An Analysis of the Educational Potential of Augmented Reality Games for Learning

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ABSTRACT

This paper presents a review of practical research papers on augmented reality games for learning. The study evaluates how these games may impact motivation (affective learning outcomes) and knowledge gain (cognitive learning outcomes). For the analysis, we use game design patterns for mobile games and Bloom's taxonomy of educational objectives. Our study results substantiate the generally assumed motivational potential of augmented reality games. Also, they indicate that augmented reality games may have the potential to bring about cognitive learning outcomes.

Author Keywords

augmented reality games, mobile learning, mobile games, game design patterns, learning outcomes

INTRODUCTION

Taken into consideration the younger generation's habits of using media, e.g. their affinity for digital games and mobile handheld technologies, traditional education has long lived a life of its own. For the last several years however, the interest of teachers and educational scientists in innovative technology for learning and teaching has grown. They have recognised the educational potential these technologies provide, i.e. setting up challenging and engaging scenarios that enable new forms of teaching and learning (Carstens and Beck, 2010; Johnson et al., 2011; Klopfer et al., 2011; Squire, 2010). Game studies and mobile technologies have thus become a fast-growing field of research. Most of the projects still centre on technological aspects though. In order to determine the factors, mechanisms and design elements that make the use of novel learning scenarios successful and transferrable, it is necessary to explore how these technologies can be used for teaching and learning (Dunleavy et al., 2009; Huizenga et al., 2009; Klopfer, 2008).

The objective of this paper is therefore to scrutinize the learning effects of augmented reality (AR) games for learning and to understand the specific mechanisms that have led to these effects. The results could provide valuable insight into the working mechanisms of AR learning games that may positively influence future design decisions.

AUGMENTED REALITY

Augmented Reality and game based learning is commonly expected to gain widespread usage (Johnson et al., 2011) and for the last couple of years, AR games have increasingly been subject to practical studies (Botella et al., 2011; Fotouhi-Ghazvini et al., 2009; Specht et al., 2011; Wetzel et al., 2008). AR can be defined as 'a system that enhances a person's primary senses (vision, aural, and tactile) with virtual or naturally invisible information made visible by digital means' (Specht et al., 2011, p. 117). It has been considered significant tool for education (Johnson et al., 2011) with the potential to shape 'participants' learning styles, strengths, and preferences in new ways beyond what using sophisticated computers and telecommunications has generated' (Dunleavy et al., 2009, p.8). Integrating AR technology into mobile games can give educators powerful new ways to show relationships and connections (Yuen et al., 2011) and 'can increase learning by immersion as well as provide a richer learning experience' (Liu and Chu, 2010, p. 633).

AR games extend wireless games towards being more bound up with real locations and activities. They take advantage of the real-world context (Fotouhi-Ghazvini et al., 2009) and provide the realization of the probability of immersive learning (Liu and Chu, 2010). 'Real world games that are augmented with computing functionality and supported by the combination of real and virtual game elements create new and exciting gaming experiences for highly motivated learning' (Winkler et al., 2008).

The game concept is being used with a wide range of technology. It spans mobile handheld-based systems running on a PDA or a smart phone as well as AR systems comprising a backpacked laptop and a head-mounted display to augment reality (Wetzel et al., 2008; Yuen et al., 2011). By now, supplementary core technologies, such as Global Positioning System (GPS), portable displays, Radio Frequency Identification (RFID) reader or augmented devices such as the smart phone's Bluetooth, Infrared or camera, are an integral part of almost any up-to-date mobile device. Thus, and because of the 'increasing pervasiveness of smart phones, AR is set to become a ubiquitous commodity for leisure and mobile learning' (Specht et al., 2011, p. 117).

DESIGN PATTERNS FOR MOBILE GAMES

Traditionally, games are categorized according to game genres, i.e. adventure games, role-playing games, strategy games or simulations (cf. Prensky, 2007). In the context of current game research, this categorization has proved to be of little use though (cf. Davidsson et al., 2004; Gros, 2007). Especially in the context of educational games the categorisation according to genres is not stable and rather difficult to apply. Efforts to find a more adequate structure and language to better understand the complex issue have resulted in the development and application of game design patterns (cf. Björk and Holopainen, 2004; Cook, 2010; Kelle et al., 2011; Kiili and Ketamo, 2007).

This paper is thus based on the pattern approach. It applies the Game Design Patterns for Mobile Games by Davidsson et al. (2004) to establish a framework for the analysis of augmented reality learning games. The approach by Davidsson is advancement to the work of Björk and Holopainen (2004), who established an initial set of more than 200 game design patterns for computer games. Each pattern is identified by a core definition, a general definition, example(s), descriptions of how to use the pattern (by listing related patterns or patterns that can be linked to it), the description of its consequences, relations with regard to instantiation (patterns causing each other's presence) and modulation (patterns influencing each other), as well as references.

