Adaptive Serious Game Development

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***Abstract*—Learning is a process that is associated with a lot of effort and perseverance. In learning theories, motivation can be observed as a key factor. In some cases learning can become playing if the learning experience is so intrinsically satisfying and rewarding that external pressures or rewards for learning are of secondary importance. Serious games are able to increase motivation for learning by realizing diverse approaches which can address cognitive as well as affective learning. By using a variety of elements such as visual environments, story-lines, challenges, and interactions with non-player characters, serious games can be optimal learning environments. Even though, they have such motivational power, several studies have shown that there are no known forms of education as effective as a professional human tutor. This paper explores the interaction of human tutors with learners in a serious games with the focus on 'Social Development Theory'. It will present results that show how human tutors observe players in executing learning tasks, and interacting with the game environment in serious games. Based on the results of this studies we provide a definition of adaptivity for serious games.**

***Keywords*-serious games; adaptivity; game development;**

I. Introduction

Serious games can engage the learner in a way most traditional teaching methods cannot. They provide a platform where the two points – motivation and interactive learning – can be perfectly put together. This work describes studies that explore the effects of human tutors in serious games.

Observations by developing serious games showed that without help, children require more time to learn how to play the game than adults, while both groups could reach the same time with help. [1] Learning theories like 'Vygotsky's Social Development Theory (SDT)' [2], 'Piaget's Stages of Cognitive Development' [3], and 'Erikson's Developmental Stages' [4] explain this phenomenon based on the *social* context of learners during the learning process. The reason why learners learn with human tutors better than with other tools is the higher adaptability to the learner. [5]–[8] The problem is that serious games of the current state of the art do not adapt to the learner. and there is no approach that adapts the game environment based on learning content. [9] A major goal in modern serious games research is making the game adapt to the learner and provide the missing link in order to achieve higher individuality. [1], [9] The aim of this paper is therefore, exploring ways of applications of adaptivity to serious games, and building a foundation for software frameworks for adaptivity in serious games.

The contribution of this paper is twofold. First we provide two studies, that explore the role of human tutors in serious games. Secondly we provide a definition for adaptivity for serious games, that considers different aspects of the role of human tutors in serious games.

II. Exploratory Studies

Learning theories attempt to explain how learners learn. In constructivistic theories, learners learn by constructing knowledge and by interacting with other humans, where learning is an active and constructive process. They actively construct or create their own representations of reality. [10]

One of the most important and influential theories of the social aspects of learning is provided by Vygotsky. [2] Vygotsky defines the maximum level for the challenge of one specific content/topic and for each individual as the upper limit of the Zone of Proximal Development (ZPD) [11]. The lower limit of the ZPD is the minimum level that can be learned by each individual without help. ZPD is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance. [2]

Applying SDT to serious games requires finding out what tutors can observe when watching and/or learning with the learner using a serious game. Additionally we need to understand how observations are used by tutors in order to characterize learners. When a human tutor observes and consequently provides help to the learner, he can identify the learner's skills. In order to transfer this method to serious games, we need to find out how tutors carry out this task in a serious game. Therefore we focus on answering the following question: *What can be observed when a learner plays a serious game and how can this information be used to characterize the individual learner?*

A. Study 1: How to Characterize Players in Serious Games?

In an exploratory study based on qualitative research methods we first carried out interviews with experts (educators, psychologists, professional game developers, serious game researchers, students and players). Second we iteratively worked together with those experts to develop a serious game that helped us to gain observational data and enabled the experts to optimize their answers. Third we

used this serious game to observe children while playing and passed the observed data to experts. Finally, we carried out retrospective interviews with the experts based on the given case study. We iterated the steps described in the Figure 1 for four serious game independently.

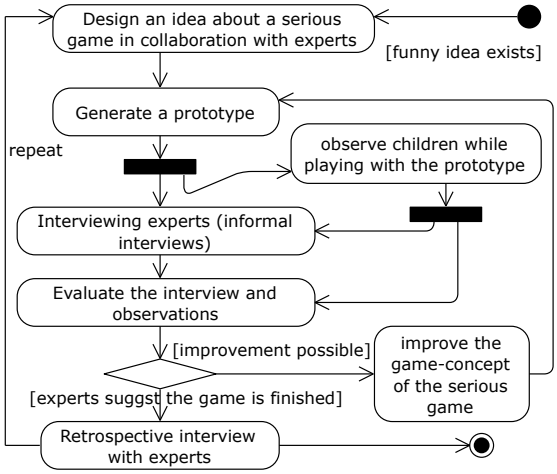


Figure 1: Study Overview (UML Activity Diagram)

The goal of this study is to provide a detailed description of data that can be observed in a concrete serious game for children with one specific topic and a detailed description of how experts characterize the child in the given example.

