Emergence in Digital Educational Games: A World of Incidents in a Universe of Rules

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Abstract: Using computer games for educational purposes is a compelling idea that is increasingly adopted by researchers, developers, and educators. Still, digital educational games are at an early stage. A crucial factor that must be increasingly addressed by future research is a personalization of learning and gaming experiences in the rich virtual worlds of computer games. In the present paper we introduce an approach to combine frameworks of psycho-pedagogical adaptation, interactive storytelling, and emergent game design in order to provide the individual learners with tailored learning experiences without corrupting the game's storyline and without requiring massive content production.

Keywords: Competitive educational games, adaptation, personalization, interactive storytelling, emergent game design

1. Introduction

Computer games are an outstanding and incredibly successful part of the present entertainment landscape. The compelling technology of leading edge computer games, at least in our opinion, must be considered for teaching and learning also. With the increasing time people of all age groups spend on playing computer games, the idea of utilizing the games' motivational and educational potential becomes more and more convincing and fascinating. Still, today's computer games not only have a tremendous motivational potential, 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.

For several reasons, the vision that digital educational games (DEGs) become a serious part of educational technology did not come true yet; from today's perspective, the realization of this vision is still in its infancy (Oblinger 2006). This is particularly true if educational games for older children and adolescents are concerned or when considering games related to school curricula. Most existing DEGs are rather small and often simple games, focusing on a limited set of competencies (e.g., basic algebra) or addressing specific skills (e.g., job application trainings). They generally do not related to school curricula or do not attempt to enable learning about school-related subject matter. More importantly, existing games do not provide sound assessment methods and generally there is an imbalance between learning and gaming. Finally, while game intelligence is well developed, educational games do not include adaptation to the learner in terms of knowledge, learning progress, motivation, or individual preferences. Thus, they cannot compete with their commercial counterparts and they cannot utilize the full potential of immersive digital games with respect to learning efficacy and learning experience. In conclusion, a key aspect of the success of an educational game (i.e., effective learning and fun) is an intelligent adaptation to the individual learner.

1.1 Around an Inspiring Virtual Learning World in Eighty Days

The psycho-pedagogical personalization in DEGs is in the focus of the European research project 80Days (www.eightydays.eu). Inspired by Jules Verne's novel "Around the world in eighty days", the project aims at developing psycho-pedagogical and technological foundations for intelligent adaptation. Basically, the project's endeavours include melding curriculum-related subject matter with the fun and excitement of an attractive and compelling computer game. In this context, the intrinsic motivational potential of computer games is the key to learning success in the sense of voluntary and maybe hidden learning activities.

In the focus of research and development is an intelligent technology that allows an adaptation to individual learners, their prior knowledge, abilities, preferences, and learning progress, even more, a technology that allows a so important but so fragile dynamic balance between challenge and ability.

Undoubtedly, the motivation to play and therefore to learn is crucial for learning games; only those learners who are perfectly challenged, neither overburdened by too difficult gaming and learning activities nor bored by too simple ones will optimally use the educational potential. In 80Days, this kind of adaptation is realized by providing the learner with adequate psycho-pedagogical interventions (e.g., hints or feedbacks) but also by the adaptation of the entire gaming context and ambience (e.g., the level of difficulty, the mood, the pace, or even the entire storyline). Therefore, in the heart of the project is the fusion of educational adaptation/personalization with interactive storytelling.
Non-Invasive Psycho-Pedagogical Adaptation

Using more or less “intelligent” machines for educational purposes has a long history. It can be traced back to 1926 when Sidney Pressey (1926) tried to build a machine that presented multiple choice questions, their answers, and immediate feedback. The driving force behind intelligent educational systems is to provide individual learners with individual solutions, essentially because a large body of research yielded that meaningful and suitable one-on-one teaching is the most effective way of teaching (Bloom 1984), however, the most expensive way. Over the past decades several methods and frameworks for intelligent (ITS) and adaptive (ATS) tutorial systems were developed. An overview is, for example, provided by Paul De Bra (2008).

