The journey : a service-based adaptive serious game on probability

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Abstract. Serious Games (SGs) have a lot of potential in education, possibly making learning more engaging and satisfying. Adaptive Games strive to keep the challenges presented by the game balanced with the player's abilities, as to keep the player in the "flow" state. We have used a Service-Oriented Architecture (SOA) approach to develop a simple adaptive SG for teaching basic elements of probability to high school and entry-level university students, called *The Journey*. The game performs continuously the updating of a user model with the competencies of the student and presents the new challenges according to the student's current level. This paper presents details of the educational aspects of the game, as well as of its implementation. It also presents a preliminary validation study and discusses future work.

1 Introduction

Games are being more and more recognized by their importance in education and training settings. Serious Games (SGs) have been shown to have a lot of potential in education [1], making learning more engaging and satisfying than in traditional educational settings [2,3]. More attention is being given to meaningful insertion of games in curricula [4], to supporting authors and educators in the development of SGs [5,6] also in specific situations such as users with motor and cognitive disabilities [7,8], and to appropriately connecting pedagogical practices to the game mechanics [9] in order to create more effective games.

Motivation plays a crucial role in learning, and thus it is important that the learning environment provide the player with an appropriate level of challenge, always balancing on the limits of the learner's competences and skills [3]. Adaptive serious games draw on the research on Intelligent Tutoring Systems and Adaptive Hypermedia to create a personalized learning experience, which has been shown to be beneficial in terms of motivation and learning outcomes [10].

In this paper, we present *The Journey*, an adaptive serious game for teaching basic elements of probability to high school and entry-level university students, and also report the results of a preliminary evaluation of the game. *The Journey* has been developed following a Service Oriented Architecture (SOA) approach, in which software is built as a set of independent components that are loosely coupled to deliver certain functionalities.

This paper is organized as follows. In Section 2, we discuss the basic concepts of adaptive SGs. In Section 3, we present the benefits of the SOA approach in SG development and list a few examples. In Section 4, we explain the Competence-based Knowledge Space Theory (CbKST) and how it can be used in adaptive SGs. In Section 5 we describe the game in detail. Section 6 describes the evaluation of the game. Finally, we present a conclusion and discuss future work on the topic.

2 Adaptive Serious Games

Research in Adaptive Serious Games has roots in the fields of Intelligent Tutoring Systems (ITS) and Adaptive Hypermedia, both with an established tradition in using technology to provide personalized experiences [10]. Inspired by Bloom's findings in the superior performance of tailored tutoring when compared to regular teaching [11], psychologists, educationists, and technicians started to develop technology to take the role of a private teacher and to intelligently provide learners with suitable tutoring. [12]

The concept of "flow" is central to educational game development: the game should provide an adequate level of challenge to the player, neither too hard, causing frustration, nor too easy, causing boredom [3]. A meta-review of more than 300 scientific articles on the educational efficacy of computer games found out that 90% of the games that reported non-trivial educational results bear some form of educational adaptation or personalization [13]. These results are in line with experimental findings that demonstrated that adaptation results in superior gaming experience and educational gains [14].

The adaptation to be realized in-game can be different from that of traditional virtual environments. Steiner et al. [15] argue that, in this case, subtle ways of adaptation are needed, basing assessment on continuous input and output of information about the learner. Shute and Ke [16] discuss the concept of "stealth assessment", in which learning assessment happens without disrupting the game flow, using observable evidences to infer knowledge, skills or other attributes.

3 Service Oriented Architecture for SG development

A Service-Oriented Architecture (SOA) is a set of recommendations, policies and practices for software architectural design which implements business processes by using loosely coupled components which are arranged to deliver a certain level

of service or set of functionalities [17]. The goal is to manage the complexity of large systems by employing modularization and compositionality [18].

The benefits of using a SOA approach are many, from the reuse of services without the need for code replication to the establishment of formal obligations between service consumer and provider [18]. There are challenges in adopting a SOA approach as well, mostly related to increased complexities in testing and quality assurance processes [17], and the crucial role played by appropriate documentation and definition and description of service interfaces, which, when missing or lacking in quality, can cause difficulties in the development [19].

