A Model-driven Framework for Educational Game Design

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Abstract. Educational games are a class of serious games whose main purpose is to teach some subject to their players. Despite the many existing design frameworks, these games are too often created in an ad-hoc manner, and typically without the use of a game design document (GDD). We argue that a reason for this phenomenon is that current ways to structure, create and update GDDs do not increase the value of the artifact in the design and development process. As a solution, we propose a model-driven, web-based knowledge management environment that supports game designers in the creation of a GDD that accounts for and relates educational and entertainment game elements. The foundation of our approach is our devised conceptual model for educational games, which also defines the structure of the design environment. We present promising results from an evaluation of our environment with eight experts in serious games.

1 Introduction

According to Zyda [35], a serious game is "a mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives". Educational games are a class of serious games having an educational/learning purpose in the context of primary or secondary school, higher education, etc.

Despite the recent traction that serious and games gained, thanks to the increasing usage by parents and teachers [30], and despite all the available technologies, the design process of these games have not changed significantly, and still largely relies on tools such as simple text editors and prototyping software systems [18].

Moreover, the usefulness of game design documents (GDDs) as design artifacts is being questioned. A recent survey by Sundström [29] shows that less than 50% of game professionals believe that GDDs are an effective way to communicate the design of a game, and only 5% read GDDs to analyze a specific aspect of game design.

In this paper, we propose an approach that aims to make GDDs a useful artifact. Our hypothesis, also supported by Sundström's [29] research, is that GDDs are either hardly or inefficiently used due to a variety of reasons:

- *Inconsistency* [6]: the same concepts are documented using different terminology in the GDD, and some design decisions are conflicting.
- *Infrequent updates* [6]: after the initial stages, the GDD is not updated regularly.

- *Multiple communication means*: Bethke [5] identified three different ways of communication in a gaming company, a) through an explicit GDD, b) through digital means (emails, Skype, wikis, etc.), and c) oral. Using multiple ways to communicate can potentially lead to communication loss or overload.
- *Heterogeneous users*. GDDs are used by professionals with different educational and/or professional background, like artists and programmers. This leads to high chances of different interpretations of the same text.

The solution that we propose is based on the construction of a conceptual model [32] of educational games that describes its main constituents and their relationships. Such model defines the structure of the GDD and provides a common ground for communication among heterogeneous stakeholders. We also present a model-driven, web-based environment that enables the creation of GDDs that align with our conceptual model. Specifically, we make the following contributions:

1. Based on our study of the literature, we identify and relate the elements of educational games into a conceptual model for the design of educational games.
2. We describe the main features of our web-based, model-driven design environment that can be used for building GDDs for educational games.
3. We report on a qualitative evaluation of our environment with eight experts in serious games (design), which aims to assess the perceived usefulness of our solution.

The rest of the paper is structured as follows. After reviewing related work in Sec. 2, we introduce the conceptual model in Sec. 3, and we present the web environment in Sec. 4. We discuss the results from the evaluation in Sec. 5, and conclude in Sec. 6.

2 Related Work

The Design, Play and Experience (DPE) framework [33] extends the Mechanics, Dynamics, Aesthetics (MDA) framework [12] (for designing entertainment games) for the design of serious games. DPE has four layers of components, one of which is MDA. Each layer has one subcomponent for each of the three pillars of DPE, meaning the Design, the Play and the Experience. The contribution of DPE is the methodology it proposes in order to analyze and process the design of serious games, which when combined with an agile design environment, it provides a solution applicable to the whole spectrum of serious games.

The Serious Game Design Assessment (SGDA) framework [22] takes a similar standpoint, and defines six main aspects for the design of a serious game that shall be successfully combined to achieve the game's purpose: content, aesthetics/graphics, fiction/narrative, mechanics, framing, and interaction.

The LEGADEE online authoring environment [18] guides designers through multiple toolbars that support different design roles. The approach is model-driven, and is realized through an online environment. LEGADEE's intention is to offer a methodology and tools to guide the various actors that participate in the learning game conception, such as clients, teachers, game designers and developers. Our approach shares the same spirit with LEGADEE, but focuses on educational games.

Amory et al. [2] conducted an experiment on twenty students aiming at identifying which game type is more suitable depending on the learning environment and which are the game elements that students find interesting or useful. Results showed that the preferred genres are the 3D adventure and strategy games, whereas the game elements that students identified as the most useful were logic, memory, visualization and problem solving. Based on the results from the experiment, the authors presented a model that links pedagogical issues with game elements.