For the psycho-pedagogical interventions in DEGs we developed an approach of adaptation on a micro level. The approach is essentially based on *Competence-based Knowledge Space Theory* (Albert & Lukas 1999). This framework allows modelling a knowledge domain as formal structure of admissible and meaningful *competence states* on the basis of *prerequisite relations* among the latent competences. As an example, being able to add two integers is considered a prerequisite to perform multiplications. By this means, the number of meaningful states is significantly reduced in comparison to the power set of all possible combinations of competencies. The basic idea of micro adaptivity is to perform an assessment of knowledge / learning progress by monitoring what the learner is doing in the game (e.g., which objects are manipulated in which way) and to interpret those actions in terms of available and lacking competencies and competence states in a probabilistic sense. To give an example, if a learner closes an electric circuit as a task in the game (e.g. to open a door) we can assume with a certain probability that this learner knows that the task requires electricity. Of course, one observation is not very convincing but by continuously observing the gaming behaviour our picture of the learner’s competence state is getting clearer and clearer. The same principle we can use to make assumptions about other aspects (inner states) of the learner, e.g., assumptions about the motivational state. The probabilistic assumptions are used to provide the learner with suitable interventions, for example, individual feedback or hints that are suited for a specific situation. In this way we can avoid interrupting the gaming flow by inappropriate psycho-pedagogical measures. A more in-depth description of the micro adaptivity concept is given by Kickmeier-Rust and colleagues (Kickmeier-Rust, Albert, Hockemeyer, & Augustin 2007; Kickmeier-Rust, Marte, Linek, Lalonde, & Albert 2008).

1.2 Educational Storytelling in DEGs

In the last section we described how micro adaptive assessment contributes to provide the learner with “soft” interventions embedded in the game flow. Important techniques for educational adaptation such as adaptive sequencing of learning units (learning situations in a DEG) or adaptive presentation, however, are difficult. For example, in a game with a fixed story line it is not possible to skip a learning unit because the system concludes that the learner already has the respective knowledge. This would immediately destroy the story’s flow and therefore the gaming experience. To address this problem we aim at merging psycho-pedagogical adaptation with interactive storytelling, essentially to enable an adaptation of the story to the psycho-pedagogical requirements.

A focal aspect of interactive storytelling in an adaptive DEG is to find an appropriate storyline on the basis of a pool of given atomic game elements (these can be viewed as the rooms of a house; each room has a specific goal, for example, to provide the learner with information, to assess internal states, or just to contribute to the story and gameplay). During the game, the single game elements must be adaptively re-combined to a meaningful storyline, which is in accordance with the psycho-pedagogical requirements. By aforementioned example, if the system concludes that a specific learning unit can be skipped, the re-sequencing of game elements must be made in way that skipping a unit does not break the storyline.

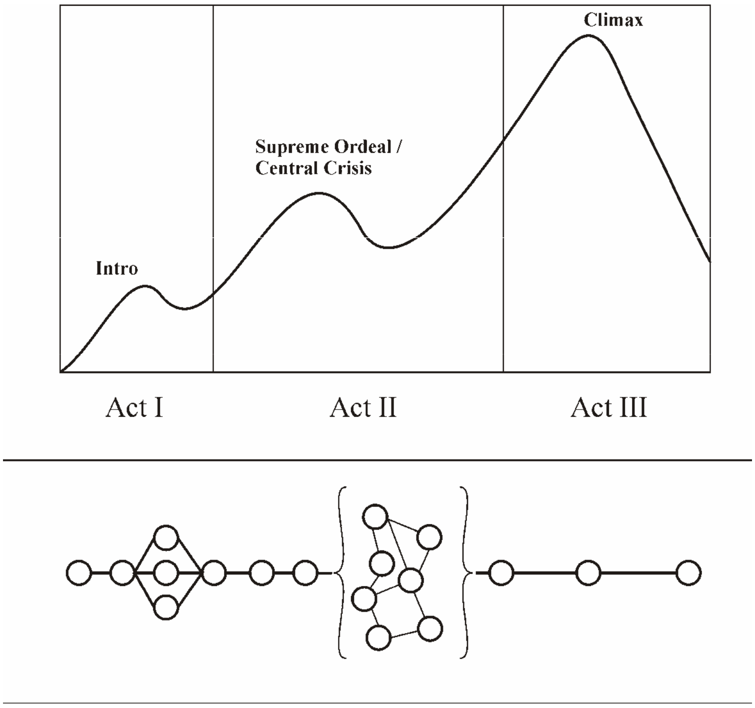

Figure 1: The three act story model and its translation to a sequence of game elements

