

Emergent Design: Serendipity in Digital Educational Games

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Abstract. Using computer games for educational purposes is a fascinating idea that is getting increasingly popular amongst educators, researchers, and developers. From a technical as well as psycho-pedagogical viewpoint, today's educational games are at an early stage. Most products cannot compete with non-educational, commercial games and not with conventional educational software. Research must address fundamental challenges such as methods for convincing learning-game design or individualization of gaming experiences. An important key factor is development costs. To enter the market successfully requires reducing development costs significantly, however, without reducing gaming or learning quality. In this paper we introduce an approach of using existing methods for educational adaptation and personalization together with ideas of emergent game design.

Keywords: Digital educational games, game-based learning, adaptation, personalization, interactive storytelling, emergent game design

1 Introduction

Computer games are a very successful element of the today's entertainment landscape and an integral part of everyday life. The young people, the so-called digital natives, spend a many hours on playing computer games. Thus, it is not surprising that educators developed an affinity to the idea of using computer games for educational purposes. The result is a significant hype over educational or serious games. Digital educational games (DEGs) are on their way to become a mainstream genre of educational technology. Of course, this idea is not new, educational games are as old as computer games. An early example is the game *Oregon Trail* released first in 1971 and re-released by the educational publisher *Brøderbund* for the *Apple II* in 1985. The game focused on teaching resource management. Today, the examples for educational games are manifold, ranging from so-called *moddings* (modifications of commercial, non-educational games) to games and simulations for primarily educational purposes. Also the scientific community addresses educational games for a while now, conducting research on the foundations of effective yet appealing DEGs. The reason for the hype, however, is not only the appeal of computer games to young people, computer games enable realizing elementary and essential pedagogical and didactical

principles in a very natural way. Computer games, for instance, provide an emotionally and semantically appealing and meaningful context for learning, rich and immersive possibilities for visualizing contents, or the possibility for self-directed, active learning. In short, computer games do have the potential to make knowledge attractive, important, and meaningful.

Surveying the market as well as the body of scientific prototypes and projects, however, educational computer games are still at an early stage [1]. There exists a great many of small and simple games for the very young children and also “gameplay-enhanced” approaches with clear limitations in educational impact and gaming quality. However, there is a clear lack of DEGs that can compete with their “non-serious” counterparts in terms of gameplay, narrative, and visual quality as well as with conventional learning technology in their educational impact.

One fundamental problem of DEGs – and at the same time their most prominent advantage – is the intrinsic motivational potential of computer games. Children, adolescents, and adults play computer games voluntarily, for fun, and they spend a significant amount of time on playing. Today’s gamers are used to an incredible visual quality and appeal of game play of entertainment computer games. However, if educational games cannot compete with this level of quality, the motivation to play them will be rather limited. Since the costs of current computer games are exploding – a good game might well cost 50 to 100 million dollars – educational publishers cannot keep up with game industry. Even worse, the “education” in educational computer games makes the development even more expensive. So it is clear that a prerequisite of commercial and educational success is cost-effectiveness. The consequence is that compelling DEGs are still rare. Quite in the contrary, more and more off-the-shelf entertainment games or modifications are used in class rooms.

An obvious idea to overcome the problem of cost-effectiveness is reducing the development costs. Unfortunately, this is most likely bound to reducing the quality of education, design, narrative, and game play. In conclusion, driving the establishment and quality of DEGs requires games that are effective from an educational point of view, effective from the development point of view, and competitive from the gaming point of view. And this is a non-trivial problem. In this paper we present an approach that, essentially, is based on a fusion of an intelligent in-game personalization and adaptation (in a psycho-pedagogical sense) with interactive storytelling and with ideas of emergence in game design.

2 Personalization in Digital Educational Games

Using “intelligent machines” for educational purposes has a long history; in fact, it can be traced back at least to 1926 when Sidney Pressey [2] tried to build a machine that presented multiple choice questions, their answers, and adequate feedback. The driving force behind intelligent educational systems is to provide individual learners with individual solutions, essentially because of the fact that meaningful and suitable one-on-one teaching is the most effective way of teaching. Unfortunately, a personal tutor is the most expensive way of teaching also. To address this problem with a

technological solution, over the past decades several methods and frameworks for intelligent and adaptive tutorial systems were developed [3].