Aleven et al. [1] propose a design framework that requires the aligned definition of three main aspects, always keeping in mind that educational games need to be both educational and fun:

1. Learning Objectives: they are identified and defined by answering three questions: (a) What is the required prior knowledge?; (b) What is the knowledge that players will acquire from the game?; and (c) What potential knowledge players can learn that goes beyond the scope of the game?
2. MDA [12]: this is used for designers need to define the mechanics and to influence the dynamics and the aesthetics of the game.
3. Instructional Principles, that define how the learning process will be conducted.

Our research is motivated by the fact that the existing frameworks are rather high-level, as they include abstract elements as opposed to concrete ones that can serve as a basis for a design environment. For example, many of these approaches use the term "Learning" without going deeper into the core elements that define learning. The next section will address this limitation by proposing a detailed conceptual model.

3 Conceptual model

We describe how we combine research from different domains into a conceptual model that defines the core elements of educational games. Our aim is to tackle the inconsistency problem of GDDs, for the conceptual model guides the design of educational serious games by providing a common ground that should minimize misunderstandings by defining a standard terminology to be adopted.

The main challenge in this endeavor is how to combine the gaming aspects with the educational aspects. Our aim is to build a combined model as opposed to a simple merging of two independent models. To such extent, we started from a study of the literature from both fields, and we paid particular attention to the findings related with the interconnections between the two domains. The assembled conceptual model is shown in Fig. 1 using an UML class diagram.

A *game* consists of *game content elements* that represent its structural components; *game design elements* that explain the choices of the designers in terms of mechanics, goals, etc.; and desired *cognitive outcomes* that the game aims to trigger in the players. Among the cognitive outcomes that are to be evoked in the player, important ones are *fantasy* [17], *mystery and curiosity* [10], and *concentration* [8].

As far as game contents are concerned, we refer back to Aristotle's work [20], who defined the key dramatic elements to hold the attention of the audience as: well-defined, evolving *character*s; a *meaning* that stimulates intellect; *dialog*s that are memorable;

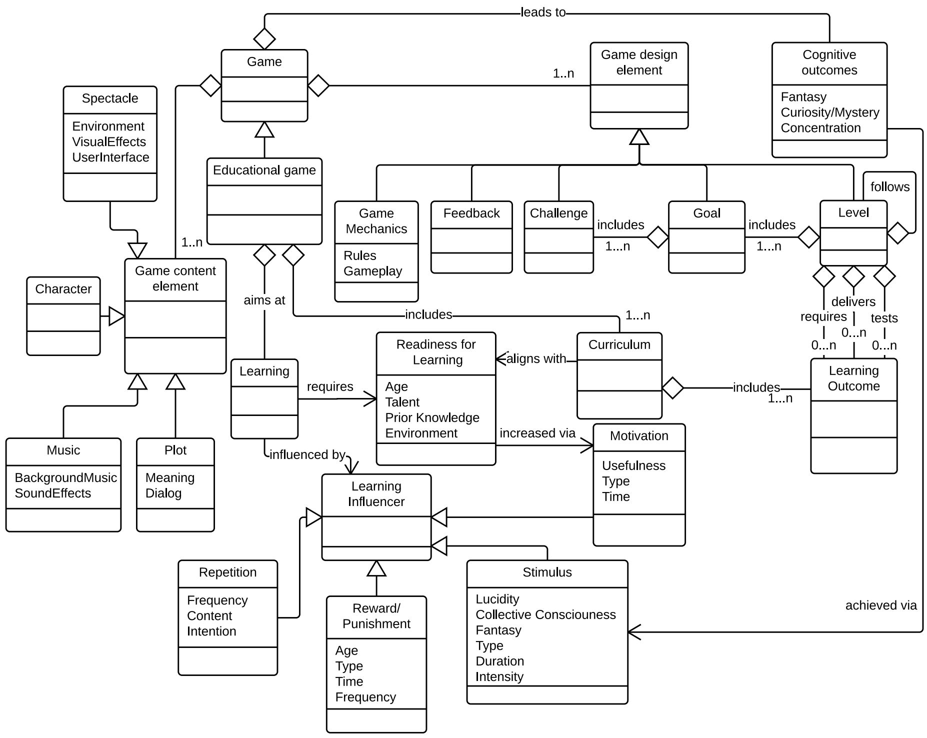

Fig. 1: Conceptual model of educational serious games

music (or audio in videogames) that enhance the auditory experience; and *spectacle* to stimulate the visual experience.

