Challenges in the Development and Evaluation of Immersive Digital Educational Games

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Abstract. In this paper, we describe a conceptual framework and address the related issues and solutions in the identification of three major challenges for the development and evaluation of Immersive Digital Educational Games (IDEGs). These challenges are (i) advancing adaptive educational technologies to shape learning experience, ensuring the individualization of learning experiences, adaptation to personal aims, needs, abilities and prerequisites; (ii) providing technological approaches to reduce the development costs for IDEGs; by enabling the creation of entirely different stories and games for a variety of different learning domains, each based, more or less, on the same pool of story units; patterns and structures; (iii) developing robust evaluation methodologies for IDEGs by the extension of ISO 9241 to include user satisfaction, motivation and learning progress and other User Experience (UX) attributes. While our research and development is by no means concluded, we believe that we have arrived at a stage where conclusions may be drawn, which will be of considerable use to other researchers in this domain.

Keywords: Immersive digital educational games, Marco adaptivity, Micro adaptivity, User experience, Reusability, User Experience

1 Introduction and Motivation for Research

Developing Digital Educational Games (DEGs) that can cost-effectively foster learning has been a challenge for researchers and practitioners in the fields of HCI& UE and Technology Enhanced Learning (TEL) for a long time. DEGs offer exciting and dynamic environments, which engage players in meaningful and motivating learning activities, inspiring them, through fun and pleasure, to explore a variety of topics and tasks.

The characteristics of the simulations within DEGs can contribute substantially to individual player's ability to construct knowledge, while the games' social aspects can enhance players' collaborative learning skills; however, in order to realize this vision, three major challenges must still be dealt with:

(i) The large degree of freedom, enabled by digital game environments, renders it extremely difficult to tailor the games to the end users' personal learning experiences and preferences, and to provide end users with purposeful and unobtrusive advice;

(ii) The relatively high competitiveness of the DEGs commercial counterparts, which attract a huge amount of investment and corresponding high quality production has raised the expectations of today's experienced players;

(iii) The difficulty in obtaining support from parents, educators and policymakers for the incorporation of to incorporate DEGs into regular curricula is mostly due to a lack of well established approaches towards yielding persuasive evidence about the educational efficacy of DEGs.

Our suggestions include the improvement of the development methods to ensure intelligent and adaptive educational technologies; to identify technological approaches to reduce the development costs of DEGs; and at the same to classify innovative and robust evaluation methodologies to validate pedagogical models and technological solutions for DEGs. The newly launched R&D project – 80Days (www.eightydays.eu) – aims to address these challenges.

Specifically, our aim is to tackle the problem of *reducing the costs* of developing methods of IDEGs by providing a methodological framework, including technological advancements; adaptive and interactive digital storytelling and *generic adaptive tutoring methodology* (cf. Competence-based Knowledge Space Theory (CbKST), [1]) and by realizing different scenarios within the same base game.

The scenarios implemented in our project are inspired by Jules Verne's appealing novel "Around the World in Eighty Days", which inspired our project's name. The primary topic of the game demonstrator is the discipline geography. The rationale for selecting this discipline is threefold: First, a broad range of sub-topics and knowledge domains provide well-defined internal structures in terms of prerequisites among specific competencies. Second, available curricula ranges from primary education to university level, enabling scalability. Third, attractive 2D and 3D learning resources (e.g. cartographic material, satellite images, etc.) can be perfectly utilized for immersive games with motivating narratives. In this paper, we present our conceptual frameworks and address the related issues and possible solutions.

2 Background and Related Work

Due to the common view that immersive DEGs can make learning engaging, inspiring and presumably effective, enthusiasms and efforts over game-based learning have soared in recent years in various application domains [2], [3], [4], [5], [6], [7].

Many researchers argue that playing computer games provides learners with a mental workout [8], i.e. that the *structure* of activities within computer games can develop cognitive skills due to the fact that end users are faced with decision making, consequently they must plan problem solving strategies in advance, which involve the monitoring of a series of tasks and sub-tasks, so called *Judgement-Behaviour-Feedback* loops [9].