In contrast to conventional adaptive educational technology, for example learning management systems, DEGs are challenging the technological state-of-the-art by requiring a non-invasive assessment (e.g., of knowledge or learning progress) and adaptation. In simple words, typical assessment methods such as multiple choice questions or cloze texts cannot be utilized in immersive DEGs because, in all likelihood, popping-up assessments would immediately destroy game flow and immersion. The challenge is to find ways and methods to embed assessment subtly in the gameplay and narrative. In addition, the methods of personalization and adaptation must occur in a non-invasive way as well. Prominent methods are adaptive curriculum sequencing (selecting and re-ordering learning objects) and adaptive presentation (changing the look and feel of a learning environment). These methods (e.g., skipping a learning situation because the system concludes that the learner already has the related knowledge) are hardly realizable in an immersive DEG because they would corrupt gaming experience and game flow, ending up with an implausible and confusing storyline without any motivational and educational potential.

Our solution is a non-invasive way of personalization and adaptation, that is, *micro adaptivity*, which was developed particularly for DEGs and which is related to techniques of adaptive problem solving support. The principle of micro adaptivity is to monitor the learner's behavior in the virtual world and to interpret the behavior in terms of available and lacking knowledge or in terms of specific inner states (e.g., motivation). To give an example, imagine a game-like exploratory learning situation within which the learner is required to narrow a light cone from a torch to a small light beam using a couple of blinds (see Figure 1). If the learner cannot narrow the light cone, we can conclude that this learner lacks the understanding of the blind principle. Of course, a single observation is not very significant but with an increasing number of actions, the (probabilistic) picture of the learner becomes continuously clearer and more valid. The micro adaptive assessment is complemented with subtle educational and motivational interventions, which are strictly embedded in the

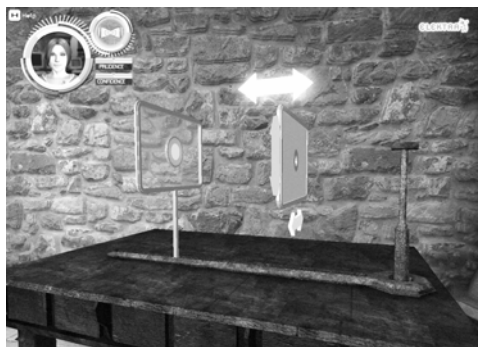


Fig. 1. Screenshot of a competitive educational game about the physics of optics. The game is a prototype developed in the context of the European ELEKTRA project (www.elektra-project.org).

game. An example is to provide the learner with feedback of the learning progress or hints. By aforementioned example, a non-player character (a NPC) might suggest the learner promising locations for the blinds. A more in-depth description of the micro adaptivity concept is provided by [4].

2.1 The Macro Level: Adaptive Storytelling

So far our concept of personalization and adaptation for DEGs just concerned assessment and interventions within specific limited and pre-defined learning situations. Educationally important techniques for personalization and adaptation such as adaptive sequencing of learning units (learning situations in a DEG) or adaptive presentation, however, are not addressed. To extend and enrich our approach to in-game personalization and adaptation, we aim for a fusion of the micro adaptivity concept with interactive and adaptive storytelling. In that way, we can realize a personalized sequencing of learning situations and units according to educational aspects as well as personalized adjustments of the game according to individual needs and preferences. In other words, we can shift in-game adaptation to the *macro level*.

In the literature several techniques for interactive or adaptive storytelling are described, varying in the openness of story generation and in their operational reliability. The approaches range from a recombining of self-contained story elements to an open-ended automated generation of “new” stories. For our goal of adaptation we rely on a robust approach based on the specification of atomic story-related entities (ranging from single spoken sentences to self-contained story units). In this context, a crucial aspect of interactive storytelling is to find an appropriate storyline on the basis of a pool of given atomic story or game elements. These entities can be compared to the rooms of a house and the furniture in those rooms, each entity has a specific goal (e.g., providing the learner with information, assessing internal states, or contributing to story and gameplay), specific characteristics and properties. During a gaming episode the single game entities must be adaptively re-combined and re-assembled into a meaningful storyline and a meaningful environment. The assembly is driven by specific sets of rules which refer to aspects of the game genre, the story model, educational aspects, and individual aspects.

The story model underlying our approach relies on a formalization of the classical *three-act structure* of *Aristotle* providing an arc model with ‘exposition’, ‘rising action to climax’, and ‘denouement’ (Figure 2, left panel). The related set of rules is supplemented with domain-related rules, defining the set of educationally meaningful sequences of learning, so-called *learning paths* through the learning situations of the game (or learning objectives of a conventional learning environment). This combination generates *game paths* (Figure 2, right panel), possible and meaningful paths through the game accounting for story model, learning objectives, and pedagogical interventions (see [5] for details).