The pattern *Physical Navigation,* for example, 'forces players of a mobile game to move or turn around in the physical world in order to successfully play the game' (Davidsson et al., 2004, p. 18). The AR game *Explore* (Costabile et al., 2008) for instance uses this pattern. It requires groups of students to walk around ruins trying to identify the place the mission refers to. Also, the AR game *Alien Contact!* (Dunleavy et al., 2009) uses this pattern. Players have to move around their school playground or sports field to find digital objects and to complete tasks. The pattern *Physical Navigation* is instantiated by (caused by the use of), e.g., the pattern *Player-Player Proximity, Player-Artefact Proximity, Player-Location Proximity* and *Artefact-Artefact Proximity.* The pattern *Player-Location Proximity* in turn is defined by the distance between the player and a certain physical location, which can affect game play and trigger an event. *Alien Contact!* makes use of this pattern, too. 'When students come within approximately 30 feet of these digital artefacts, the AR and GPS software triggers video, audio, and text files, which provide narrative, navigation and collaboration cues as well as academic challenges' (Dunleavy et al., 2009, p. 10).

LEARNING BY PLAYING

We classified the effects, which we extricated from the review of practical papers according to learning outcomes. A learning outcome is the specification of what the successful learner is expected to be able to do at the end of the module/course unit or qualification (Adam, 2004). One of the main ideas of learning outcome orientation is to prepare students for the requirements of professional life (Vander Ark, 2002). Rather than defining the resources to be used during the learning process, outcome-oriented learning scenarios focus on the results of the educational process, e.g. the skills and content students are able to demonstrate.

To depict the various learning outcomes, we applied Bloom's taxonomy (1956), which sorts learning outcomes into three domains: *affective domain* (motivational learning outcomes), *cognitive domain* (knowledge learning outcomes) and *psychomotor domain (*manual/physical learning outcomes). According to Bloom, the affective domain encompasses attitudes and motivation. The cognitive domain deals with the recall or recognition of knowledge and the development of intellectual abilities and skills. The psychomotor domain encompasses manual or physical skills or the performance of actions. For the review we focused on motivational and knowledge learning outcomes. Learning outcomes that relate to manual or physical learning outcomes, e.g. exergames (Lucht et al., 2010; Yang and Foley, 2011) or console games we did not consider, as they have a different didactic approach.

For the cognitive domain, Bloom distinguishes six successive levels that can be fostered – Knowledge (e.g. observation and recall of information, knowledge of dates, events and places), Comprehension (understanding information, grasping meanings or ordering, grouping, inferring causes), Application (using learned material in new situations, putting ideas and concepts to work in solving problems), Analysis (breaking down information into its components, understanding organisational structure), Synthesis (putting parts together) and Evaluation (judging the value of material for a given purpose). This analysis aims at identifying which level of knowledge AR learning games may enable.

LITERATURE REVIEW

Our study evaluates well-documented AR games designed for teaching and learning (educational games or serious games). Patterns and learning outcome definitions provide the framework for our analysis. Due to the educational focus of our analysis, we excluded any study focusing at technology aspects, such as the study on 'The Eduventure' by Ferdinand et al. (2005) or the 'Museum Scrabble' by Yiannoutsou et al. (2009). We also excluded papers that state evaluation results on an unspecific level with regard to patterns, e.g. 'the use of mobile learning games contributes to the development of collaboration skills' (Sánchez and Olivares, 2011; p. 1950). The terms we used in the search included the following keywords: (ubiquitous, mixed reality, augmented reality) learning game, mobile educational game, mobile serious game, mobile game-based learning.

Results

In a first step, we scrutinized what augmented reality games impact motivation (affective learning outcomes) and what games impact knowledge gain (cognitive learning outcomes). We then went into detail, focusing on the patterns that were used in these games and analysed how they impact learning outcomes.

Affective Learning Outcomes

In the course of our review, we identified several patterns that positively influence motivation both in terms of fun as well as getting engaged with a learning environment or a certain topic, which for instance helps the learned material to penetrate into the long-term memory (Kittl and Petrovic, 2008). Table 1 lists these patterns, describes them and presents the effects. The pattern descriptions are taken from the list of patterns by Davidsson et al. (2004).