Some of the main strengths of DEGs include [10]:

1) A high level of intrinsic motivation to play and to proceed in the game;
2) clear goals and rules;
3) a meaningful yet rich and appealing learning context;
3) an engaging storyline with random elements of surprise;
4) immediate feedback;
5) a high level of interactivity, challenge and competition.

These characteristics are in line with *Merrill's model for successful learning* [11]. Key factors of this model include *motivation* and *incidental learning* [12], [13], [5], however, memorable educational experiences should not only be enriching but also enjoyable [14], [15], [7].

Nevertheless, DEGs have some drawbacks such as difficulties in providing an appropriate balance between playing and learning activities or between challenge and ability; in aligning the game with national curricula and in affording extensive costs of developing high quality games. Also the lack of sound instructional models, based on pedagogical standards and didactical methods, is seen as the common weaknesses of most educational games, leading to a separation of learning from playing.

Despite these negative issues, commercial computer games are tremendously successful and the game industry constantly increases sales to several billion Euros. A large number of people of all age groups, especially secondary school ages, spend many hours a week playing games. Our observations corroborate the presumption that utilizing gaming activities for educational purposes and exploiting the educational potential of computer games is a highly promising approach to facilitating learning by making it enjoyable and pleasant [2].

The current project *80Days* is based upon the results of its predecessor *Enhanced Learning Experience and Knowledge TRAnsfer – ELEKTRA* [16], which made significant contributions to advancing the state-of-the-art of competitive DEGs in terms of educational game design, integration of pedagogical models and taxonomies, and the possibility of personalization by the use of adaptive technology.

Pedagogically, 80Days is grounded in the framework of *Self Regulated Personalized Learning* (SRPL) [17], [18] which propagates the importance of *Self Regulated Learning* (SRL) through meaningful choice and exploration, reflection and self-personalization in the learning process.

Self regulation [19], [20] can be defined as including an interactive *process* involving both cognitive self-regulation and motivational self-regulation; wherein cognitive self regulation can be taught and that students who use these self-regulatory skills obtain better grades in the content domain to which these skills apply [21].

However, it is argued that self-regulated learning can be domain-specific or domain-transcending and that competent performers in a specific domain rely on different types of previous knowledge related to that domain, consequently to address the previous knowledge is always an important issue [22]. This contributes towards the creation and *sustainability* of intrinsic motivation, which is a key factor of effective game-based learning.

3 The first Challenge: Adaptive Learning Technologies

Individualization of learning experiences, including adaptation to personal aims, needs, abilities and prerequisites, entails in-depth understanding of individual learners and their behaviour with a IDEG. It is critical not to destroy the immersion and gaming experience by intervening knowledge assessments, which are commonly used in traditional approaches to adaptive educational technologies that focus on knowledge and learning progress. IDEGs take into account a broader scope of issues such as individual preferences (e.g. visual styles or gaming genre). Prevailing cognitive models for adaptive educational technologies (which are primarily competence-based) should thus be merged with theories of achievement motivation and models of interactive and adaptive storytelling to establish a comprehensive theoretical framework for combining learning and gaming.

Techniques of adaptation and individualization are essentially adaptive presentation, adaptive navigation support and adaptive problem solving. In the framework of ELEKTRA [16] a new terminology was introduced, basically because of the reason that game-based approaches to learning are substantially different from traditional approaches to e-learning. The new concepts, which are tailored to learning environments with large degrees of freedom, are adaptive on macro and micro levels ([23]; Figure 1).

Macro-adaptivity refers to traditional techniques of adaptation, such as adaptive presentation and adaptive navigation on the level of learning objects (LOs) or learning situations (LeSs) in a IDEG [24]. Generally, macro-adaptive interventions are based on a stable learner model (e.g., traits) or an adaptation model (e.g., pedagogical implications) and on typical (knowledge) assessments (e.g. via test items).