In game development, a SOA approach can enable easier scalability and usage-dependent payment model. It also releases the games from the dependency on gaming hardware. Providing pervasive gaming experiences becomes easier, as support for different platforms is highly simplified if the core of the gaming experience is service-based. [20]

Despite the benefits, current examples of SGs and related technologies that employ SOA are very few. The *Rashi Intelligent Tutoring System*, which teaches human anatomy through a problem-based environment, is built as a web service architecture [21]. The envisioned *Mobile Augmented Reality (MARL)* gaming platform would use a service-based architecture to provide on-demand location-based instruction through a head-mount display [22]. The Serious Games Society has developed the *Serious Games Web Services Catalog* (`http://services.seriousgamessociety.org`), a repository of web services with documentation and example applications.

4 CbKST services

The CbKST services' approach to formative, competence-centered assessment is inherited from the Knowledge Space Theory (KST) and the Competence-based Knowledge Space Theory (CbKST) [23]. It assumes a finite set of atomic competencies (aptitude, ability, knowledge, or skill) and a prerequisite relation between them, which defines the competence model of the domain. Due to the prerequisite relations, not all subsets of competencies are possible competence states. A person's level of knowledge, ability or proficiency is described, theoretically, by exactly one competence state.

The structural model focuses on unobservable competencies, making hypotheses about the brain's black box. By utilizing interpretation (p, in Figure 1) and representation functions (q), the unobservable competencies are mapped to observable evidences relevant for a given domain. No one-to-one correspondence is required to link competencies to the indicators. CbKST considers indicators on a probability-based level, in order to account for the fact that indicators cannot be perfect evidence for the latent knowledge or ability.

The CbKST services are part of the ProNIFA tools of the ECAAD methodology, in the scope of the NEXT-TELL (`http://www.next-tell.eu`) and ROLE (`http://www.role-project.eu`) projects. The Compod services, which were

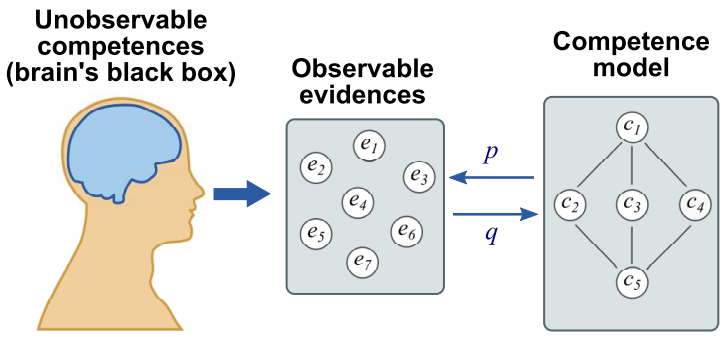

Fig. 1. Interpretation and representation functions in the CbKST model.

used for this study, are research prototypes and are available online in the NEXT-TELL project website.

5 *The Journey*

5.1 The game

The Journey is a simple serious game to teach and train basic concepts of probability theory to high school and entry-level university students. It was developed at the University of Genoa as a prototype implementation of a service-based adaptive SG, employing the CbKST services to provide basic adaptation features. Being a prototype, the game can be further developed in the future.

In the game, the player represents the head of a group of hikers who wants to reach the top of a mountain chain. Players have to understand how to calculate the probabilities of events that are related to the journey, and also use their knowledge to make the best possible decisions along the way.

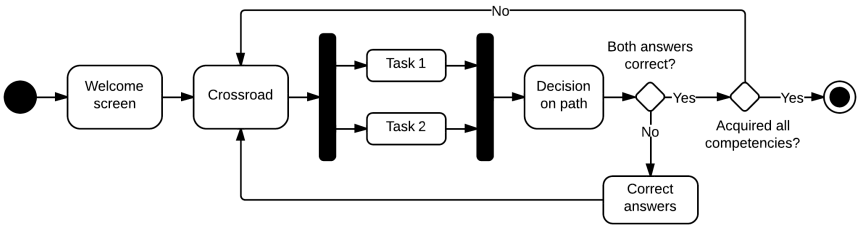

Fig. 2. Game sequence

The game sequence, represented in Figure 2, is as follows. After the introduction, the player reaches a crossroad (Figure 3). Two paths are presented, each with different probabilities of success and different lengths. After calculating the probabilities for each path, the player must choose a way. If she calculated the probabilities correctly, the system decides on the success of the choice, following the probability distribution of that path. If successful, the group moves forward to the next crossroad; if not, they have to go back and try the other path. If the player calculates one or both probabilities incorrectly, the game shows the correct answers and takes her back to the crossroad, where a new set of tasks is presented. The process repeats until the end of the game.

