A Methodology for Developing Adaptive Educational-Game Environments

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Abstract. In this paper we present a methodology for describing adaptive educational-game environments and a model that supports the environment design process. These environments combine the advantages of educational games with those derived from the adaptation. The proposed methodology allows the specification of educational methods that can be used for the game environment generation. The educational goals, the activities that the users can perform, their organization and sequencing, along with the games to be played and the game stories are selected or dynamically generated taking into account the user's features and behaviors.

1 Motivation

Educational computer-based games are those games that promote the growth of people's reasoning and the acquisition of skills and knowledge in a pleasant way [1].

Their background is related to pieces of knowledge that the users have to put in practice in order to reach the goals proposed in the games. From the first studies about the use of games in education [2] until now, they have proved that can constitute a very good resource of motivation [3] for the users to test the knowledge they own, improve it by practicing, and learn what they do not know while enjoying. Particularly, the use of multimedia resources, stories that present real or figured goals attractively, and agents that accompany the user during the game execution (motivating them to go on playing, providing feedback and so on) increases the learning achievements [4].

From a high-level point of view, there exist basically two different kinds of educational game environments: those composed by a fixed sequence of sceneries which the user has to interact with [5], and those who allow the user to select the game (s)he wants to play among a set of games [6]. In both cases, the whole game environment is developed ad-hoc. Adaptation exists in the sense that each concrete game's behavior depends on user actions, but the decisions about the next scenery or the available

games at every moment are fixed during the game development phase, being the same for every user at runtime.

There exist some factors that affect the effectiveness of educational games. These are related to personal user's features, preferences and behaviors [7]. As it is well known, not all the users have the same preferences or styles while interacting with games and solving problems. From the game developer's point of view, there are several educational methods and strategies that can be applied during game-environment creation [8]. They are related to the kind of tasks proposed to the users, the sequencing among them and so on. Each developer may want to apply different methods depending on the features of the users the game is intended for. Moreover, (s)he can consider as necessary the use of different kind of multimedia games and storylines for each type of user.

In order to broaden the number of potential users and to improve the effectiveness of the games for each of them, we propose the development of *adaptive* educational game environments. In these environments the cognition activities that users have to perform, the difficulty of the problems behind the game, the sceneries presented and the organization of these elements, among others, can be dynamically selected or generated for each particular user depending on his/her personal features and behaviors. In such a way the advantages of using computer-based games in education [9] along with those that come from the adaptation [10][11] can be exploited together.

In the section 2 of this paper we present a methodology that has been created for supporting the design of adaptive educational game environments along with the specification of the educational methods to be used in them. In section 3 we propose a model that supports this methodology, and section 4 shows the adaptation process carried out during the dynamic game environment generation. Finally, section 5 contains the conclusions and future work.

2 The Proposed Methodology for the Environment Design Process

In order to assist the process of creating educational adaptive games we have developed a methodology that establishes a set of steps for the game environment design process. In the following subsections this methodology is presented, as well as an example about its application for developing an adaptive game environment.

2.1 Steps to Follow

The methodology establishes the following steps:

1. Identifying the *types of users* who the environment is directed to, by fixing the personal features that will be taken into account during the adaptation process and their possible values.
2. Specifying the game *goals* from an educational point of view, namely, the user's knowledge or skills needed to play the games or those that can be acquired/improved while playing them.

3. Creating or providing the *computer-based games*, indicating, for each of them, the learning goals involved and the type of users the game is intended for, in case they are specifically oriented to certain kinds of users. Games can be taken from existing game repositories, or generated and stored in one of them.
4. Establishing the educational method for each type of user, by:
   4.1. Determining the *activities* that will be proposed to the users. These activities can be of two different kinds: educational activities or relaxing activities. The former are those proposed with the purpose of motivating the acquisition of certain knowledge, that one described by the educational goals; the latter can be non-related to education, they all have the same goal ('relaxing') and can be included so that the users can relax after performing difficult tasks. For every activity the developer must specify its type, goals and the number of games that will be presented to the users to play with while performing the activity. Optionally, the name of the concrete game(s) can be specified. Otherwise, games will be selected from the ones in the game repository, selecting the games whose goals match with those indicated in the activity.
   4.2. Describing how the environment *structure* will be generated for each user at runtime. This requires the specification of i) the organization of activities for each type of user in *activity groups*, where several activities can be gathered ii) the sequencing mode for these activities execution and iii) the prerequisites that can be established among them.
5. Describing stories, where the game goals, activity feedbacks, agents and other multimedia elements can be included. These components are associated to the game structure components (activities and activity groups) and constitute altogether a story that can be independent from the concrete games presented to the users. In this case, the users can consider games as ways of achieving the story goals. Different stories can be created for distinct types of users, being included in a game environment by:
   5.1. Creating or providing *starting sceneries* that are presented to the users before they carry out an activity or access a group of activities. They present challenges and goals in an attractive way so as to catch the user's attention and make them get involved in the environment. The goals presented can be either related to the activity goals or fictitious, being part of a fantastic story.
   5.2. Developing or supplying *menu sceneries* that will be used for game menu generation. They can contain objects or agents that stimulates the users to select one activity among any set of available ones. Menu sceneries can be used for story construction by presenting fictitious goals that will be achieved if the user perform the activities, for example, or by motivating the users to go on playing for reaching the goal (whichever the goal is).
   5.3. Creating or supplying *feedback sceneries* for providing the users with comments about the activity execution, giving them a positive reinforce both when the results are good, to reward them, and also when they are bad, to motivate them to learn and go on playing. This comments should be inserted into the story explaining in an attractive way why the story goals have (not yet) been achieved.