B. Study 2: How to Provide Help in Serious Games?

The next step when trying to simulate the tutor in a serious game is defining what needs to be changed in a serious game in order to make it adaptable. The research question that needs to be answered is: *What changes need to be applied to a serious game (while playing) in order to change the difficulty of the tasks based on the model in Figure 3?*

The goal of this study is to find the possibilities for changes in learning content and game elements. Additionally, we need to find the relation between the skills for learning content and motorical skills. To answer this question, we used the four serious games we designed in order to explore possible changes in the game together with experts. We interviewed experts and observed children. Our assumption was that the changes in the game would include both: adaptivity of the game environment, and adaptivity of learning content. We explicitly asked question to experts where we did not make any distinction between learning content and game elements for providing help. In the next step we focused on finding different difficulties that experts considered reasonable.

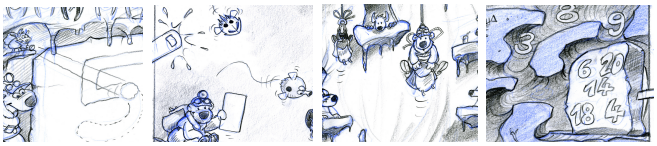
C. Results

In the described studies we developed four serious games (see Figure 2). All games are designed for teaching math to preschool and first grade children. We identified game elements, learning content and skills necessary for the content of each serious game as presented in Table I.

Table I: Game elements and learning content identified in the study

Serious games	*SG1*	*SG2*	*SG3*	*SG4*
Learning goals	C, W, R	C, R	A, S	A
Game elements	3	7	9	4
Skills for learning content	3	2	4	4
Skills for non-learning content	1	2	1	1

C=count, W=write numbers, R=recognize numbers, A=addition, S=subtraction



(a) SG1 (b) SG2 (c) SG3 (d) SG4

Figure 2: Serious games, used in the study. Games for preschool children. (Illustrated by [12])

We used the Knowledge Space Theory (KST) [13] for the description of the learning content and as a mathematical model for characterizing learners based on their skills. [14] We extended the concept of KST as described in [15] to design the model for the content of adaptive serious games as presented in Figure 3. This model is able to define skills and relations between skills.

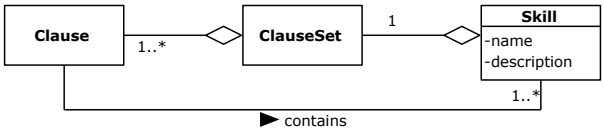


Figure 3: KST-based Domain Metamodel for Characterizing Learners based on Skills (UML Class Diagram)

Our results show that tutors first need to recognize an assessment situation and then if the learner is able to solve a task in this situation. Therefore, the tutor needs to understand tasks and be able to solve them. All tasks need to be associated with skills that would group the tasks in specific sets. After several iterations, we found different reasonable task sets groupings as shown in Table II. This grouping needs to reflect the skills identified in Table I. The difference in the amount of skills and task sets is based on the grouping of the tasks related to addition and subtraction.

Based on the given observations and data in the Tables I and II, we found that a tutor would observe the correct and incorrect solutions of the tasks. Based on the amount of correct and incorrect solutions, the tutor is able to rate a skill related to the given task set. Additionally, we found that the correct and incorrect execution is not always a binary

Table II: Domain specific tasks identified in the study.

Task-sets	*SG1*	*SG2*	*SG3*	*SG4*
1	W 1,2,3	C	A with $c < 10$	A with $c < 10$
2	W 4,5,7	R	A with $c \leq 20$	A with $c \leq 15$ ◎
3	W,C < 9		A, S: $a \pm b = c$ ⊞	A with $c \leq 20$ ◎
4				A with $c \leq 20$

C=count, W=write numbers, R=recognize numbers, A=addition, S=subtraction

A: $a + b = c$

◎: addition $a_1 + a_2 + ... + a_n = c$ with $c \leq 15$ and in some situations $\forall a_i, a_j, a_k$ with $i < j < k$ if $c = 10$ then $(a_i + ... + a_j) < 10 \wedge a_k < 10$ and if $c > 10$ then $(a_i + ... + a_j) \geq 10 \vee a_k \geq 10$

⊞: $c \leq \pm 20$ and $a > 9$ or $b > 9$

decision. In some of the games, the incorrect execution of the task was related to the difficulty of the game elements. Therefore the tutors were observing the intention of the learner while trying to solve the task. We conclude that the assessment situation produces results that can be correct but unsuccessful. On the other hand, an incorrect result can be successful by coincidence.

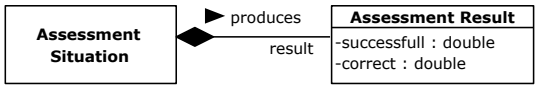


Figure 4: Assessment result model (UML Class Diagram)

We additionally found that we need to relate some of the game elements to skills that are affected if the behavior of the game element is changed. We call these game elements "adaptable properties".

