# Undercover: Non-Invasive, Adaptive Interventions in Educational Games

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**Abstract.** Computer games are extremely successful and popular – and the potential of using this medium for educational purposes is increasingly recognised and researched. To keep the engaging character of a computer game, an educational game needs to appropriately contextualise learning activities in the game and its narrative in order to retain flow and engagement of the gaming experience. The realisation of good educational games furthermore requires that such new learning technologies are appropriate for all students and ensure learning opportunities with individually appropriate levels of challenge, which calls for adaptation mechanisms to learners' abilities and motivation. In the present paper we present adaptation mechanisms that are strongly embedded into an educational game. Personalisation of learning and gaming experiences is realised in a two-fold manner, targeting a learner's competence as well as motivational state. The described non-invasive, adaptive interventions are researched, implemented, and evaluated in the context of the European research project 80Days.

## 1 Introduction

Information technology is an integral part of today's life and kids are nowadays familiar with the whole range of toys and tools of the digital age – computers, video games, internet, cell phones etc. Consequently, these children are – as characterised by Marc Prensky – no longer digital immigrants but rather digital natives [1]. This necessarily has also consequences for education; students of today are disengaged with traditional instruction – they are no longer the kind of students our educational system was designed for [2]. As a result, the application of computer technology for learning is growing. Aside from the development of general e-learning environments and computer-based trainings and courses, since the 1990s research has been increasingly dedicated to the use of computer games for learning and since then a widespread public interest has grown in using games as learning tools. On the one hand, this is inspired by the fact that playing is the most natural form of learning. On the other hand, the great interest in digital game-based learning is due to the

popularity of computer games – digital games constitutes a multi billion industry per year and kids spend a considerable portion of their life- and free time in playing these games.

The design of good computer games for learning, however, constitutes a challenge. Not every educational game is necessarily good for learning – and not necessarily for all learners. The implementation of a successful and effective educational game needs to take care for an attractive and competitive game design while at the same time realising an appropriate learning design – both design aspects need to accompany and complement each other. The quality of an educational game can in general be maximised by having the game play done by game designers and the design of learning done by teachers [2].

One of the main reasons why games are assumed to be effective for learning is their engaging character. Games are able to induce what Csikszentmihalyi calls 'flow' [3] – a positively perceived experience and state of full immersion in an activity that typically goes along with a loss of sense of time. A successful educational game therefore needs to ensure to keep and promote this 'optimal experience' of flow. Anything that disrupts this experience and causes the player to 'leave' the current game situation should be avoided [2]. Because of that, conventional educational measures and activities as applied in classroom and 'traditional' e-learning environments, like intermediate explicit knowledge assessments, are not suitable in the context of educational games. Any time the player is forced to stop the game itself to do something else, flow is interrupted and thus, engagement, immersion, and motivation are compromised. As a consequence, the 'additional' activities that are due to the instructional character of an educational game need to be strongly embedded in the game such that the disruption of flow is minimised. This aspect of embedding instruction into the game experience and narrative is a crucial factor for realising good educational games and can be related to the educational conception of situated learning or cognition [4, 5]. Learning takes place in a situated context – learning events are embedded and contextualised in a meaningful situation of the game. The knowledge elements and skills targeted are relevant in the game context and are at the same time applied and practiced directly related to this environment [2, 6].

Another important aspect for effective game-based learning is the level of challenge an educational game imposes on the learner. An educational game needs to feature an appropriate difficulty level for the individual learner [2]. A game that is too easy or too difficult is not engaging for the player. Rather, an educational game should address the current capability of the learner by providing an appropriate level of challenge without exceeding his/her capacity to succeed and, in this way, retains motivation and engagement. Referring to Piaget's theory of cognitive development, Van Eck [2] aptly describes "games thrive as teaching tools when they create a continuous cycle of cognitive disequilibrium and resolution … while also allowing the player to be successful" (p. 20). As individual learners may largely differ with respect to their level of competence as well as their motivational constitution, effective game-based learning should make use of adaptation mechanisms that are able to personalise the learning experience to the individual learner. To this end, a game needs continuous input from the learner and to provide appropriate feedback

and interventions. Due to the previously outlined claim for embedded and situated educational activities in the game, conventional adaptation technologies [7, 8] can sometimes hardly be directly adopted to the field of educational games.

