermann Ebbinghaus. This curve describes how information in human is lost over time. The third pillar of our approach is a learning technique of using

flashcards developed by Sebastian Leitner (Leitner system). The key idea is that flashcards containing chunks of information are grouped and assigned with a level according to how well a learner knows the respective information. Different repetition intervals are defined for the different groups depending on the assigned level.

The remainder of this paper is structured as follows. The next section presents related work in the field of serious games and competence-based learning. Section 3 describes the concept of the novel competence-based approach in detail. Section 4 describes how this approach is implemented and applied. Finally, conclusions are drawn and further work is outlined.

## **2 RELATED WORK**

### **2.1 Competence-based Learning and Personalisation**

Adapting learning to suit the learner's characteristics, knowledge, and competence has a big influence on the learning performance [7]. The importance of the adaptation to the learner's characteristics (also called personalisation) has been shown in several studies (e.g.[12]).

Knowledge Space Theory (KST) and its competence-based extensions Competence-based Knowledge Space Theory (CbKST) are prominent examples of adaptation strategies grounded on a theoretical framework [5]. KST constitutes a psychological mathematical framework for both structuring knowledge domains and representing the knowledge of learners [2]. Due to dependencies between problems, prerequisite relations can be established. The knowledge state of a learner is identified with the subset of all problems this learner is capable of solving. By associating assessment problems with learning objects, a structure on learning objects can be established, which constitutes the basis for meaningful learning paths adapted to the learner's knowledge state.

Competence-based Knowledge Space Theory (CbKST) incorporates psychological assumptions on underlying skills and competences required for solving specific problems [4]. In this approach, competences are assigned to both learning objects (taught competences) and assessment items (tested competences). Similar to the knowledge state, a competence state can be defined consisting of a set of skills that the learner has available. Furthermore, there may also be relationships between competences modelled in a prerequisite relation structure. CbKST provides adaptive assessment algorithms for efficiently determining the learner's current knowledge and competence state, which builds the basis for personalization purposes. Based on this learner information, personalized learning paths can be created. Goal setting can be done by defining skills to be achieved (competence goal) or problems to be capable of solving. The competence gap to be closed during learning is represented by the skills that are part of the goal, but not part of the competence state of a learner.

### **2.2 Game-based Learning**

Digital games are an important topic in the research field of smart educational technologies. Game-based learning has become a major field of psycho-pedagogical research and very likely digital educational games will play an important and accepted role in the future educational landscape [1].

Adaptation and personalisation is also a relevant and successful aspect in digital educational games [9]. Especially in the genre of digital educational games, a psycho-pedagogically sound personalization is a key factor since the learning performance heavily depends on fragile and highly individual constructs like motivation, immersion, and flow experience. An example of a digital educational game that takes care of these individual constructs is found in the 80Days project [8]. The basis of the 80Days project is an intelligent technology that allows an adaptation to individual learners, their prior knowledge, abilities, and preferences. Thus it allows for a dynamic balance between challenge and ability. Such intelligent technology employs Competence-based Knowledge Space Theory for adaptive assessment and personalised learning paths.

## **3 NOVEL APPROACH**

In the last section key aspects have been described how personalisation can be achieved in digital educational games. Competence-based Knowledge Space Theory was employed in the past to adapt the game play to the player's knowledge. In this way an optimal sequence of game situations could be dynamically created, which balanced the player's current knowledge and challenges.

However, there are important aspects missing in this type of personalisation, which led to the development of a new approach for personalising the game play. These aspects that are described in this section in detail are:

- Forgetting should be taken into account.
- Learning should happen in repetition.
- Difficulty levels of game situations should be taken into account.
- Weights for competence assignments should be taken into account.