The outlined approach, unfortunately, has an important drawback that is contracting our initial aim, the cost factor. A comprehensive adaptation throughout an entire game would require massive content (i.e., game elements) production. We address this problem by extending the approach of adaptive, educational storytelling with ideas of *emergent game design*.

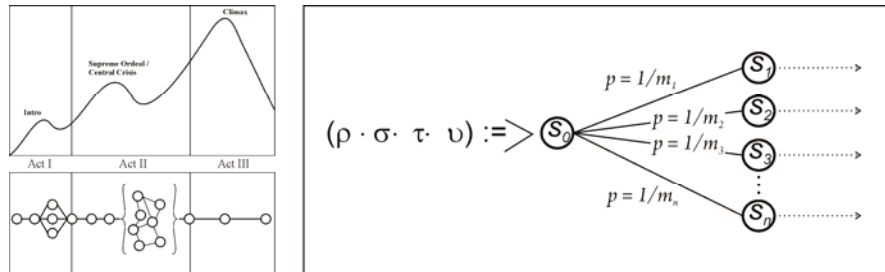


Fig. 2. The left panel shows the three act story model and its translation to a sequence of game entities. The right panel shows a formal representation of restrictions in the sequencing of story elements.

2.2 Emergence in (Educational) Game Design

A potential solution to the dilemma is making the game more “autonomous”. In regular games, a sequence of scripted events occurs throughout the game. According to [6], however, this bears the downside that the game system has a limited awareness of what is happening and, more importantly, the game is lifelessly determined by what the designers think is exciting and fun. *Emergence*, on the other hand, occurs when more or less simple rules interact to give rise to behavior that was not specifically intended by the developer of a system. Emergence refers to the process of deriving new but coherent patterns or behaviors in complex systems. Emergent phenomena occur due to a non-trivial interaction of system components with each other and with the user. As [7] suggested, the collective of such kind of interactions forms novel, complex, and unexpected results. Emergent game design offers a ‘platform’ and ‘tools’ for gaming, however, without any further blueprint; this is comparable to improvisational theatre or giving a kid a box of toy cars. The context is fixed but what happens occurs interactively and incidentally.

One method of realizing emergent game design is that gameplay is based on excellent and comprehensive simulations. Rich virtual worlds enable the player to interact with a large degree of freedom and, more importantly, to interact with game entities that respond in a realistic way. Examples might be *SimCity*, *The Sims*, or *Grand Theft Auto*. The key to emergent gameplay and emergent narrative is a meaningful and “intelligent” interaction with the game and within the game. The advantage is that players receive a very unique and personalized gaming experience as a direct result of their own behavior.

There exist several techniques from complex systems, machine learning, and artificial life that potentially enable emergent behavior in games. According to [8] some examples are flocking (simulating group behavior such as a flock of birds), cellular automata (discrete time models simulating complex systems), neural networks (machine learning techniques inspired by the human brain), or evolutionary algorithms (optimization techniques using concepts from natural selection and evolution to evolve solutions to problems). Some of those principles have already

been transferred to real games; for example, *Half-Life* used flocking to give its monsters more lifelike responses. Another example is *Blade Runner*; here a pre-defined storyline is “enriched” or altered by accidental aspects, making the game different at each time. Important work in this area comes from [9] who developed and evaluated a technically sound framework for realizing emergent game design. Several authors claim that emergence is the direction game development is heading, which includes more flexible, realistic, and interactive worlds.

3 Educational Game Design

Realizing emergent game design requires a game context. Two fundamental dimensions of a game are gameplay and narrative. The gameplay determines the *what and how*, the narrative determines the *why*. Although both dimensions occur on a continuum, specific games are either gameplay-oriented (e.g., role playing games, action adventures, or campaign games) or narrative-oriented (e.g., simulation games, management games, or strategy games). To give very prominent examples, a game like *Tetris* is fundamentally driven by the gameplay without any story behind; adventure games such as the famous *Zak McKracken* are, almost like an interactive movie, driven by a story.

These dimensions also aroused some debate on which a game should focus more: The *ludologists* say that games should be played and not perceived like interactive movies. The *narratologists*, instead say, games should follow a red story thread. Both, the gameplay dimension as well as the narrative dimension can be described on a continuum between open/emergent and predefined/scripted.