Micro-adaptivity or micro adaptive interventions are non-invasive, meaning that an overall narrative is not compromised and only affects the presentation of a specific LO or LeS.

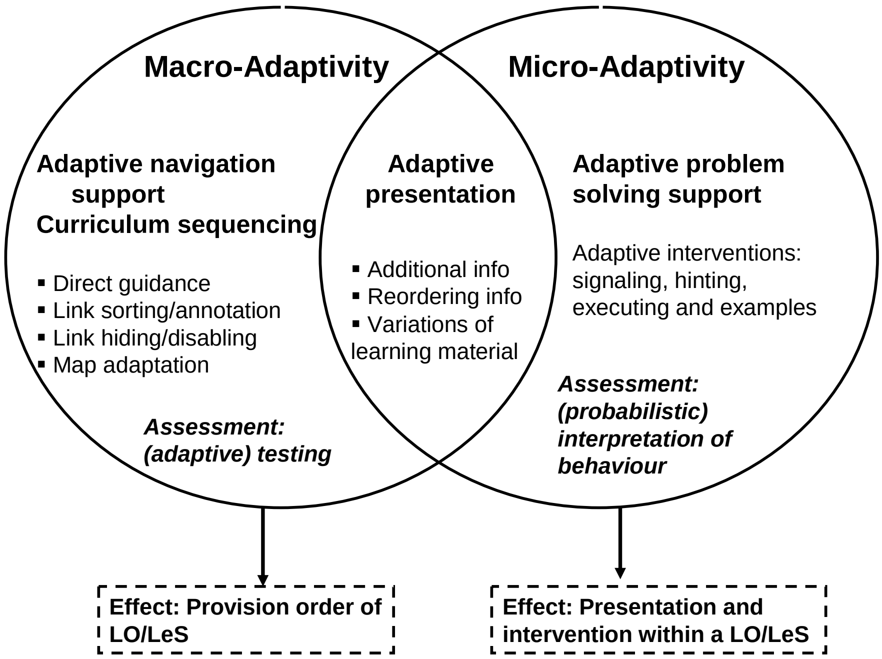

Fig. 1: Macro-adaptive and micro-adaptive techniques
(NB: LO = Learning Object; LeS = Learning Situation)

To support the (r)evolution of cognitive and psycho-pedagogically inspired frameworks for purposeful adaptive interventions, it is imperative to extend the existing state-of-the-art by integrating motivational and emotional aspects, adaptive storytelling and dynamic processes of learning and navigation (cf. [23]) into a sound cognitive framework, i.e., a dynamic three-component framework for adaptive interventions and probabilistic knowledge assessments.

In contrast to existing approaches, which separate learner, domain and adaptation models, this framework is based on a holistic understanding as well as a formal ontological representation of interacting processes involved in active and dynamic learning processes (Figure 2).