Pattern	Pattern Description	Affective Learning Outcome
Collaborative Actions	Two or more players being at the same location at the same time or attacking a target simultaneously.	Students are engaged in the game (Costabile et al., 2008; Dunleavy et al., 2009; Liu and Chu, 2010; Rosenbaum et al., 2006).
Cooperation	Players are forced to work together in order to progress in the game.	Students exchange and discuss game progress (Klopfer and Squire, 2008).
		Participants are driven by a good team spirit (Costabile et al., 2008).
Social Interaction	Players have the possibility to meet face to face.	Students are engaged in discussion (Klopfer and Squire, 2008).
Augmented Reality (AR)	Players' perception of the game world is created by augmenting their perception of the real world.	Students feel 'personally embodied' in the game. Their actions in the game are intrinsically motivated (Rosenbaum et al., 2006).
		Learners are attentive (Wijers et al., 2010).
		Students are mentally ready for learning (Schwabe and Göth, 2005).
Physical Navigation	Players have to move or turn around in the physical world in order to successfully play the game.	Students are highly motivated (Dunleavy et al., 2009).
		Participants are interested and moved (Schwabe and Göth, 2005).
		Students's are exited (Facer et al., 2004).
Agents	Entities controlled by the game system, e.g. to support narrative structure.	Students are motivated to deal with the learning material (Liu and Chu, 2010).

Table 1. Motivational effects of mobile game design patterns used within AR learning games.

The pattern *Roleplaying* is not part of the revised list by Davidsson et al. (2004). It is part of the original list of *Game Design Patterns* provided by Björk and Holopainen (2004). However, the pattern seems to be highly relevant for the design of AR learning games. We therefore included it in the study. Table 2 comprises the results.

Pattern	Pattern Description	Affective Learning Outcome
Roleplaying	Players have characters with at least somewhat fleshed out personalities. The play is centred on making decisions on how these characters would take actions in staged imaginary situations.	Learners are involved in the game (Facer et al., 2004).
		Students feel highly engaged and identify with their roles in the game (Facer et al., 2004, Costabile et al., 2008).
		Students merge with the game (Rosenbaum et al., 2006).
		Learners are tightly associated with their tasks in the game (Rosenbaum et al., 2006, Wijers et al., 2010).
		Students take on an identity and are eager to work together (Dunleavy et al., 2009)

Table 2. Motivational effects of the pattern Roleplaying used within AR learning games.

Mobile game-based learning approaches seem to be a viable way to go about the 'disengaged learner' for they provide the potential to engage learners with the material to be learned. The 'MobileGame' (Schwabe and Göth, 2005) for example helps students to get accustomed to a new university campus. By virtually attaching tasks to objects, it electronically supplements the traditional orientation rally with handheld devices. Based on a map, the rally leads students through a parcours with several tasks to carry out at certain spots. Its main concept is that of teams competing against each other while solving different tasks. Thus, the 'MobileGame' makes use of patterns such as Augmented Reality, Collaborative Actions, Common Experiences, Communication Channels, Cooperation, Extra-Game Information, Physical Navigation, Player-Location Proximity, Predefined Goals, Race, Team Play or Score.

The evaluation of the 'MobileGame' by Schwabe and Göth (2005) indicates that both, the pattern *Augmented Reality* and the pattern *Physical Navigation* positively influence students' engagement and attitude towards learning. Working on the various tasks at significant places provides the base for learners to 'immerse into a mixed reality that augments both physical and social space' (p. 204). According to the study results, AR moves students into a state where they are 'mentally ready for learning, where they are in the right environment for learning and where they also already experience some socially oriented learning" (p. 215). The game element of 'map-navigation', which provides the base for the orientation game, keeps participants interested and moved.

Also, the evaluation of the 'Virus Game' (Outbreak@The Institute) by Rosenbaum, Klopfer and Perry (2006), reports on motivational learning outcomes. It uses patterns such as *Augmented Reality, Collaborative Actions, Common Experiences, Imperfect Information, Physical Navigation, Player-Location Proximity, Score, Team Play and Roleplaying.* The positive learning outcomes can be correlated with the patterns *Augmented Reality* and *Collaborative Actions*. The pattern *Augmented Reality* is defined as player's perception of the game world that is created by augmenting the player's perception of the real world (Davidsson 2004). Rosenbaum et al. state that by augmenting reality, students 'felt personally embodied in the game' (p. 38). When the bar graph on their PDA screen that represents their health started to drop for example, they spoke and acted as though they were actually sick (p. 38). 'When they were not sick, they responded to sick players with fear and alarm attempting to physically move away from them' (p. 38).