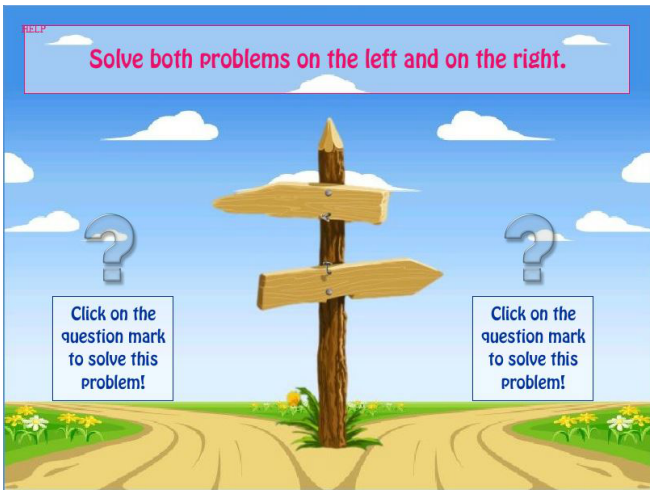

Fig. 3. The crossroads screen of *The Journey*.

We now describe the game using the elements presented by Game Ontology Project [24]. *The Journey* has a **User Interface** based on **Indirect Manipulation**, as decisions are made via a **Menu Interface**. The **Input Device** is the mouse. It shows a **Challenge Segmentation** of gameplay, implemented as **Puzzles**. **Randomness** is also used.

There are two **Goals** in the game: (1) reaching the end of the journey as fast as possible (explicit goal) and (2) acquiring all the competencies (not communicated to the player). Similarly, there are two **Goal Metrics**: **Time** and **Score**. The "faster" the player is (in the game's internal time), the higher the score. The score also depends on the performance of the player in the tasks.

5.2 Learning, assessment and feedback

The competence model of the game is composed of the following competencies and their dependencies:

1. **Probability space** The learner understands the relationship of a collection of events and their probability measure within a sample space. The learner is able to estimate the probability of an event from data of observed outcomes. The learner is able to derive that $P(\neg A) = 1 - P(A)$. No dependencies.
2. **Probability of mutually exclusive events** The learner understands the relationship between two mutually exclusive events in the same probability space, which can be represented by the formulas $P(A \cap B) = 0$ and $P(A \cup B) = P(A) + P(B)$. Depends on competency 1.
3. **Probability of non mutually exclusive events** The learner understands that when there are two non-mutually exclusive events in the same probability space ($P(A \cap B) \neq 0$), they can be represented by the formula $P(A \cup B) = P(A) + P(B) - P(A \cap B)$. Depends on competency 1.
4. **Probability of independent events** The learner understands that the probability of two consecutive and independent events is calculated using the formula $P(A \cap B) = P(A) \times P(B)$. Depends on competency 1.
5. **Probability of dependent events** The learner understands that the probability of two consecutive events is calculated differently when the one of the events is dependent on the other. In that case, $P(A \cap B) = P(A) \times P(B|A)$, and consequently, $P(B|A) = P(A \cap B)/P(A)$. Depends on competencies 2, 3 and 4.

In the game database, there is a set of tasks for each competence in the model. See below one example question, which refers to the competence Probability space. The values inside the curly brackets are generated by the game.

> Up to now, {n} people tried to take this path, but only {x} of them managed to get through. Based on this sample, what is the estimated probability of arriving at your destination through this path?

The concrete implementation of the learning process in "The Journey" is, therefore, via the mechanism of Questions & Answers. The game provides guidance via hints, shown after 3 minutes of inactivity while working on the tasks.

There are two levels of reasoning that are expected from the player: (1) solving the problems correctly; and (2) deciding which direction to take, considering time and probability of success. Table 1 details how the game supports each of the levels of Bloom's revised taxonomy of learning goals in the cognitive domain [25].

The assessment is based on the answers that the player gives to the challenges, which are sent to the CbKST service. The service updates its model of the player's competencies, selects the next tasks that are appropriate to the user's level, and replies to the game suggesting the IDs of the next challenges to be presented to the player. The tasks are chosen from the pool of tasks for that competency. Once all the competencies in the model have been acquired, the service informs the game that there are no more tasks, and the group reaches their destination, ending the game.