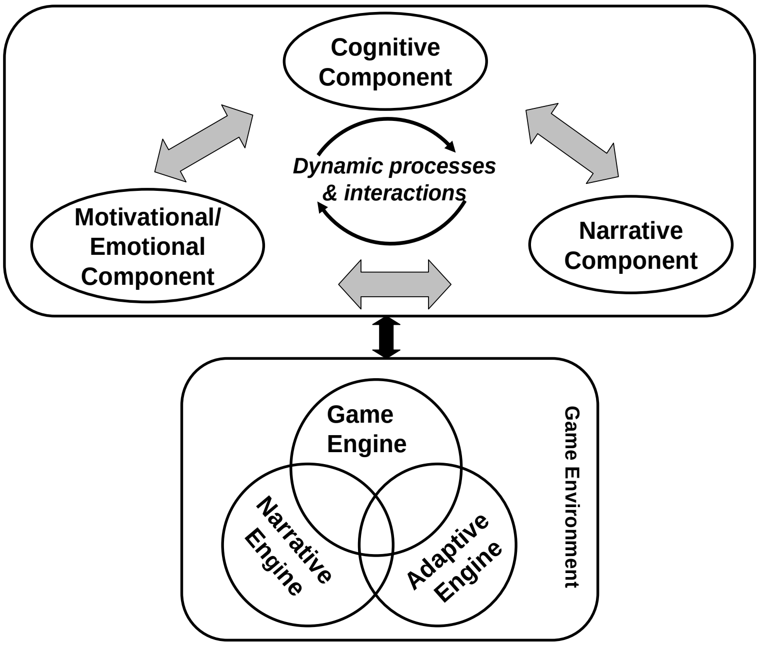

Fig. 2: Macro- and micro-adaptive techniques
(NB: LO = Learning Object; LeS = Learning Situation)

4 The second Challenge: Reusability of Learning Resources

In an IDEG, adaptive and interactive digital storytelling serves two essential purposes: First, it strongly supports a personalized learning experience by adapting the game's story to individual preferences and by providing the possibility of explorative learning processes. Second, it serves the re-usability of learning material by enabling the creation of entirely different stories and games for a variety of different learning domains, each based, more or less, on the same pool of story units; patterns and structures; as well as learning and playing concepts and elements/objects. Furthermore, re-using learning material contributes to minimizing costs, particularly with regard to the design of documents.

The development of competitive DEGs is cost-intensive and, when the topic relates to a limited age group or specific curricula, there is a narrow, albeit specialised, market for the end product.

Thus, the integration of existing learning resources is a crucial aspect of efficient and cost-effective learning design and game development. The integration of external resources (e.g., learning media; websites; web services; 3D material or cartographic material) with a game engine into a coherent and immersive game environment is difficult.

Since the development and application of immersive DEGs is still at an early stage, no appropriate methodologies exist to date, which would enable an effective integration of existing learning resources and their (re)use in DEGs.

Hence, it is deemed critical to analyze the technological and didactic demands and mutual dependencies between learning resources, learning activities, pedagogical models, and narrative/game engines. An approach of resource harmonization; resource symbolization and ontological resource description should also be established.

5 The third Challenge: Evaluation Framework

Given the complexity of digital game environments, mixed-method evaluations are deemed necessary, which will enable the triangulation of multi-source and multi-perspective quantitative and qualitative data.

Given the complexity of digital game environments, it is deemed necessary to use mixed-method evaluations, which enable the triangulation of multi-source and multi-perspective quantitative and qualitative data.

Essentially, evaluation and validation activities comprise two nested aspects: the software quality of the game environment and the effectiveness of IDEGs in reaching their objectives of facilitating motivated, engaged, and successful learning.

Usability evaluation of digital games can employ a combination of empirical, analytic, and model-based methods [7]. While it is important to measure effectiveness and efficiency (ISO 9241) in terms of task completion rate and time, in the case of IDEGS, we find it extremely important to consider user satisfaction, motivation and learning progress that subsumes a range of User Experience (UX) attributes.

There have been recent attempts to provide theories and frameworks for UX but a unified view on UX is still lacking [25], [26].

Past research on UX acknowledged the demand for a theoretical model to put together cumulative knowledge in research. On the example of an experimentally tested and extended Hassenzahl's model of aesthetic experience, it was demonstrated that beauty was influenced by hedonic attributes (identification and stimulation), but quality by both hedonic and pragmatic (user-perceived usability) attributes as well as task performance and mental effort [27].

Hedonic quality can be measured, for example, by the application of the AttrakDiff questionnaire [28], [29], [30]. This questionnaire is embedded in a theoretical model, which differentiates between the pragmatic quality and the hedonic quality of a user interface [31].

Pragmatic quality describes traditional usability aspects, including efficiency, effectiveness and learnability. It focuses primarily on task related design aspects. Consequently, hedonic quality describes quality aspects, which are not directly related to the tasks the end users want to accomplish with the software, for example originality and beauty [30], [27].