5.4. *Classifying the games* according to their subject (i.e., animals, sports, etc.) so that games related to the same subject can be selected during the environment generation.

2.2 Ecotoons2: An Adaptive Educational Game Environment

The educational environment Ecotoons2 has been created starting from Ecotoons, an educational game (developed inside the frame of the Geometrix project) whose main goal is to promote the children mathematical reasoning development in an attractive and pleasant way. The game was conceived for children from 5 to 9 years old. Several experiences with Ecotoons, involving about 120 children from three different schools located in Aveiro, have proved that it is a well-designed game with respect to the interface usability [12], the motivational elements, and so on. In Ecotoons the stages are presented sequentially to all the users in the same way.

Ecotoons2 is an adaptive educational game environment that incorporates some of the games and resources of Ecotoons. This environment is intended for users from 5 to 18. By now, there have been established three different ranges: children from 5 to 9, those from 9 to 11, and users from 11 to 14.

Its main goal is to help and motivate users to construct knowledge about mathematical concepts and improve their mathematical reasoning. The educational goals involved in the game are related to mathematical concepts and operations such as counting, adding, subtracting, manipulating fractions, and so on. Ninety independent computer-based games that support the performance of these activities are being developed. Some of them are distinct games with the same goal, specifically developed for certain kind of users (i.e., younger users can add by counting and provide the solution by selecting among several numbers, while older ones should be able to solve problems by adding numbers and writing the result). All the games developed until now for the youngest are related to environment conservation while those provided for teenagers are related to sports and animals, among others. Each game has its own feedback messages that are shown to the users while they are playing it.

With respect to the educational method, in many cases educators have decided that mixing activities with different goals or letting the users to choose the order of activities is better than establishing a fixed sequence. Otherwise, users could get tired or bored while performing the same task for a long time, or feeling certain lack of freedom while interacting with the game. In other cases, the establishment of a fixed sequence of activities has been considered convenient.

There have been specified thirty activities, which have been organized in groups of five, resulting in six activity groups. These are grouped into three activity groups that compose the main one. The corresponding relations among them have been established in order to describe the game structure.

Stories are included by means of different starting and feedback sceneries that have been attached to each activity group. We have used the story of Ecotoons for sceneries generation. In the main activity group the starting scenery contains an agent that states the main goal of the whole game: "Saving the planet Platoon by avoiding that the Poluxes destroy it. If your help is positive, Poluxes will be transformed into Platoons.

Otherwise, the planet will be lost forever". In every starting scenery, an agent presents the fictitious goal (what Poluxe can be converted, in the case of the three activity groups, or the planet area to be protected, for the six activity groups) and the way of achieving it. Feedback sceneries contain animations showing the Poluxe transformation or the area saved, along with the Platoon explanation of what is happening, depending on the score obtained while performing each activity. The menu sceneries are related to Platoon landscapes and agents.

3 The Adaptive Game Environment Specification Model

In order to support the previously described methodology we have developed a model for describing adaptive educational environments. These environments are generated on the fly. The main components of the model are related to the types of users, educational goals, computer-based games, educational methods and stories.

- The *types of users* the game is intended for are described by a series of *attributes.* The possible *values* for each attribute can be described by specifying the ranges of values or the set of possible discrete values (see Table 1).