When aiming for an effective and efficient design of DEGs, of course, more dimensions of computer games must be considered. A valuable contribution to formalizing viewpoints to computer games came from Smed and Hakonen [10]. These authors argue that the main dimensions of the computer game concept are linked together in a subtle way by the representation form (medium), by rules, by the goal definition, and by the absence or presence of opponents. Figure 3 illustrates these dimensions. A further important systematization of game genres we have to consider came from Lindley [11]. This approach begins with a classification of games on a ‘plane’ of ludology, narratology, and degree of reality (the author terms this ‘simulation’ or ‘prosthetic reality’). In a next step, the model is extended by a 3rd dimension, that of chance (the author terms this ‘gambling’ or ‘decisions about gain and loss’). The model manifests as a three-dimensional pyramid, which allows for classifying game types along its dimensions (Figure 3). Although Lindley’s taxonomy offers a systematic approach that covers a wide range of aspects, the “purpose” aspect is not represented very well. Particularly educational aspects and intentions establish a micro universe of educational game types that must be considered in educational game design. With respect to the idea of emergence, finally, this dimension must be considered as well.

Emergent approaches involving intelligent gameplay and intelligent characters might play a crucial role in future mainstream game design, particularly in the context of serious games. The “intelligence” of game characters can be considered as essential

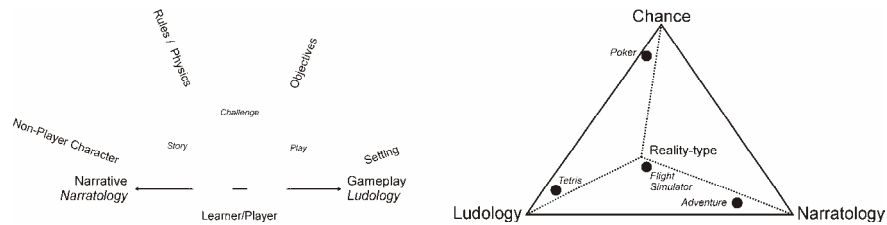


Fig. 3. The left panel shows the dimension of computer games according to [10], the right panel shows a different approach to describe game types according to [11].

factor. Those characters are supposed to behave flexible, challenging, unpredictable, or cunning [12]. An intelligent agent can be considered autonomous if it relies on its own precepts and not on the predefined ‘will’ or ‘knowledge’ of the game designer [13]. Being autonomous, in turn, requires situational awareness. An example for such approach in an existing computer game is the agents in *Half Life*. Those characters “look” and “listen” to what is happening in their neighboring areas [14]. Still, the realization is rather simple; pre-defined check scripts are processed. In psychological terms, existing models perform a top-down approach driven by the designers/developers intelligence. The next generation of artificial in-game intelligence will rather pursue a bottom-up approach by meaningful responses on changes in the agent’s neighborhood.

3.1 Serendipity Instead of Emergence

If we consider emergence, as mentioned above, as a box of toy cars, certain rules and possibilities are fixed, what the play will be exactly is open – in other words, emerging. The problem is that this idea of openness is not compatible with (most) educational purposes. The existing ideas and approaches were developed in the context of entertainment games. Educational computer games cannot simply overtake such ideas since a distinct difference between the two kinds of games is that educational objectives require the learner to pass through certain learning situations following a certain curriculum. This means that pedagogical implications limit the degree of freedom and randomness in emergent approaches to game design. It is necessary that a learner is exposed to certain learning situations in a certain sequence.

Quite naturally, the question is arising whether both ideas can be merged into one game; the designers do not want to (and also must not) lose all control and system-only generated story plots are likely not very convincing. Thus, a subtle balance is required between a global idea of the story and emergent aspects; research proposed a dual layer model that separates a narrative layer and an agent/simulation layer [15]. The story generation is based on the interaction with the beholder, a story-ontology, and vectors of story elements and relationships.

To overcome the incompatibility of emergence and educational purpose while still taken advantage of an open approach, we generated a *narrative context model*. This model is based on the characteristics of the hero’s journey [16] and the classical three-act story model. It determines a general red thread through the game and it

defines the intro act and the closing act. As underlying data model we extended an ontological approach [17]. As shown in Figure 2, the atomic story elements provide the game with a certain degree of freedom of how the story proceeds and about what is happening in the game. To bring education into play, the story elements are mapped to educational objectives and pedagogical implications – utilizing a formal cognitive theoretical framework, that is, *Competence-based Knowledge Space Theory* [17], which establishes a structure of story/game elements that are meaningful in terms of education and in terms of story. The cognitive model reflects the psycho-pedagogical requirements and thus determines the admissible game parameters.