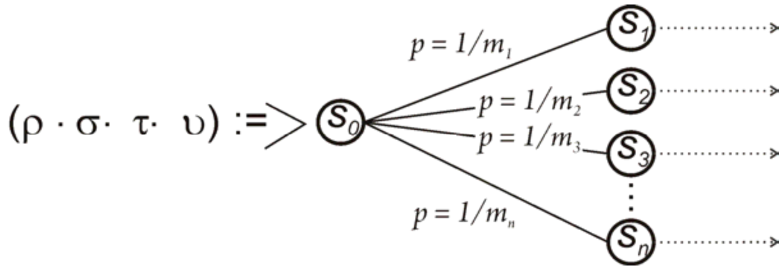

Figure 2: A formal representation of restrictions in the sequencing of story elements

This task is not trivial; it requires not only the adaptive mechanisms described earlier, it requires a formal and computable story model. 80Days relies on the classical three-act structure of Aristotle providing an arc model with 'exposition', 'rising action to climax' and 'denouement' (Figure 1). Thus, we can combine the story and learning by linking competence structures with story plots (Figure 2). This, in turn, generates game paths, possible and meaningful paths through the game accounting for story model, learning objectives, and pedagogical interventions (see Kickmeier-Rust, Göbel, & Albert 2008 for details).

The outlined approach, unfortunately, has an important drawback: the cost factor. A comprehensive adaptation throughout an entire game requires massive content (i.e., game elements) production. However, cost-effectiveness is a crucial factor for a DEG's success on the market. We address this problem by extending the approach of adaptive, educational storytelling with ideas of *emergent game design*.

2. Emergence in (Educational) Game Design

In regular games, a sequence of scripted events occurs throughout the game. According to Smith (2002), 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. Emergent behavior, 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 Johnnson (2001) pointed out, 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 perspective is that emergent gameplay appears due to 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 the interaction with the people in *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 each player receives a very unique and personalized gaming experience, which is potentially enriching the possibilities for educational adaptation/personalization. On the other hand, to create such intelligent and complete game world may require a significant amount of resources, perhaps much more than scripted games need.

There exist several techniques from complex systems, machine learning, and artificial life that potentially enable emergent behavior in games. According to Sweetser (2006a) 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 might be *Blade Runner*; but also in this example a pre-defined storyline is only "enriched" or "altered" by accidental aspects, making the game different at each time. Important work in this area comes from Sweetser (2006b) 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 Sweetser (2006b).

2.1 Gameplay versus Narrative

Gameplay and narrative are two fundamental dimensions along each game can be described. The one determines the what and how, the other determines the why. Although both dimensions occur on a continuum, specific games are either predominantly gameplay-based (e.g., role playing games, action adventures, or campaign games) or predominantly narrative-based (e.g., simulation games, management games, or strategy games). Those 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.

With respect to emergent approaches on the gameplay side, intelligent characters play a crucial role. The "intelligence" of game characters is a essential factor. Those characters are supposed to behave flexible, challenging, unpredictable, or cunning (Sweetser, Johnson, Sweetser, & Wiles 2003). 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 (Russel & Norvig 2003). 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 (Leonard 2003). 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 purse a bottom-up approach, meaningful responses on changes in the agent's neighborhood.

2.2 The Educational Ways

However, aforementioned approaches were developed in the context of entertainment games. Educational computer games cannot simply overtake such ideas since a crucial difference between the two kinds of games is that educational objectives require the learner to pass through certain learning situations (in whatever way they are realized). 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.

These limitations contribute to an interactive dilemma (Peinado, Gómez-Martín, & Gómez-Martín 2006) 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 (Peinado, Gómez-Martín, & Gómez-Martín 2006). The story generation is based on the interaction with the beholder, a story-ontology, and vectors of story elements and relationships.

In this work we want to present a model for involving emergent game design ideas in educational contexts. This model considers the learning domain, the learner, and it relies on character-based and plot-based foundations.