Table 1. Establishing some user features and their possible values

Attribute	Values
Age	[5, 9) [9, 11) [11, 14]
Language	Portuguese/Spanish/English
Preferred-media	Sounds/Texts/Images/Animations

- An *educational goal* is specified by its *description* (a word or a sequence of words). Example: 'adding numbers'.
- A *computer-based game* is included by specifying its *identifier*, *description, goals*, *location*, *icon* (for menu generation), *difficulty* ('H' for high, 'M' for medium, 'L' for low and 'P' to indicate that the game can be generated from a template with parameters whose values can be set), *features* (list of descriptive game attributes such as the age of the users it is intended for, the predominant media, the language used in texts, sounds, etc.), and, optionally, *subject* (i.e., 'sports', 'animals', 'races', and so on). An example of a template-based game that is oriented to portuguese children from 5 to 9 can be seen in Table 2. When generating the game, the number of fishes that appear in each fishing rod is randomly selected from the range of possible values.

Table 2. Game example: adding fishes

Attribute	Value
Identifier	Adding-fishes
Description	The user has to count the number of fishes that appear in three fishing rods, write the three numbers, and write the total number of fishes

Goals	Add
Location	/games
Icon	Fishing.gif
Difficulty	P
Features	[5-9), Portuguese
Subject	Ecology

In order to describe the educational method of an adaptive game environment the following components are used:

- *Activity*: it is the basic unit of the game structure and represents a task to be performed. It is described by its *name*, *type* ('educational'/ 'relaxing'), *goals,* and, optionally, identifiers of *starting sceneries*, *menu sceneries,* and/or *feedback sceneries* (the way of describing sceneries is explained below). The *number of games* that should be played while performing the activity can also be specified (otherwise one game will be played). Table 3 shows an example of an activity with no sceneries associated. For the activity performance, one game whose goal is 'add' will be selected for each particular player.

Table 3. Activity example: adding numbers

Attribute	Value
Name	Adding-numbers
Type	Educational
Goals	Add

- *Activity Group (AG)*: it groups several activities or activity groups. It is described by its *name*. It may have associated *starting sceneries*, *menu sceneries,* and/or *feedback sceneries* that will be used for the story generation. This sceneries can be different depending on the type of user, so it is possible to associate several sceneries including the *condition* for each of them to be selected (which is related to the user's features). One of the AGs constitutes the *main* AG of the game environment. An example of an AG with associated sceneries (the same for every kind of user) is shown in Table 4.

Table 4. Activity Group example

Attribute	Value
Name	Oceanus-Place
Starting scenery	Saving-Oceanus
Menu scenery	Ocean
Feedback-OK scenery	Feed-OK-Oceanus
Feedback-Wrong scenery	Feed-Wr-Oceanus

- *Decomposition Rule (DR)*: it describes which activities or activity groups are part of a given activity group, and the order they should be performed at runtime, if any. It is possible to define several DRs for the same AG, showing different ways

of decomposing it and/or different orders in which activities must be carried out. In this case, the DRs must include activation conditions that have to be satisfied for the DR activation. These conditions can be related to the user's features and/or behaviors while interacting with the environment. In such a way it is possible to specify different educational methods by providing each user with different activities for the same AG. It is also possible to combine the same activities in different ways for every type of user. Moreover, the use of conditions allows the decomposition of the same AG in different ways depending on the results obtained by the user while performing other activities. In order to describe a DR it is necessary to indicate the *AG identifier*, the *AGs and/or activities identifiers*, the *sequencing* mode among them (according to the sequencing modes proposed in [13], 'AND' means that the activities must be performed in the order they appear in the DR and 'ANY' means that they can be performed in any order) and, optionally, the *activation conditions,* related to user's features and/or behaviors (other activities execution). Optionally, it is possible to associate a weight to each subactivity, indicating the contribution of the score obtained by the user while performing the subactivity to the calculation of the score obtained in the activity group (by default the score will be calculated as the media of subactivity scores). Table 5 shows an example of two strategies for the same AG: while the order of activities for the youngest children will be fixed, children from 9 to 11 will be able to select, a priori, the activity they want to perform at every moment among those that appear in the DR. In addition, older children will have available the 'Subtracting-numbers' activity, which will not appear in the environment generated for younger ones.