In the present paper we describe adaptation mechanisms and principles for educational games, which implement personalised learning experiences that are embedded into the game situation. They ground on the non-invasive and continuous assessment of the learner's current competence and motivational state. By the use of adaptive interventions tailored to the information coming from this assessment a learner can be supported and guided in the game and motivation can be retained. In the following sections first the assessment procedures are briefly described. Subsequently, a detailed description of intervention types suitable for adaptation at the micro level of an educational game is provided. The 80Days project is presented, where the described research is implemented into an educational game teaching geography. We conclude with a short wrap up of the outlined work and future directions.

## 2 Non-Invasive Assessment

The basis of a non-invasive, continuous assessment of learning progress and motivational states is to monitor and interpret the learner's actions in the game. The respective assessment procedures ground on well-founded and elaborated psycho-pedagogical theoretical frameworks.

For knowledge and competence assessment the formal framework of Competence-based Knowledge Space Theory (CbKST) [9, 10] is utilised. Originating from conventional adaptive and personalised tutoring, this set-theoretic framework allows assumptions about the structure of skills in terms of underlying cognitive constructs of a knowledge domain and to link these latent skills with observable behaviour. Hereby, the entities (i.e. skills) of a knowledge domain are structured by the use of a well-defined relationship, the so-called prerequisite relation. The collection of subsets of skill corresponding to this prerequisite relation makes up the so called competence structure and characterises meaningful learning paths. Combining the competence structure with the problems or tasks of a learning situation the relation to observable behaviour can be established, such that from a learner's observable behaviour or actions inferences on his/her available and lacking skills can be made. While on principle, the CbKST framework builds the basis for an effective adaptive skill assessment that is carried out in form of explicit testing procedures [11], in a game context this assessment needs to be realised on a non-invasive micro-level, in a problem solving situation that is embedded into the game context and narrative [12]. A simple example for such a task in the context of an educational game may be to fly with a space ship to a certain city and to take a picture. The learning objective of this task might be (among others) to learn about the location of the city on the map. In this situation there are various manipulable objects, for example the space ship. The learner can perform certain actions to achieve the goal, in this example primarily

changing the directions while flying or controlling speed and altitude. The aim of micro level assessment is in the first instance to assign a problem solution state from the problem space to each action (e.g., pressing an arrow key). This mapping is done by classifying actions according to a set of rules. An example for such rule might be 'the distance between space ship and target location is increasing'. The second aim is to assign a set of available and a set of lacking skills to each problem solution state; for example, flying in the right direction indicates that the learner knows the wind direction towards the city. Of course, a single observation is not very convincing. Thus, CbKST provides a probabilistic approach to assessment. We have a probability distribution over all possible competence states and with each action we update the probabilities of those states that include the relevant skills and we decrease those states that include the lacking skills. At the end of this procedure stands a more or less well-founded assumption about the skills the learners have, the skills they don't have, and their position in the problem solving process.

The non-invasive assessment of the learner's motivational state is grounded on an advanced model of motivation for educational games (see Fig. 1, [13]) that fuses several established theoretical approaches to motivation and learning [3, 14, 15, 16]. Similar to the non-invasive skill assessment sketched above, we can assign specific motivational assumptions to specific classes of actions. Certain behaviour patterns and characteristics, like e.g. mouse movements, time measurements, help demands etc., can be utilised as indicators for certain aspects of a learner's motivational state. If, for instance, the mouse movements of a learner are random, this can be interpreted as a lack of attention, and if hints are demanded frequently this can under certain conditions be a sign for a lack of confidence.

The continuously gathered and updated assumptions on the skills and motivational state throughout the game serve the provision of adaptive interventions tailored to the learner's current needs.