Several game design elements are necessary to coordinate the dramatic elements into a genuine gaming experience: *goals* that the players shall strive for [4], *game mechanics* that determine the gameplay and constrain the possible behavior [27], increasingly hard *challenges* that keep the player engaged within a flow experience [8] (challenges are also part of the three dimensions of gameplay [9]), *levels* that split the game into multiple smaller episodes [4], and *feedback* that provides an immediate reaction on the players' actions [8].

An *educational game* is a type of game (see the is-a relationship) that aims at *learning* and does so by including a *curriculum* of knowledge to be transferred to the players. The curriculum is defined in terms of *learning outcome*s for the game [10] that define what knowledge the player is expected to achieve.

Our conceptual model details the main factors that affect the learning process. In the first place, learning requires that the learners/players have an adequate *readiness for learning* [31] in terms of age, talent, prior knowledge, and environmental factors: an excellent instructional method would not work when a misfit with the audience exists. Moreover, learning is affected by a number of influencing factors: the *motivation* [19] of the learner, the use of *repetition* to boost learning effectiveness [25], the provision of *stimuli* [13], and the inclusion of *rewards/punishments* [11] in response to positive and negative learning behavior.

A key chunk of the conceptual model is that relating *level* and *learning outcome*: every level requires the achievement of learning outcomes, delivers other outcomes, and tests outcomes as well. This structure enables defining an order relationship among levels in educational terms: a level that requires a certain learning outcome shall appear in the game only after a level that delivers such outcome has been successfully played.

4 Design Tool

The conceptual model is put in practice through the design and development of a web-based, model-driven environment for the design of educational games. In other words, the environment is aligned with the conceptual model in terms of the fields that are required to specify an educational game. Model-driven approaches have the advantage of being language independent [28]: the conceptual model can be used independently and contribute on building an environment with any programming language. As such, one could reuse the conceptual model to develop her own environment.

Web applications provide several advantages that help overcome some of the problems associated with GDDs: (i) they are accessible from everywhere and from multiple users; (ii) the look and feel can be easily customized ; (iii) they can be accessed from a variety of devices; (iv) in comparison to desktop environments, they can achieve greater levels of interoperability.

In our environment[3], we made some implementation choices that are intended to facilitate the process of creation of high-quality, useful GDDs:

- *Semi-structured design environment*. Many game elements are common for all types of games, while some depend on the type of game and on the game studio. Thus, we designed a semi-structured environment which is more flexible than fully structured environments and at the same time more rigorous than free text.
- *Linkages of game objects*. Connecting the various objects in a GDD is crucial, as demonstrated by the many relationships between the classes that exist in our conceptual model of Figure 1. Thus, we implemented these two features aiming at enabling game designers to "navigate" through the conceptual model:
  - *Hyperlinks*. Free text areas are enriched with the possibility for designers to link objects that they have already created, such as goals, challenges, character, audio files, etc. By doing so, the designer creates relationships between the current element and other ones. An example is shown in Figure 2;
  - *Dropdown Menus*. The relationships between elements of Figure 1 are implemented through dropdown menus, where the list includes objects that the designer has previously created and that can be accessed by navigating our conceptual model. An example is shown in Figure 3. The usage of dropdown menus helps in two ways: (i) by only linking objects that already exist, this reduces the risk of inconsistency by referring to non-existing elements; (ii) changes in objects (e.g., renaming) are propagated automatically, without the necessity to apply the changes wherever the object is being referenced.

[3] Available at: http://seriousgamesdesign.com

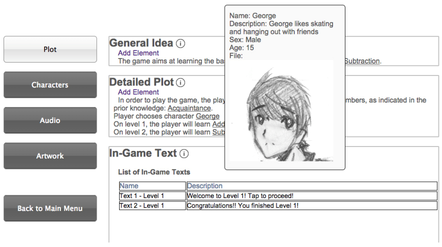

Fig. 2: Using hyperlinks in text areas to reference other GDD objects (here, a character)