### 3.1 Domain Model

A core part of any personalisation technique is the domain model that covers the topics and material to learn. In our case the key elements are competences and game situations. Competences are those abilities that should be acquired by the players. Game situations are conditions of the digital games where players interact with games in order to acquire certain competences. The domain model defines which game situations a game can offer to players and which competences can be acquired with each game situation. In addition to past approaches, game situations and their relations to competences are enriched with additional information. First, a type is defined for each game situation. The type can be one of “learning”, “assessment”, and “learning and assessment”. Second, a difficulty level can be defined for each game situation. The level is one of “easy”, “medium”, and “hard”. Third, a weight can be defined for each assigned competence. The weight indicates to which extent the assigned competence is relevant in a game situation. Figure 1 gives an overview the described domain model structure.

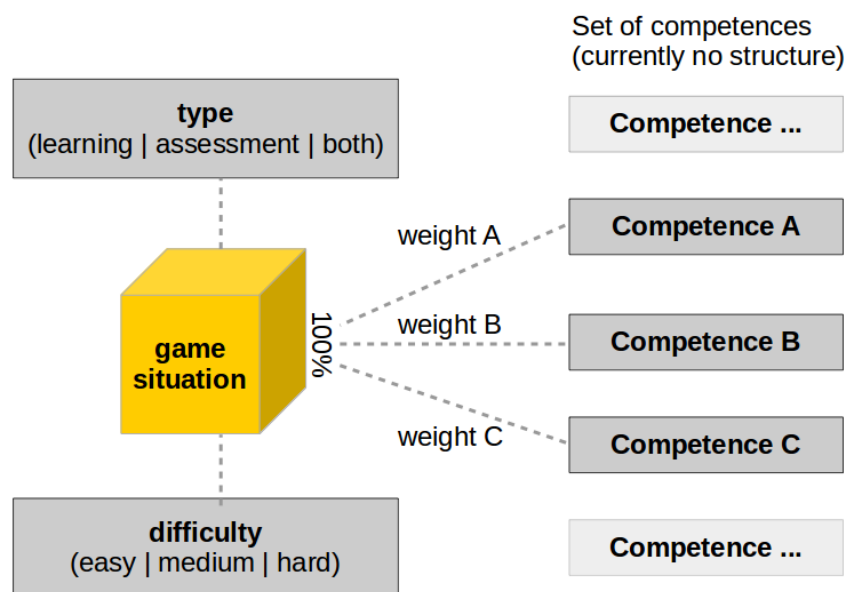


Figure 1. The diagram outlines the structure of the domain model for one game situation.

### 3.2 Forgetting Curve and Leitner System

While traditional personalisation approaches only focus on learning and acquiring competences in a most effective sequence, they more or less ignore that once learned competences can be forgotten after some time. Forgetting of learned knowledge is reflected in cognitive psychology by the German psychologist Hermann Ebbinghaus. Ebbinghaus proposed a forgetting curve that shows how newly learned information is forgotten after some time. While this curve is rather steep for information that has been learned the first time (much information is forgotten quickly), it becomes less steep with each new learning repetition.

In order to establish a scheme for systematic learning repetition, Sebastian Leitner developed the so-called Leitner System in the 1970s. The Leitner system provides an effective way of systematic repetition information chunks by using flashcards that are organised in different piles. All flashcards

start from the first pile. If the information of a flashcard is remembered correctly, then this flashcard is moved to the next pile, otherwise it is put back on the same pile. The flashcards of the first pile are repeated more often than the ones on a higher pile. This idea has often been used in the context of vocabulary learning. An example to employ the Leitner system for online vocabulary learning is described in [3]. The Leitner system is outlined in Figure 2.