Table 5. Decomposition Rule examples

Attribut	Value
Activity group	Oceanus-Place
Subactivities	Identifying-objects, Adding-numbers, Associating-objects, Ordering-numbers
Sequencing	AND
Activation condition	[5, 9)

Attribute	Value
Activity group	Oceanus-Place
Subactivities	Identifying-objects, Adding-numbers, Associating-objects, Ordering-numbers, Subtracting-numbers
Sequencing	ANY
Activation condition	[9, 11)

- *Prerequisite rule (PR)*: it describes the dependence relation that can exist among activities. By means of a PR it is possible to state that some activities should not be performed before doing other ones previously. A PR is composed by the *activity* whose availability depends on the performance of other activities, the *prerequisite activities*, those that have to be performed before that one, and the *activa-*

tion condition, that indicates for which type of users the rule will be active, that is, in which cases the dependence relation will be taken into account. Optionally, it is possible to associate a weight to each prerequisite activity, indicating the minimum score that must be obtained during the activity execution for considering the prerequisite condition satisfied (by default it will be 5 in a scale from 0 to 10). Table 6 shows an example of a PR defined for children from 9 to 11 that establishes that they will not be able to perform the 'Subtracting-numbers' activity unless they have performed the 'Adding-numbers' one.

Table 6. Prerequisite Rule example

Attribute	Value
Activity	Subtracting-numbers
Prerequisites	Adding-numbers
Activation condition	[9, 11)

As for the story generation, sceneries are included in the model. These sceneries can be used for presenting the story, stating the fictitious or real goals at every moment, generating menus, providing feedback, etc.

- A *scenery* is described by its *name*, *type* ('starting'/'menu'/'feedbackOK'/ 'feedbackWrong'), *description*, *location* and the kind of users it is created for, that is directly related to the scenery *features*. If it is intended for every kind of users this attribute will be empty.

4 The Adaptive Environment Generation

Once the description of an adaptive educational game environment has been provided, it is possible to generate the components that will be presented to each particular user while interacting with it. The adaptation mechanism operates in two stages: at the beginning of the environment generation and at runtime.

4.1 First stage: structure generation and story attachment

The environment structure is generated starting from the main activity group, considering the decomposition rules and user features in order to determine the activity groups or activities in which the main one is decomposed for this particular user. This process is repeated recursively until the game structure is generated. For every node of the structure (activities and groups of activities) it is checked whether it has any scenery associated. If it is the case, the scenery is attached to the activity. In case there are several sceneries available for the same node, the most suitable one for the user is selected.

In this stage the basic environment structure along with the story in front of it have been generated. This does not mean that all the activities are available. The activity availability will be decided for every user at runtime.

4.2 Second stage: selection of available activities and games

While a user is interacting with the environment, the available activities at every moment are selected on the fly. This selection is done by taking into account the user's features and behaviors, along with the decomposition and prerequisite rules. For each set of available activities, a menu is generated so that the user can select the activity to be carried out. For each activity execution, the most suitable game supporting it is selected, considering the available games whose goals match the activity goals, their features and the user's characteristics. Once the user has selected an activity or the system has decided which one will be the next, the computer-based game will be presented/generated: if the game can be constructed starting from a template, it is dynamically generated; otherwise, the game is directly presented to the user.

The availability of activities and the difficulty of the games presented will depend on the user's actions and behaviors while interacting with the game environment.

5 Conclusions and Future Work

In this paper we have presented a methodology that establishes the suggested steps for describing adaptive educational game environments. These environments combine the advantages of educational games [9] with those derived from adaptation [10][11]. We have also presented a model that supports the adaptive environment design.

The environments described following this approach are dynamically generated taking into account the particular user's features and behaviors for the personalization of: i) the activities that are part of the environment, ii) their organization in the environment structure, ii) the order in which activities should be performed, if any, or the free activity selection, iii) the computer-based games that will be presented for activity performance, including their subject and difficulty, and iv) the displayed storyline.

The use of activities, activity groups and rules for the environment description allows the specification of educational methods. In such kind of environments, the users can acquire skills and improve their own knowledge in a personalized way. The educators can include the most appropriate educational methods, activities and games for each kind of user.

The separation among the activities to be performed and the games that support them makes it possible to select the most suitable games for every user while performing the activity. We have created a game repository with games labeled with their educational goals and difficulty. This makes possible the game reuse in different educational environments. Furthermore, existing games stored in game repositories can also be tagged and used in the environments generated.

By providing different sceneries for distinct types of users, it is possible to create several stories for the same activities, widening the possibility of attracting users' interest in playing the game. Sceneries can compose a fantastic story that can be used in different environments independently of the activities and the games behind them.

Currently we are experimenting with the use of the proposed methodology and model for different game environment generation. We are also considering the adapta-

tion of the kind of game selected at every moment (educational vs. relaxing games), provided that some user features such as the age, the difficulty of the last activity performed and/or the score obtained by the user while performing it may affect the type of activity that should be proposed next. In the future we plan to create a model for the internal game components and behavior representation.

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