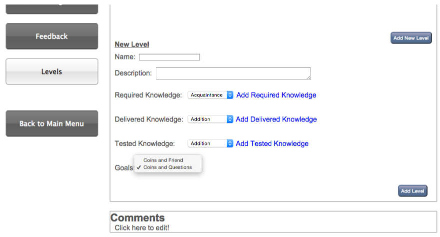

Fig. 3: Dropdown menu: linking required, delivered, and tested knowledge to a level

– *No predefined flow*. According to Meredith [21], decision makers on a design process face the dilemma: too much structure may stifle the creative process, while too little structure provides inadequate support. Therefore, given that we have opted for a relatively structured environment, we decided not to force designers to follow a specific sequence while designing their game (unlike the work by Marfisi-Schottman [18]). The prototype's layout resembles that of content management systems, where users can navigate freely to whichever page they want. This does not only gives more freedom to designers, but also offers a known, and thus more user-friendly, user interface.

Other important features of the prototype are the progress page and export options. The progress page is a dashboard for designers that shows the status of a GDD at a glance. We have partially implemented the customization of the exported document, depending on the stakeholder for whom is intended for.

Throughout our design process, we tried to adhere with the most important usability guidelines, especially those related with the key purpose of the environment: *Consistency* [23] and *Learnability* [16], by using standard terminology; *Clarity* [24], by introducing as few distractions as possible; and *Relevancy* [14], by keeping the concept of the environment aligned with the conceptual model.

5 Evaluation

We describe the process we followed to evaluate our environment and the outcomes of the analysis of the obtained results. The evaluation is intended not only to understand the strengths and weaknesses of our environment (so as to improve it), but also to collect feedback concerning the conceptual model which powers the environment in a model-driven engineering fashion.

The aim of the evaluation is to check the accuracy and comprehensiveness of the conceptual model, the usability of environment, and the benefits of features like hyperlinks and dropdown menus. More generally, our wish is to obtain insights concerning the extent to which our environment and Web 2.0 technologies can help game development teams to overcome the inconsistency and the lack of updates on GDDs and the problems associated with communication within educational game development teams.

We chose to conduct our evaluation through face-to-face interviews that are conducted after demonstrating the online environment. We have defined a plan for the evaluation and have taken several decisions with regard to the conducted interviews [34]:

- *Interview Type*. We decided for semi-structured interviews [26] through the use of a pre-defined set of questions to be rated on a Likert scale or through boolean values[4], followed by the possibility for the interviewees to comment on their response. This protocol combines the strengths of the structured, comparable results provided by scale-based questions with flexibility and richness of feedback from the oral comments.
- *Data Collection*. We decided to conduct face-to-face interviews at the subjects' working place (also known as first degree data collection techniques [15]). The reasons for this decision are a) the possibility to demonstrate the environment in detail and also give the interviewees the opportunity to experiment with it, after the presentation, b) the option to verbally explain aspects of the environment when the documentation is not sufficient, c) the visual observation of the interviewees, which could provide additional feedback regarding their interaction with the environment, and d) the informal comments of the interviewees regarding aspects of the environment that would not be possible through an online questionnaire.
- *Selection of Subjects*. We decided to interview serious game experts from both the commercial gaming market and the academia. In total, we interviewed eight experts: three of them are working on serious game companies and five are working in academia. All of them work in the Netherlands.

The results from the individual interviews[5] are generally positive. All the interviewees found the idea very interesting, and the feedback we received gave us insights on how representatives from both the academic and the commercial communities of games perceive the present and the future of game design. The results to the closed questions are shown in Table 1. A comprehensive report is available in our online appendix.

The number of the interviewees does not allow us to make a statistically reliable generalization of the results. Nevertheless, due to the high expertise of the interviewees in serious games development, the results provide interesting information of how our environment can be adopted by academics and by professionals and can be potentially useful for the design of educational games and for further research.

Experts from both categories find that linking game objects (question 3.1) is an important feature to design serious games. Thus, an environment like ours can be of great help, by providing structure and facilitating the linkage of game objects. The interviewees reported the lack of game-specific tools that help game designers in documenting a game; this indicates a clear potential for an environment like ours.