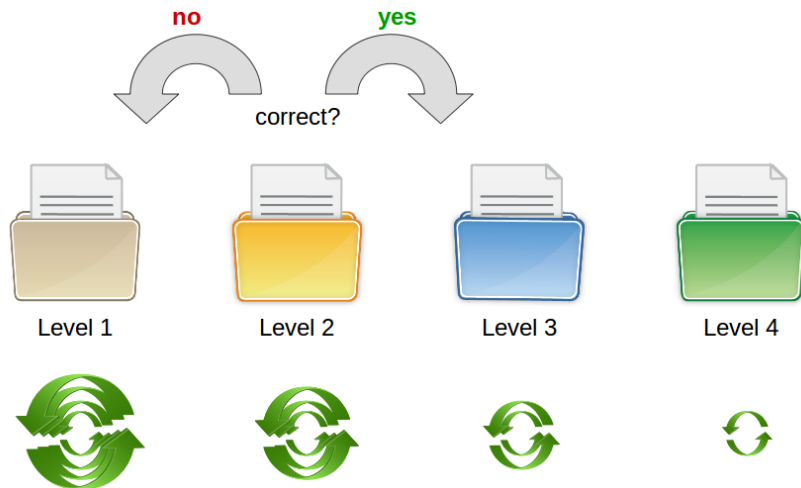


Figure 2. The diagram outlines the Leitner system with four different levels (piles).

### 3.3 User Model and Competence State

The user model (see Figure 3) in a personalisation strategy defines the current state of a player in terms of knowledge and competence (competence state). While in past CbKST applications the user model refers to the availability or probability values for the availability of competences, the user model in our approach refers to the level of the Leitner system. The base idea is that for each competence in the domain model levels are defined that refer to the piles of the Leitner system. This allows to deal with competences in a similar way as flashcards are used. Competences on a lower level are repeated more often than those on a higher level. If a competence is assessed positively, then it is moved up one level.

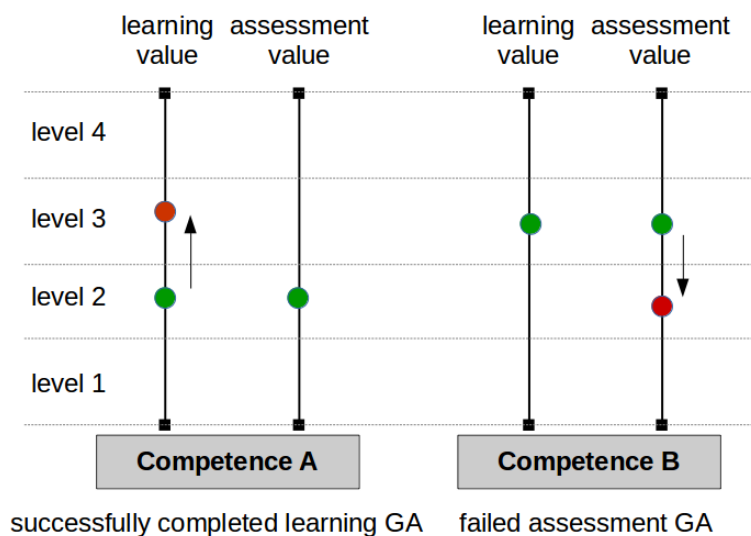


Figure 3. This diagram outlines the user model for two competences with learning and assessment values and changes after player interactions.

Since game situations can be designed for learning only, for assessment only, or for learning and assessment, the user model includes two values for each competence: a learning value and an assessment value. If a game situation just teaches a competence without assessment, then the learning value is increased. If a game situation assesses a competence, then the assessment value is increased (if the assessment was successful). In addition to change the competence levels based on player interactions, the levels are also automatically decreased after a defined amount of time. Such automatic decrease reflects the forgetting. Figure 3 depicts competence levels in relation to player interactions.

### 3.4 Updating Rule and Recommendation Strategy

The adaptation strategy is a core element of adaptive systems. This strategy is realised through updating rules and recommendation. An updating rule refers to the change of the competence levels each time a player learns a competence or undergoes an assessment (as described in Section 3.3). If a game situation teaches competences, then the learning value is updated (increased). If a game situation assesses competences, then the assessment value is updated (increased or decreased). The calculation of the updating rule also includes the weight of the relation and the difficulty level of the game situation (see Section 3.1). Obviously the updating rule does not set discrete levels for each competence, but sets float numbers between zero and one. Leitner system levels are ranges in an interval between zero and one. Depending on the concrete value, learning and assessment values can be related to the Leitner system level.