In a next step we introduce an *abstraction layer*. On an ontological basis we separate game play features, story features, and educational features from the game entities (story elements, in-game-objects, NPCs, etc.). As a result, we obtain a set of generic modules (cells), which can be “furnished” just-in-time in accordance with the ontological cognitive model and which can be sequenced in accordance with the narrative. The theoretical background of the generation of modules and their sequencing is similar to the principles of *cellular automata*. Many of today’s approaches to modeling real-world phenomena, which aim to come up with accurate models, are based on this approach. Within games it is not necessary to be accurate in that sense; it is all about be consistent and credible. Forsyth [18], for example has described methods with which natural processes (e.g., fluid flow) can be simplified for games using cellular automata.

The game entities are seen as cells of a multi-dimensional grid. Each cell is in one of a finite set of admissible states (e.g., in terms of story or in terms of knowledge) and each cell has a set of update rules. The state of a cell is a function of the states of the neighboring cells and it is sensitive to the actions of the learner. This results in an *ebbing and flowing* of incidents and it allows an emergent development of game play as well as narrative – of course limited by the global red thread through the game and the educational objectives. The properties of cells can either be discrete or steady. For example, probability distributions over cells are used to estimate the learner’s knowledge (in the sense of an associated memory). In such a way, actions of the user influence the properties of the cells (the present game state). In turn, altering the properties of a cell changes the properties of the neighboring cells, comparable to the propagation of waves when a stone hits the water surface. To give an example, if the learner fails to narrow a light cone properly, the next learning unit automatically adjusts itself to teach the learner about the blind concept.

What does this mean for our initial goal, reducing the costs of intelligent DEGs? The big advantage of this approach is that it is not necessary to develop all possible learning situations in a traditional sense. On this basis it suffices to develop a pool of assets (basic environments, objects, characters, sentences, etc.). The underlying intelligent technology autonomously builds the game upon the given assets.

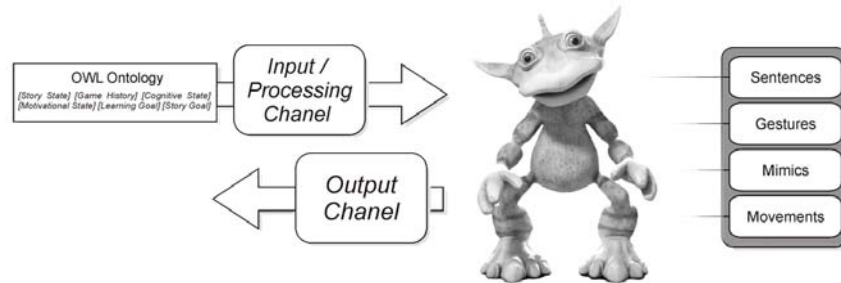


Fig. 4. Brief sketch of the architecture for an emergent behavior of the autonomous NPC – named Feon – that is currently developed in the 80Days project.

4 Conclusion and Future Directions

To make effective and competitive DEGs mainstream educational technology, it is necessary to reduce the cost factor and to increase personalization and adaptation (which is likely even more important for DEGs than it is for conventional learning environments). The presented approach takes up existing intelligent technology for adaptation in the game-context and extends by a component of emergence – or rather *serendipity* (making fortunate discoveries by accident). We presented a hybrid model which tries to combine the best of both worlds, the author driven scripting of the global context (including the educator driven design of learning) as well as the degree of freedom and cost-effectiveness of emergent approaches to game design. Of course, the ideas and their technical realization are at an early level. Future work must extend the present theoretical approach, implement it, and evaluate its applicability. In the context of the European research project 80Days (www.eightydays.eu), we are currently focusing on an autonomous and intelligent NPC (Figure 4), which is supposed to serve as teacher in a competitive DEG. As outlined, the behavior of this character as a certain awareness of the game and learning progress and tailors its own behavior to those requirements. Thus, the script of what is happening when is not authored but emergent in the interaction with the learner. At the present stage, however, we have clear limitations in the variability of the overall story. Future developments will increase the freedom by extending the cellular network and by increasingly adding the so-called smart props.

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