The pattern *Collaborative Actions* is defined as goals in mobile multiplayer games that can only be reached through a *Collaborative Action* (Davidsson 2004). Two or more of the players execute this pattern. It includes but is not limited to the action of simply being at the same location at the same time or attacking a target simultaneously. In the 'Virus Game', the pattern *Collaborative Actions* is implemented by providing different roles with distinct abilities. 'Each of the roles is dependent on the others both for information and for action. This fosters collaboration through jig sawing' (Rosenbaum, Klopfer and Perry, 2006; p.40). The study by Rosenbaum, Klopfer and Perry indicates that *Collaborative Actions* can bring about a change in students' attitude by providing insight into the working mechanisms of interpersonal communication. In the course of the 'Virus Game', students depend on each other for information and for action to reach their goal. The 'jig sawing of complementary information' (p. 35) brought about 'an understanding of the interdependence of the roles' (p. 43). Students 'grasped the resulting importance of communication and collaboration for success in the game' (p. 40).

Also, the learning game 'MobileMath' provides for motivation and aims at exploiting this motivation for meaningful learning. 'MobileMath' uses patterns such as *Augmented Reality, Collaborative Actions, Common Experiences, Continuous Goals, Cooperation, Configurable Gameplay Area, Hybrid Space, Memorabilia, Multiplayer Games, Physical Navigation, Player Location Proximity, Race, Score, Social Interaction, Team Play, Competition*. The evaluation of 'MobileMath' by Wijers, Jonker and Drijvers (2010) describes *Competition* as an essential factor in enhancing students' engagement with the game. *Competition* is implemented in terms of teams playing against each other. In the course of the game, 'teams can see themselves and the others as colored dots moving in real time in the playing field on the underlying map. The goal is for a team to gain points by covering as much area as possible with virtually constructed parallelograms' (p. 792). It showed that especially the 'option of destroying shapes of others brings in an extra competitive element. This feature proved to be very engaging' (p. 798).

As for the pattern *Augmented Reality,* the authors state that augmenting the real world increased students' attention and motivation to get engaged with a certain topic. By creating geometrical shapes on a previously defined playing field (map), students create an imaginary layer on top of the physical reality. Additionally, 'interaction between the teams mainly took place in the virtual reality: they spotted each other more easily on screen than in the physical reality' (Wijers, Jonker and Drijvers, 2010; p.797).

Cognitive Learning Outcomes

From the study results it seems that the assumed positive effects of MLGs on the student's knowledge gain are hard to substantiate. The review reveals that only few studies include quantitative data on game usage. Papers discuss the educational value of games but provide little empiric evidence that this approach leads to better learning outcomes. However, some of the evaluations show positive interrelations between using a mobile learning game and knowledge gains. In the following, we exemplary depict games that influence cognitive learning outcomes. We describe patterns they use and illustrate how they impact cognitive learning outcomes. Table 3 presents the patterns within augmented reality learning games that have cognitive effects and relates them to one of the levels distinguished by Bloom. The findings, we formulated in line with the verbs Bloom considered as suitable for describing the several levels in written objectives.

Most of the cognitive effects we subsumed to the level of 'Comprehension', which Bloom defined as a level where students are able to understand information or to grasp meanings, e.g. students can explain and rewrite the knowledge learned (Liu and Chu, 2010). The study carried out by Liu and Chu (2010) investigates the potential of the learning game HELLO (Handheld English Language Learning Organization), which uses the Internet, ubiquitous computing and AR technology to increase learning outcomes. The game implements patterns such as *Player-Location Proximity, Augmented Reality, Extra-Game Information,* or *Collaborative Actions.* To measure the cognitive effects, Liu and Chu evaluated students' English listening and speaking skills. The results indicate that HELLO improves learning. This is because the MLG provides many interesting learning materials for example (pattern: *Extra-Game Information*). The pattern *Extra-Game Information* is realized as follows: each student has access to u-tools for English learning. The u-tools include several tools, which can be used to access self-study English songs, listening materials, and conversational materials (Liu and Chu 2010, p.635). Also, with HELLO the learning improved because students collaborated in their tasks in real conditions for example (pattern: *Collaborative Actions*). During the game, the collaborative learning activity was a story relay race. In the beginning, the students could listen to several sample stories, after which they were asked to edit a story collaboratively (Liu and Chu, 2010).

Pattern	Pattern Description	Cognitive Learning Outcome
Collaborative Actions	Two or more players being at the same location at the same time or attacking a target simultaneously.	Students can explain and rewrite the knowledge learned (Liu and Chu, 2010).
Social Interaction	Players have the possibility to meet face to face.	Students are able to scientifically argument (Klopfer and Squire, 2008).
		Students can rewrite the knowledge learned (Liu and Chu, 2010).
Augmented Reality (AR)	Players' perception of the game world is created by augmenting their perception of the real world.	Students notice and discuss geometrical aspects of the world (Wijers et al., 2010).
		Students can describe and illustrate a disease model (Rosenbaum et al., 2006).
		Students reflect on the process of learning (Costabile et al., 2008).
Extra-Game Information	Information is provided within the game that concerns subjects outside the game world.	Students can rewrite the knowledge learned (Liu and Chu, 2010).
Roleplaying	Players have characters. The play is centered on making decisions on how these characters would take actions.	Students can give examples for the importance of communication and collaboration (Rosenbaum et al., 2006).