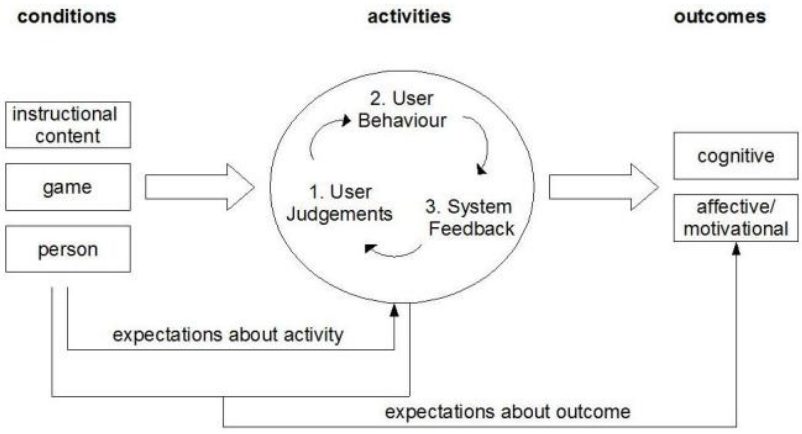


**Fig. 1.** Advanced model of motivation for educational games.

## 3 Adaptive Interventions

Depending on the information stemming from the non-invasive assessment, from a menu of adaptation types a system feedback in terms of an intervention in the game can be triggered (e.g. hints or suggestions through a non-player character, modification of display or interface) that is individually appropriate for the respective learner and situation. All types of adaptive interventions have in common that they aim at supporting a beneficial game-based learning experience. In general, the two broad categories of cognitive and motivational interventions can be distinguished, aligned with the two perspectives of non-invasive assessment.

### 3.1 Cognitive Interventions

Interventions of this type strive to enhance cognitive abilities and to support the learner adaptively according to his/her task behaviour and underlying available or lacking skills. Consequently, these interventions target the learning objectives defined in terms of skills and foster their successful acquisition in terms of prompting reflection or assisting the learner. The cognitive interventions and their selection rules are defined based on cognitive and psycho-pedagogical theories and considerations – they relate among others to the paradigm of self-regulated learning [17] and the importance of reflection on the task and oneself for effective learning, to the CbKST framework and the derivation of meaningful learning paths based on its evolving competence learning structures [10], as well as to theoretically founded principles for the design of informative tutoring feedback [18]. The following cognitive intervention types can been distinguished, whereby the line between the different types is partly somewhat blurred:

- **Meta-cognitive interventions** are supposed to provoke learners' reflection about their own abilities, thinking processes, solution behaviour, or confidence and may consist in metacognitive questions or tasks and certainty questions (e.g. 'Does this solution make sense?', 'How sure are you about this?').
- **Competence activation interventions** are applied if a learner becomes stuck in a certain task while foregoing assessment results led to the assumption that the learner possesses the necessary skills. By the use of an appropriate intervention (e.g. 'We have come across this issue already before.') the temporarily 'inactive' skills are assumed to be stimulated and reactivated.
- **Competence acquisition interventions** are selected when the system concludes that a learner lacks certain skills and thus, provide the required information – for example through a non-player character.
- **Problem solving support** is provided in the context of an ongoing problem solving process and provides hints and indications for possible next problem solution steps in order to decrease the distance between the present solution state and the target state.

- **Dissolving interventions** are a further form to present specific information to the learner. The purpose of this intervention type is to provide the solution of a problem/task if the learner was not able to show the required answer behaviour within a reasonable number of actions. Such interventions, ultimately, shall assure that the game can continue and thus the gaming and flow experience are kept going.

- **Progress feedback** is made up by interventions that provide the learner with information about the learning progress or the game – e.g. through a non-player character or different scoring mechanisms – and thus foster monitoring and reflection on one's own performance.

- **Cognitive assessment interventions** are a special form of intervention that is applied if the non-invasive assessment of skills led to unclear or ambiguous results after a certain number of actions. In order to gather additional information and improve the assessment this type of intervention is triggered. Typically this is realised by providing the learner with explicit questions or problems. As these interventions are strongly embedded into the game context and narrative, they differ significantly from conventional and possibly disrupting pop-up assessments known from 'traditional' e-learning. Assessment interventions may be realised by interactive dialogues with different answer options, which may not only refer to correct and incorrect responses but may also have a storytelling function and lead to different story strands depending on the learner's choice.