The recommendation strategy is a three-step process. First, a decision has to be made, if an assessment is needed. This is done by checking all learning and assessment values. If there is a competence with an assessment value lower than its learning value, then this competence should be assessed. Second, if no assessment is needed, then competences are selected that should be learned next. This is done based on their Leitner system levels and inactive times. In principle, competences should rather be selected if their level is low and if their last learning time is far away. In the third step a game situation is chosen for the selected competence based on the relations defined in the domain model.

### 3.5 Visual Feedback

The domain model, the user model, the updating rule, and the recommendation strategies are kept inside the software component and hidden from the player. The game can make use of this information and functionality to adapt the game play for the sake of educational purposes. It is well known that feedback and insight in the educational technology supports and stimulates the learning process and motivation. Therefore, the component opens up the information on the learning and assessment levels for each competence. A schematic visualisation is depicted in Figure 4. However, it would be the task of a game how to visualise this information for the player.

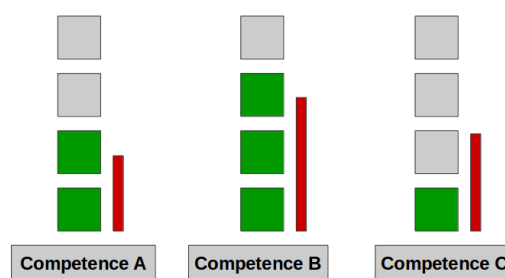


Figure 4. This diagram provides a schematic outline how the current competences state can be visualised by a game.

## 4 APPLICATION

The last section explained the basic concept of the novel approach of the competence component. This component is not an application of its own but a component that can be integrated by a game. It

is implemented according to the guidelines of the RAGE component framework [13][14]. This allows a standardised way of communication and data storage. The component has been developed in C# in a Unity environment in the same way as the predecessor component [10].

Including the component in a game is rather simple and relies on an API with a few methods for the core functionality. The most important methods or methods group are:

- setting the domain model: A set of methods are available to set the domain model as a whole or to add and relate game situations and competences individually
- initialise the component. This method is used to initialise the component in the context of the RAGE component architecture and to provide initial configuration and parameters.
- update game situation: This method is used to send information if a game situation has been completed including the result if the completion was successful or not. This is the core method to tell the component about the player's achievement in the game.
- get game situation recommendation: This method returns a set of recommended game situations according to the current competence state (learning and assessment values of the competences). This is the core method to adapt the game play to the player's current competence state and game history.
- reset competence state: This method clears all values and resets the internal state. It can be used to reset the game play.
- get competence values: This method returns all learning and assessment values of the competences. It can be used for providing a visual overview of the current competence state.

The design and development of this novel approach has been stimulated and guided by the French games company Kiupe (<http://kiupe.com/en/>). Kiupe formulated requirements for a real life project designed for pupils. The requirements included the need for personalisation of the learning content delivery. Since every child is different in terms of pre-knowledge, learning speed, and interest, an individual adaptation to children is needed, in order to ensure learning success.

Kiupe has structured their games and mini-games in relation to the game situations they offer to the player. These game situations and related competences to be learned are defined in the domain model. This approach provides the flexibility to add or remove game situations in terms of the educational perspectives, but also according to a story telling point of view. So depending of what has been played before, game situations can be added or removed to ensure that the game story stays logical.

## **5 CONCLUSION AND OUTLOOK**

This paper presents a novel approach for a game component that allows to personalise the game play based on traditional competence approaches, but also includes new concepts such as the Leitner system and the Ebbinghaus forgetting curve. This game component has been motivated and included in a prototypical application of the games company Kiupe.

Future work will focus on simulating, testing, and evaluating the developed game component. In order to validate the methodological soundness and the educational benefit for players, a simulation and evaluation will be conducted in the future. The simulation will automatically and systematically test a series of different domain models regarding the output of meaningful recommendations of game situations. The educational benefit will be evaluated with real life examples and real players in natural settings. Therefore, concrete tasks and learning goals will be defined and based on an evaluation plan the educational value will be assessed.

## **ACKNOWLEDGEMENTS**

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