Both qualities are subjective; consequently end users may differ in their evaluation of these aspects.

Moreover, it is deemed important to evaluate the *educational effectiveness* of the digital game environment in specific learning situations and broader learning domains with high conceptual and social content, and to adapt and elaborate existing evaluation methods, considering their potentials and limits (cf. [32]. Since a digital game is a *dynamic* learning tool, the evaluation must be tightly coupled with the actual learning process (i.e., constructivist-situated learning) [33].

It is also indispensable to apply multiple measures of learning and performance along multiple dimensions: technical; orientational; affective; cognitive; pedagogical; social and others.

An evaluation framework, which addresses conceptual; practical and methodological challenges in evaluating IDEGs – an immature and exciting field –, must take the following aspects into account:

(i) Extensibility of conventional usability engineering methods for evaluating both the usability *and* user experience of interacting with IDEGs;
(ii) Multi-dimensionality of the educational efficacy of digital games, including knowledge acquisition, meta-cognition, and social interaction;
(iii) Evaluation criteria for different stakeholders' multiple goals or values (personal, social and economic) to be fulfilled by the gaming environment;

5. 1 Extensibility of existing UEMs

Two types of Usability Engineering Methods (UEM, see [34] for an overview) – heuristic evaluation and thinking-aloud user testing – are widely deployed evaluating the usability of IT products (e.g. [35], [36]) including digital games [37], [7].

Specifically, there has been some recent research on using heuristics to evaluate the *playability* of an entertainment technology such as video games [38], [39], [40], [41]. However, these discount methods, without involving actual users, can only provide an overview of usability and playability of such a game. As the value of a game is primarily determined by end-users' subjective perceptions, assessing through the lens of a user surrogate (i.e. a usability specialist who ideally should also be a game player – a double expert) to review the usability/UX of the game seems inadequate.

Some researchers are skeptical about the applicability of heuristic evaluation for evaluating digital games [42], leaving user-based evaluation as "the" viable option.

Presumably, concurrent think-aloud techniques can yield valid empirical data that will enable researchers to understand users' perceptions of the system in question [43], [44]. However, it is considered detrimental to the flow experience [45] of players if they are asked to verbalize whilst engaging in the game; cognitive loading, as in other non-game situations, is also a compelling concern.

Retrospective thinking-aloud methods [43], by asking the player to interpret video-recordings post-hoc, seem more appropriate. There also exist some schemes for coding users' emotional behaviours (e.g. [46]).

However, the inherent problem of retrospective reporting is memory reconstruction, which is especially acute in a playing situation because players' emotional responses normally change very rapidly. Hence, they may not be able to recall or interpret what actually triggered their specific emotion at a specific time. While such moment-to-moment, or situated feedback, may be relevant for identifying usability problems of a game design, some game developers query, from the pragmatic point of view, why bothers to capture data at such a fine-grained level. Their argument is: If players have an overall positive experience, which overrides its negative counterpart, and are thus willing to play it again in the future, then the game can be seen as a success.

While this argument may be valid, to some extent, for entertainment technologies, it is insufficient to evaluate a IDEG, since it fails to take its educational value into account.

Other retrospective self-reporting methods, such as questionnaire and differential semantic, are commonly employed for evaluating games. However, there exist only a few standardized questionnaires for measuring UX with established psychometric properties (e.g. [6]).

Apart from the issue of standardizing inventories, the timing of administering a questionnaire is also critical because UX fluctuate in the course of system use. It boils down to the above mentioned issue - situated vs. average UX, and to also the basic question: Why do we evaluate?

With the aim to complement, as well as supplement, subjective self-reported data, there is an increasing trend towards employing physiological measures for assessing UX in games [42], such as eye-tracking; galvanic skin response; electrocardiography; electromyography of the face and heart rate [47], [48].