3. Educational Adaptation - Interactive Storytelling - Emergent Game Design

First, a narrative context model must be generated. This model is based on the characteristics of the hero's journey (Campbell 1993) 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. In-between, we have a large number of possible story/game paths (Figure 1). These are associated with educational objectives and pedagogical implications – using the cognitive competence-based knowledge space theory (Kickmeier-Rust & Albert 2008), 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. Formally, we can summarize the psycho-pedagogical aspects as an "inner state", which constitutes n-tuples, which in turn determine transition probabilities (Figure 2). However, in terms of game development this model is the anti-thesis of cost-effectiveness since it requires massive content production.

As a consequence, we introduce an abstraction layer. On an ontological basis (extending Kickmeier-Rust & Albert 2008) we separate game play features, story features, and educational features. The game progresses through a sequence of generic modules (cells) which are sequenced adaptively and filled with game play, story, and education in real time and system driven.

The theoretical background is similar to the principles of *cellular automata.* Many of today's approaches to modeling real-world phenomena aim to come up with accurate and error-free models. Often such modeling occurs in the context of scientific applications and forecasts. In games this complexity is not necessary. It's all about providing appealing and realistic visual effects (e.g., smoke or fire) – not necessarily accurate but rather credible. Forsyth (2002), for example has described methods with which natural processes (e.g., fluid flow) can be simplified for games using cellular automata.

The game elements are seen as cells of a multi-dimensional grid (Figure 3). Each cell must be 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. In more practical terms this means, if the learner performs an action (e.g., closing the electric circuit) the probability distribution over the competence states is altered. In combination with other indicators (e.g., intervals between actions or the number of re-trials) this determines the properties of the game elements (the cells). 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 establish an electric circuit, the next learning unit automatically adjusts itself to teach the learner about electric circuits. The advantage of this approach is that the game only needs the assets for the described adjustments (maybe a set of re-combinable sentences an avatar could say), it is not necessary to develop all possible learning units.

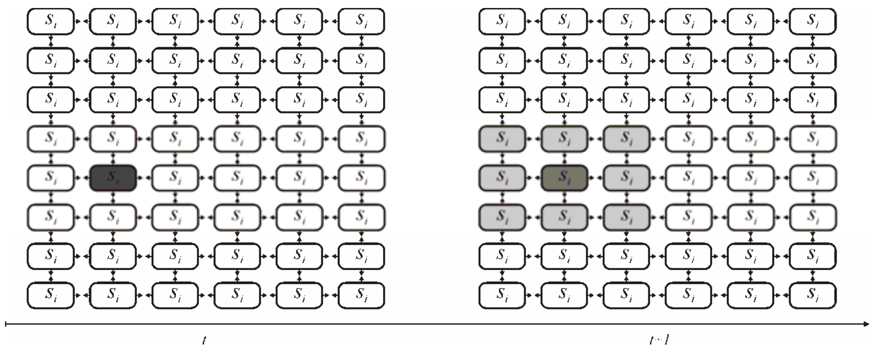

Figure 3: Cellular automata – or a stone hitting the water. The image – in a very basic way – illustrates the grid-like relationship between the game elements (e.g., props, furniture, non-player characters). The relationships are probabilistic in nature. When the player interacts with one game element, the properties of this element change and, subsequently, specific properties of related elements change.

4. Conclusion

In conclusion, the presented attempt to emergent game design in educational contexts can be seen as 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. Apart from the educational context, the hybrid model provides also ideas for designing virtual environments in general.

Emergence is primarily driven by “intelligent” characters and “smart props” (prop is a term for objects in the game such as tools, weapons, furniture, etc.). The approach of cellular automata enables changes in the game context (by actions of the player and by micro or macro adaptive assessments) affecting not only one specific character or prop but, driven by more or less complex rules, semantically neighboring characters and props.

Particularly from an educational perspective it is crucial, of course, that the information recorded by the system during gaming episodes and the conclusions drawn from that information are appropriate and valid. Although the approach is at an early stage, especially the combination of educational adaptation with interactive storytelling and aspects of emergent behavior, first evidence comes from the context of evaluation studies in a predecessor project (ELEKTRA, www.elektra-project.org; cf. Kickmeier-Rust et al., 2008). Currently the ideas are implemented in a prototype demonstrator game in 80Days and evaluated at schools in Austria and the UK.

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