Table 3. Cognitive effects of patterns used within AR learning games.

The study results by Costabile et al. (2008) on Explore! – Gaius' Day in Egnathia also argue that augmenting the players' reality positively influenced their learning outcome. The debriefing phase of Explore! provides 3D reconstructions and interactive maps, enabling students to reflect on their learning. They allow students to 'see their movements in the site and their overall performance, and so better understand the errors they made' (p. 152).

Wijers et al. (2010) recognized that the pattern *Hybrid Space* changed students' perception of the city. In 'MobileMath' the players immerse in a mixed reality game environment, in which they create virtual elements (i.e. mathematical shapes) by interacting with the real world. The game changed their perception of reality. Mathematical details became a natural part of it. When playing, the students 'noticed and discussed geometrical aspects of the world such as if streets make right angles or not and whether they are running parallel' (p. 798).

DISCUSSION

To truly understand the implications of the many patterns that exist and to make effective use of their corresponding individual shapes, we must explore isolated patterns or groups of related patterns. The studies we reviewed did not explicitly focus on this but on a set of diverse patterns embedded in the games. Therefore, the impact of one particular pattern on knowledge gain is difficult to determine.

Also, the effects occurred with a given condition of the patterns, e.g. time, level, etc. We assume that varying the conditions of the diverse patterns (game balancing) has an influence on the effect too. Also, the studies we reviewed varied with regard to study design and terminology. The same applies to the statistical base (dependent/independent variables) and the research methods (quantitative/qualitative) the studies were based on, as they addressed various research interests. Still, some verifiable effects are in existence.

In order to reduce such complexities in the pattern approach, further research on the correlations between patterns and learning outcomes has to focus on a limited number of the patterns in existence (cf. Björk and Holopainen, 2004; Davidsson et al., 2004). The study settings have to comprise (a) an experimental variation of patterns, i.e. game settings that enable/disable individual patterns and (b) an in-depth variation of patterns, i.e. game settings that allow different instances for the same pattern. This way, measurable and feasible results can be obtained that are suitable as a base for design guidelines which define (a) patterns that support the achievement of a desired learning outcome and (b) ways of applying the patterns. Future research needs to verify the effectiveness of mobile learning games and to corroborate their educational value in order to motivate teachers to use such tools for teaching. Otherwise, the educational system may run the risk of disengaging future learners (Klopfer et al., 2011).

CONCLUSION

Studies on AR learning games frequently stress the manifold teaching and learning challenges they provide. Especially their power to create learning environments that foster teamwork, collaboration, social interaction and cooperation is frequently emphasised, e.g. the provision for 'jigsaw pedagogy' (Dunleavy et al., 2009, Rosenbaum et al., 2006), which is documented a most engaging and interesting feature. It is characterized by providing different information to different roles in the game. Just as in regular schooling, forms of collaborative participation support learners' engagement and motivation in the game and may eventually help to process and memorize the knowledge provided. However, few studies empirically prove the assumed cognitive learning outcomes (Costabile et al., 2008; Huizenga et al., 2009; Klopfer and Squire, 2008; Liu and Chu, 2010). Henceforth, it will be necessary to conduct more quantitative and qualitative research in order to define how AR learning games and their individual patterns or groups of related patterns support or hinder teaching and learning.

FUTURE WORK

Identifying the specific elements that students and teachers found most motivating is critical for developing progressively more effective AR curricula (Dunleavy et al., 2011). There is a need for a more detailed analysis of the effect of MLGs, on design patterns that occur in AR learning games and the relation between the patterns used and their effect on the learners.

The study results show a small, though positive correlation between diverse patterns and cognitive learning outcomes: *To what degree does a particular pattern, e.g. Augmented Reality, increase the learner's knowledge gain?* Also, from the study results, positive correlation between patterns and affective learning outcomes emerged: *How does a single pattern, e.g. the provision for Alternate Reality in the game, influence the learners' motivation to actually deal with a particular subject or a given learning content?*

A comprehensive study is yet to follow which examines the research questions stated and seeks to understand which specific patterns have the greatest impact on a stated learning outcome. The results of this study will be published in due course.

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