While applying these advanced measuring techniques in HCI is not new, the major issues of reliably interpreting or calibrating the related measures remain. For instance, prolonged viewing at a special location of a user interface, as indicated by certain patterns on a heat map, may imply that the user is cognitively absorbed by the content or that they are simply struggling to figure it out. Similarly, sweaty foreheads/hands may imply negative restlessness or positive excitement; individual and socio-cultural differences in facial expressions make interpreting electromyography data difficult; or a deviation of heart rate can also indicate emotional changes.

Furthermore, while automatic logs enable researchers to capture a huge body of data, the effective and efficient integration of these data, to produce coherent and convincing conclusions about players' behaviour and experience, is still very challenging, despite the advance in data mining techniques. To complicate the picture further, the low ecological validity of lab-based tests, albeit neat and structured, demands their replacement with field tests. Evaluating the usability/UX of IDEGs entails the adaptation and augmentation of existing approaches to address the tradeoffs: retrospective vs. real-time data capture, subjective vs. objective data types, and lab-based vs. field studies.

5.2 Assessing Educational Efficacy

It is very interesting that current research efforts on evaluating user experience in games mostly address the entertainment rather than educational aspects (e.g. see [49]), though increasing attention is being given to Serious Games. It is a dual challenge to evaluate both the fun and serious aspects of games. Measuring the success of educational technology and particularly of IDEGs is a complex issue. Much of the literature in the field of educational technology revealed that inconsistent and, at best, non-significant differences were found between technology-based and traditional delivery media.

Based on the results of previous research and guidelines for measuring the "success" of technology-based learning material and environments, the project 80Days aims to develop a scientifically sound methodology, grounded in criterion-based designs and, for specific cases, comparison-based designs. Criterion-based designs utilize a-priori specified criteria to measure educational effectiveness, e.g., whether students learn what they were supposed to learn. Comparison-based designs can potentially be applied to evaluating and validating adaptive sequencing of learning material; adaptive story generation, and non-invasive assessment and interventions. Three significant factors [50] to be included in our evaluation framework are:

a) Performance outcomes (e.g., time and efforts required for achieving educational objectives)
b) Attitude outcomes (e.g., attitude towards the learning environment/media; motivation and interest)
c) Programmatic outcomes (e.g., is there a return on investment? Does the learning environment reach its target audience?)

Therefore, while there is a large body of existing methods and research for the evaluation of software, as well as conventional educational technology and learning media, this knowledge cannot be transformed one-to-one to the genre of IDEGs (e.g., [6]. The investigation of the adaptive features in a narrative learning environment with a large degree of freedom challenges the existing evaluation and validation methods. Moreover, aspects of motivation, audio-visual preferences, personality, or individual ability and their interactions with game design, learning design, usability, or narrative are a complex and novel field of research.

The ambition of 80Days is to fill the gaps thus identified and develop a reference framework for the in-depth evaluation of IDEGs at design time (accompanying the design and development stages) and at run time (evaluating interim and final versions of games).

5 Conclusion and Future Outlook

Exploiting up-to-date 3D computer games for educational purposes is a dawning technology but still in its fledgling stage. It is one of the challenges of 80Days, which also aims at augmenting and integrating the related theoretical frameworks in cognitive psychology. Exploiting the desirable features of digital games, to design and develop effective learning tools, entails the well-orchestrated efforts of a highly interdisciplinary team to tackle the three major challenges addressed above.

In contrast to existing approaches, which separate learner, domain and adaptation models, our framework is based on a holistic understanding and a formal ontological representation of interacting processes involved in active and dynamic learning processes. The measurements include performance outcomes (e.g., time and efforts required for achieving educational objectives), attitude outcomes (e.g., attitude towards the learning environment/media; motivation and interest, and Programmatic outcomes (e.g., is there a return on investment? Does the learning environment reach its target audience?).

The range of applications for this technology is not limited to a specific age group, it also provides a special opportunity to use the educational games to familiarize the elderly, who lack previous exposure to technology, to modern live saving communication technology.

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