Feedback is offered to the player only with regard to the answers to the tasks. If the player answers the tasks incorrectly, the game will inform so and offer

Learning Goal	How the game supports the level
Remembering	Memorizing is not required, as the game shows relevant formulas when needed. Nevertheless, repetition helps remembering.
Understanding	The player needs to understand how the concepts and formulas are relevant to solve the task.
Applying	The player needs to interpret the values of probability distributions and apply that knowledge when making decisions.
Analysing	The player must be able to analyze the information available in the task to be able to apply the correct formulas.
Evaluating	Weakly supported, when the player is asked to choose between paths. To support it more explicitly, in class it could be asked of a student to explicitly justify her choices.
Creating	Not supported.

Table 1. Levels of Bloom's cognitive learning goals covered by "The Journey"

the correct answers, with the explanation of how to calculate the probabilities correctly. The representation of the competence model itself is not made visible to the player inside the game.

5.3 Implementation architecture

The Journey has been developed following a Service Oriented Architecture (SOA) approach. It is a Flash Desktop Application using Starling, an ActionScript 3 2D framework, for the graphical interface. It is connected to a local SQLite database, which holds the list of tasks for the game and the profile information of each player, and it access the CbKST adaptation service via a REST interface (Figure 4).

The CbKST service has to be configured in advance with a representation of the competence model. The service does not hold any information about the game tasks, except for the relationship between the tasks IDs and the competences in the model. In addition, the service does not hold information about the players other than their ID, which is passed to the service in the beginning of a learning session. While the learning session is open, the service holds an instance of the competence state of each player currently using the game, which can be deleted once the learning session is closed. A report on the learning session can be generate when requested.

The source code of the game is available online at `http://www.bitbucket.org/elioslab/thejourney`.

6 Validation

We performed a preliminary validation of the game in a study with 10 participants (6 males, 4 females) aged between 19 and 21 years old. Participants were asked to play *The Journey* for a maximum of 20 minutes and to complete identical pre and post-tests, with ten multiple choice questions covering all

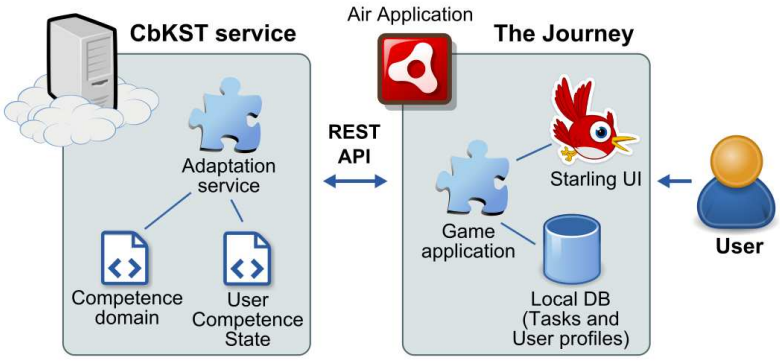

Fig. 4. The architecture of the game.

five competencies targeted by the game. In addition, the players were observed during the tests to identify possible usability issues with the game interface.

All participants showed an increase of at least one point in the post-test scores, with an average improvement in the final scores of 1.8 points. Although this study was too small to be considered statistically significant, we were encouraged by the positive preliminary results. The usability issues that were identified will be improved for the release of a new version, when a larger user experiment will be carried out to evaluate learning effects.

7 Conclusion and future work

In this paper we described the concepts, structure and software implementation of *The Journey*, a serious game to teach probability to high school and entry-level university students, which employs the SOA approach and utilizes a service based on the Competence-based Knowledge Space Theory (CbKST) to realize in-game adaptation. We also reported the results of a preliminary evaluation, which will be used in the development of future versions of the game.

We defend the application of a SOA approach as beneficial for the field of serious games development. SOA can improve the development process through components reuse and enhance product quality by enabling the implementation of features, such as adaptivity, that are still rare in SGs. It also gives the SG developer a significant amount of freedom in the development, while still taking advantage of reusing high quality existing services.

The Journey is a prototype that was used to investigate the benefits and drawbacks of a service-oriented architecture for SG development. Its current implementation can be extended with different functionalities, such as the use of stealth assessment [16] and formative evaluation and feedback [26]. It would be possible, for example, to expose the competence model to teachers and to players via an assessment interface. Another interesting possibility is the creation of a

richer learning environment that allows more than one learning technology or game to have access to the same competence model.

We hope that the SOA approach becomes more widespread in the field of SGs and that more developers embrace the possibilities brought by services that are already available.

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