### 3.2 Motivational Interventions

Motivational interventions are supposed to enhance and retain the learner's motivation and engagement on a high level or to intervene when the system detects that the motivational state or certain aspects of it decrease. The differentiation of motivational intervention types is inspired and their selection rules are defined based on psycho-pedagogical theories on motivation and motivational design, such as the expanded model of motivation to learn [16], attribution theory [19] and the concept of self-efficacy [20], and Keller's ARCS model [14]. The following intervention types are distinguished:

- **Praising interventions** are used for congratulation in case of success.

- **Encouraging interventions** are applied especially in case of failure in order to promote further trials.

- **Attributional interventions** go further than the previously mentioned interventions – they aim at fostering self-worth enhancing attributional styles for success and failure and are applied in case of lacking confidence or dysfunctional attributional styles. This is realised by a motivational training based on attribution

theory [19, 21] – in form of feedback that directs attribution of success to internal factors (i.e. effort and ability) and attribution of failure to variable components (i.e. lack of effort and bad luck).

- **Incitation interventions** in general announce pleasing outcomes like rewards in order to foster motivation to carry on in the game or to proceed in a problem solving situation.

- **Affective interventions** address emotional-affective aspects of the game experience and social interaction with other game characters and are supposed to foster a positive affect.

- **Attention-catchers** are interventions that are applied if the system detects decreasing or lacking attention through the interpretation of the learner's actions. Such interventions constitute unexpected changes or incidents and in this way increase variability and further appeal of the game.

- **Motivational assessment interventions** are similar to their cognitive counterparts. They are utilised in case of inconclusive or contradicting inferences on the learner's motivational state based on the non-invasive assessment. For gathering further indications on the learner's current motivation assessment interventions realise an explicit questioning, usually in form of an interactive dialogue with a non-player character and with the answer options relating to certain aspects and states of motivation.

## 4 Putting it into Practice: 80Days

The research, elaboration, and technical implementation of non-invasive assessment of learners' competence and motivation, as well as of adaptive interventions and adaptation principles in the context of educational games are addressed in the 80Days project (www.eightydays.eu). 80Days is a European research project aiming at advancing psycho-pedagogical and technological foundations for successful digital educational games through the development of a higher-level theoretical framework for adaptive educational technology. This shall allow an adaptation of a game's story and features to individual learners' abilities, engagement, and preferences.

Inspired by Jule Verne's novel 'Around the world in eighty days' an educational game is implemented that constitutes a modern version of a journey around the world – in a UFO with an alien travel companion (see Fig. 2). From an educational perspective, the game's main objective is to teach geography skills. From a storytelling perspective, the main task for the player is to explore the planet and collect information for an intergalactic travel guide. From the game play perspective, the main goal is to navigate the UFO to different destinations around the world and to accomplish a variety of adventurous missions.

The game incorporates adaptation to the individual learner through continuous, non-invasive assessment procedures and the realisation of interventions matching the learner's current level of knowledge and retaining motivation. All interventions of the game require manifestation in form of game assets. A main issue is the translation of the general, theory-based selection rules for interventions into associated triggers within the game context, such that appropriate interventions are provided in an appropriate extent and appropriate point in time. This is a challenge especially as the repeated and/or inadequate provision of interventions and misinterpretation of situations and actions can be counterproductive and do considerable harm to motivation, engagement, and flow. The realisation of repeated design and development cycles of successive demonstrator game releases and aligned evaluation cycles allow the continuous elaboration and refinement of the underlying adaptation mechanisms.