Table III: Adaptable properties in the serious games

Serious games	*SG1*	*SG2*	*SG3*	*SG4*
# Adaptable properties	2	4	4	1
# Adapt. properties related to learning content	2	2	2	0

Results provided us with data for each serious game concerning the difficulty of the learning content and game elements. An important conclusions we draw here is that the game elements in the form of adaptable properties can be used to increase or decrease difficulty and that they affect some skills when the difficulty is changed. This can be used to make the same task more difficult for experienced players.

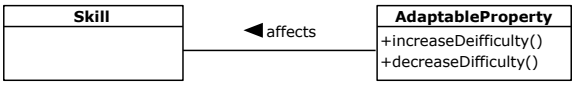


Figure 5: Adaptable properties (UML Class Diagram)

D. Threats to Validity

The discussion of validity is based on the "Qualitative Validity" criteria described in [16]. We spent sufficient time (2 years) on developing the four serious games. During these two years we observed and interviewed iteratively participants from different domains like developers, game designers, players, learners, tutors, psychologists, and pedagogues. We also worked together with developers, other professionals, and researchers.

We worked with developers that came from different contexts and cultures. We also used a variety of development techniques/processes for different iterations and different games. We worked on the same questions at different points of time with the same developers. Additionally, a different researcher worked on analyzing the data. We also examined different cases where the adaptivity method would contradict our assumptions and results. In one of these cases, for example, we developed a prototype that was adapting too fast to the player's answering speed.

We conducted post-project interviews using retrospective interviewing methods to let participants reflect on the findings. Transferability is described by [16] as a way of achieving a type of external validity. According to our description, this study can be transferred to any learning domain and any solution platform. External audits were conducted to foster the accuracy or validity of the study. We let researchers and developers not involved in the research process examine both the process of the study and the results of the interviews and resulting games.

It may be intuitively clear that a replication of the study, could reproduce our results. But learning with serious games may differ for different domains. We are confident that our results are applicable to a wide variety of domains.

III. Towards the Definition of Adaptivity

In the context of serious games based on the technology that is available today we can base the adaptivity definitions without restrictions on the SDT theory. We define adaptivity in the following way:

> Adaptivity *in serious games is an approach that enables a serious game to* (A) *learn from learner's behavior by* $(A1)$ *intelligently monitoring and* $(A2)$ *interpreting learner's actions in the game's world and* (B) *to intervene in the game by* $(B1)$ *automatically adjusting the learning content and* $(B2)$ *the game elements according to* (C) *the student's individual ZPD as necessary and using the principles of* (D) *MKO, where* Adaptivity^I *is a MKO for the learner according to the SDT.*

According to this definition, the adaptivity process in a serious game consists of four stages: Monitoring players $(A1)$, learner characterization $(A2)$, assessment generation $(B1)$, and adaptive intervention $(B2)$.

We note here that Adaptivity describes in this definition the three factors A, B, C, and D.

Factor (A): an adaptive serious game monitors the learner. All observations are used for the collection of user data

and for characterizing the user (e.g. rating his mathematical skills).

Factor (B): the adaptive serious game adapts both, game elements and learning content. Some of the game elements affect the ability to solve tasks related to learning content (e.g. the speed of a car that moves fast over the screen, where something is written on the car, and where the goal of the learner is to interpret the content). We focus on B in this work according to our findings in the studies as described previously in this chapter.

Factor (C): the adaptive serious game always individually challenges each learner.

Factor (D): the adaptive serious game takes the role of the MKO in the SDT, where the statement can be applied: Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level. The social level can be an interaction with the serious game or with peers in the serious game.

This definition describes an abstract and optimal way of an adaptive serious game. In order to be able to understand the definition based on existing research in this direction, we here provide a method of how ADAPTIVITY can be restricted based on other approaches. Using our definition of ADAPTIVITY we can define adaptive serious games as follows: An adaptive serious game is a serious game that implements the ADAPTIVITY approach with restrictions in some of the factors.

IV. SUMMARY AND CONCLUSION

We focused on answering the question how the serious game itself can be adaptive, based on these learning theories that already exist. When we researched 'the observations of learners by tutors' in the first study, we found that for characterizing the learner, human tutors observe game environments. By observing elements we include 'game elements' in the learning content of a serious game. Therefore we argue that the 'adaptive' serious game should be able to observe both, game elements and learning content.

We observed that tutors intend to change the game element properties (in addition to changing the difficulty of the learning content) when help is necessary for a learner. We found that some of the game elements, the so called adaptable elements, 'should be' adaptive and others 'shouldn't'. We also found that the adaptable elements directly influence the learners' ability to solve tasks related to learning content.

Based on this study we argue that adaptivity should include the observation of the user's actions in the serious game and the adaptation of both, game elements and learning content. We finally gave a definition of adaptivity for serious games that considers three aspects: (1) Learning theories, (2) all aspects of serious games including 'game elements', and (3) existing e-Learning approaches.

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