Due to space limitations, we limit ourselves to outlining the most notable differences between the two expert categories in Table 1:

1. The question about the easiness of navigating through the environment (question 2.2) shows significant differences between the categories: 2.33 for the market ex-

[4] Our questionnaire is available at: http://seriousgamesdesign.com/paper/questionnaire/eval_form.php
[5] Available at: http://seriousgamesdesign.com/paper/results/results.php

Table 1: Summary of the responses to the questions to be answered via a 1-to-5 Likert scale or boolean values

ID	Question	Expert type	
		Market	**Academic**
1	Are all necessary elements present?	Y: 3, N: 0	Y: 4, N: 1
2.1	Is the non-predefined flow preferable to more structured flows?	Y: 2, N: 1	Y: 4, N: 1
2.2	How easy is the navigation in the website?	2.33 (sd: 0.6)	3.8 (sd: 0.8)
3.1	How important is linking game objects in a GDD?	5 (sd: 0)	4 (sd: 1)
3.2a	Are dropdown menus an efficient way to link game objects?	Y: 3, N: 0	Y: 5, N: 0
3.2b	Are dropdown menus faster than free text to link game objects?	Y: 3, N: 0	Y: 4, N: 1
3.3a	Are hyperlinks an efficient way to link game objects?	Y: 3, N: 0	Y: 5, N: 0
3.3b	Are hyperlinks faster than free text to link game objects?	Y: 3, N: 0	Y: 4, N: 1
3.3c	How useful is it to hover over a hyperlink to see an object's information?	4.67 (sd: 0.58)	4.8 (sd: 0.45)
4.1a	How effective is the environment to get a consistent GDD?	3.67 (sd: 0.58)	3.4 (sd: 0.89)
4.1b	How effective are Web 2.0 technologies to get a consistent GDD?	5 (sd: 0)	4.2 (sd: 0.84)
4.2a	How effective is the environment to keep GDDs up-to-date?	3 (sd: 1)	3.6 (sd: 1.14)
4.2b	How effective are Web 2.0 technologies to keep GDDs up-to-date?	3.67 (sd: 1.53)	4 (sd: 1.41)
4.3a	How effective is the environment to overcome communication problems?	3.67 (sd: 0.58)	3.8 (sd: 0.45)
4.3b	How effective are Web 2.0 technologies to overcome communication problems?	4.67 (sd: 0.58)	4 (sd: 0)

perts and 3.8 for the academic experts. This can be explained by the fact that the academic experts have better understood the prototypical nature of the environment.

2. The average difference between the potential of our environment and of Web 2.0 technologies (question 4) is greater for the market experts than for the academic experts, especially in how they help overcome problems associated with game design documents: consistency (see questions 4.1a and 4.1b), updates (see questions 4.2a and 4.2b), and communication (see questions 4.3a and 4.3b).

Finally, we noticed that market experts perceived issues like user experience and user interface friendliness almost as important as the actual functionality of the environment, opening a whole new area for improving our prototypical environment.

6 Discussion

In this paper, we presented a conceptual model of educational games and an online environment based on that model. Our long-term objective is to study whether the usage of GDDs is limited due to the lack of effective tools or is rather due to the way educational games are developed. The preliminary evaluation that we conducted, which involved interviews with serious games experts, confirmed the absence of game-specific design tools, and has shown a positive attitude towards the potential benefit of a web, model-driven environment to mitigate the problems of GDD-based game design.

Our evaluation suffers from threats towards the validity affecting our evaluation. Internal validity is threatened by the use of a mixed approach that combines boolean questions with Likert scale questions: for homogeneity, we should have employed the same type of scale. Moreover, we have mostly demonstrated the tool, instead of letting the interviewees use it. Some of the questions are subject to confirmatory bias, i.e., the tendency of people of agreeing with the statements/questions. In terms of external validity, we have conducted a study with a small number of interviewees, all of which from the same geographic area. Moreover, there are threats concerning the credibility of the results, for we employed a custom questionnaire as opposed to validated questions.

This paper simply paves the way for future research in the field. The conceptual model can be further researched upon to identify any missing core element of educational games. These changes would obviously have to be mapped into the model-based design environment; maintaining this mapping could be facilitated by using a model-driven engineering development environment. Moreover, linking game mechanics with learning models, as depicted on the LM-GM model [3], will provide designers with a "dictionary" for adjusting the game mechanics to the learning objectives of the game. In the same spirit, the environment can be modified to produce all the necessary UML diagrams, as described in the ATMSG model [7], thus helping collaboration among the different stakeholders. The user interface and look-and-feel of the prototype can be greatly improved, especially in order to enable longitudinal studies on the effectiveness of our approach. Finally, case studies are necessary to fully validate our environment.

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