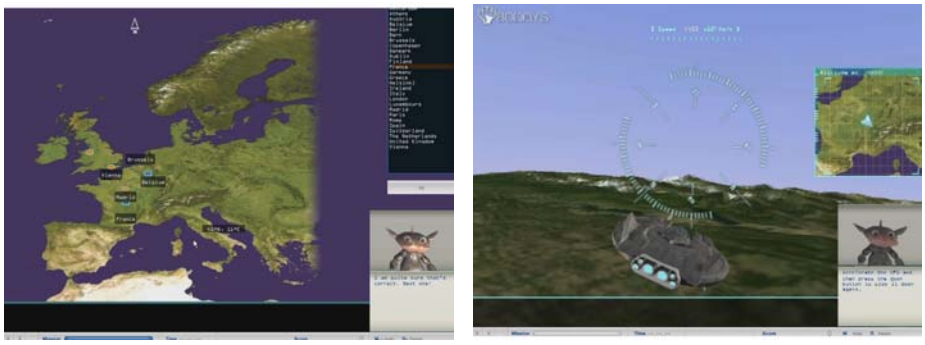

**Fig. 2.** Screenshots of the 80Days demonstrator game.

## 5 Conclusion and Outlook

Computer games are tremendously successful and popular and in recent decades an increasingly widespread public interest has evolved in using this very technology for educational purposes. Games' potential of being effective learning tools is appreciated because of their engaging character and their active and dynamic nature. The main challenge of realising successful educational games is to intertwine an attractive game design with a sound didactic design that realises learning embedded in the game's situations and context – instead of having playing interrupted by learning activities, which would compromise flow and engagement considerably. Another critical issue is an appropriate level of challenge that should be imposed to the learner in order to realise an engaging gaming and learning experience. To suit different learners an educational game therefore should continuously adapt to an individual learner's knowledge and motivation. To come up to this necessity common adaptation technologies as used in conventional educational systems are generally not sufficient and/or suitable; rather, assessment procedures and adaptive interventions

are needed that are strongly integrated into the game – in order to enable learning in a situated context, as mentioned above.

In the present paper we have presented adaptive interventions that are suitable for personalisation and learning embedded in an educational game. The purpose of these adaptive interventions is two-fold, on the one hand addressing the learning aspect and on the other hand addressing motivation. For each of these two categories different intervention types and according selection rules can be defined based on cognitive and psycho-pedagogical theories and considerations. The adaptive interventions ground on assumptions on the currently available skills and motivational state of a learner based on a continuous, non-invasive assessment and interpretation of the learner's actions in the game. A precondition for realising successful interventions is therefore a successful assessment process yielding valid assumptions on the learner's characteristics on which the interventions are relying. This calls for valid skill structures and skill assignments to tasks, for appropriate indicators of motivational aspects, as well as for the proper interpretation of learner actions. The probabilistic assessment of skills is not perfect, thus it is sometimes reasonable to strengthen the conclusions drawn by more explicit information like cognitive assessment interventions. In case of the assessment of motivational aspects especially the selection and operationalisation of suitable indicators is demanding and complicated. The frequent use of help functions, for example, might be interpreted as a lack of confidence, but may also result from help abuse and so-called 'gaming the system'. Therefore, it is necessary to carefully define the indicators and rules for drawing assumptions on the motivational state. Often the triangulation of different indicator variables will be advisable.

The outlined mechanisms of adaptation are researched and implemented in the course of the 80Days project, which aims in advancing intelligent and competitive educational games on a European level. In the context of this project and its predecessor ELEKTRA (www.elektra-project.org) empirical investigations have been initiated in order to investigate the empirical effectiveness of adaptive features in assessment and interventions. Early analyses revealed that adaptation results in better learning performance and superior game experience than it was the case in non-adaptive control groups [22]. Future research needs to address in detail the different intervention types and whether they yield the expected benefits. In addition, the considerations on motivational assessment and adaptation and the underlying advanced model of motivation in educational games need to be further investigated. The in-depth empirical evaluation of the 80Days demonstrator games will serve further refinements of the theoretical framework for the adaptation mechanisms and improvement of the game and didactic design.

The focus of our work so far was on elaborating suitable methods for providing learners with tailored psycho-pedagogical guidance and support that is strongly embedded in the game – thus realising learning in a situated gaming context, with an appropriate level of challenge, and minimising interruption of flow. A future direction of your research will be to enter also the level of collaborative learning and to apply the principles of non-invasive, adaptive interventions on the group level. To this end, the principles for personalisation and adaptation developed and implemented for individual learners need to be further advanced to take care for the specificities of

collaborative learning. This needs to take into account and synthesise state of the art on computer supported collaborative learning (e.g. [23]), (massively) multiplayer games (e.g. [24]), group adaptation (e.g. [25]), as well as psychological theories of groups and group learning (e.g. [26, 27]).

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