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Digital game-based learning in secondary education

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CHAPTER 2

CLAIMS ABOUT GAMES: A LITERATURE REVIEW OF A DECADE OF RE- SEARCH ON THE EFFECTS ON LEARNING AND MOTIVATION

This study aims at critically reviewing a decade of research into learning and motivational effects of digital game-based learning. We looked at claims made by authors regarding engagement in game-play, motivation for the content of the game and the school subject, and learning factual knowledge and cognitive and metacognitive skills. Eighty-one of the 93 claims made are grounded and discussed in this article. In general the claims that game-based learning is engaging have been proven. The results regarding motivation are more ambiguous. Claims about learning are usually proven, but when compared with other ways of learning, claims about learning more are not always proven. Several important design elements are mentioned. Two educational games are looked at in more detail. Whilst working on this review it became clear that in several studies information was lacking, for example about how long interventions lasted and effect sizes. This would be valuable information in assessing when game-based learning is or is not effective, as the question should not just be *whether* it is effective, but *how* and for *whom*.

1. INTRODUCTION

Some of the more persistent educational problems facing students today are underachievement as well as learning, behavioral, and emotional difficulties that eventually lead to many students dropping out of school (Battin-Pearson, Newcomb, Abbott, Hill, Catalano, & Hawkings 2000; Jonassen & Blondal, 2005). School dropout is theorized to be a gradual process of student disengagement and alienation, marked by a chronic cycle of tardiness, absenteeism, failing classes, suspensions, and transitions between schools (Bridgeland, Dilulio, & Burke Morison, 2006; Finn, 1989). Even among students who finish the required years of schooling, some research has found high rates of boredom, alienation, and disconnection with schooling (Larson & Richards, 1991). Studies have characterized high-school students especially as bored, staring out of classroom windows, counting the seconds for the bell to ring, and pervasively disengaged from the learning process (Goodlad, 1984). Students do not, however, experience alienation and disconnection during all encounters with school learning. Certain conditions may promote excitement, stimulation, and engagement in the learning process leading to meaningful learning. Using games in education, in particular, is assumed to be an excellent way to combine meaningful learning with fun (cf., Gee, 2003; Huizenga, Admiraal, Akkerman, & Ten Dam,

2009; Schwabe & Göth, 2005; Shaffer, 2006; Shaffer, Squire, Halverson, & Gee, 2005).

Many claims have been made about digital game-based learning (DGBL) in terms of learning and motivation. Mishra and Foster (2007) report over 250 claims about the psychological or physiological effects of game-based learning. However, they argue that most of these claims have not been validated empirically. A literature review of research on game-based learning could provide insight into how claims about games are grounded in the empirical data. Meta-analyses by Mitchell and Savell-Smith (2004) and Ke (2009) indicate several problems with research on game-based learning, for example, that while the studies carried out to date show a positive overall picture of game-based learning, many are methodologically flawed, rarely experimental and often present contradictory results. Some reviews also cover non-empirical research (e.g. anecdotal or opinion-based articles) and low-quality research, or leave out qualitative research. Moreover, the review methods are not precisely described. In this study, we will present a systematic literature review of empirical research, published in the last decade, on game-based learning in elementary and secondary education. Our focus is on claims about games with respect to students' engagement in playing a game, their motivation for the game subject and content, and their learning outcomes.

2. DIGITAL GAME-BASED LEARNING AND TYPES OF GAMES

Digital game-based learning can take the form of stand-alone instructional multimedia accessible on a desktop computer or game console, to online multi-user environments and virtual worlds (MUVE). Apperly (2006) describes the following game genres: simulation games (simulating sports, flying, driving, etc.), strategy games (where decision making is crucial), action games (which emphasize physical action, e.g. so-called shooter games) and Role Playing Games (where the player takes the role of a character). An example of the latter is World of Warcraft, a Massively Multiplayer Online Role Playing Game (MMORPG). Another genre is Augmented Reality Games (ARG) which enable players to interact simultaneously with both the fictional world and the real world (Cavanaugh, 2009).

Clustering by the platform (e.g. computer, play station, the Internet) on which the games are played is another categorization of game genres (Apperly, 2006). There is a growing interest in location-based games that use mobile technology (UMTS, GPS). Mobile equipment is seen as a suitable vehicle for learning by doing, easily accessible (relatively low costs and many students have such equipment) and makes it possible to mix the game world with the real world (Evans, 2009; Klopfer & Squire, 2008).

A frequently mentioned problem regarding games in education is that the educational objectives are not well integrated into the game; the learning is often separated from game-play, e.g. in a separate quiz (Becker, 2008). Another problem is that educational games are not as entertaining as commercial games (Verheul & Van Dijk, 2009). Attempts to combine the fun of commercial games and the learning facet of educational games often result in games being neither of these (Bruckman,

1999). However, in education the games that are mostly used to trigger students' engagement, motivation and learning are educational games, as commercial games are rarely used in schools. Teachers find it difficult to identify the relevance of games to their teaching and, when they can, they do not see the connection between much of the game content and their methods (Kirrimuir & McFarlane, 2003). Research on how commercial games might be used in classroom settings is necessary to understand their potential as learning tools (Sandford, 2006), as is research on educational games.

In this current review, we will present an overview of the effects of both commercial (also sometimes referred to as COTS games - commercial off the shelf games) and educational games that are used in elementary and secondary education on students' engagement, motivation and learning.

3. METHOD

The following questions guided our systematic literature review of empirical research on game-based learning in elementary and secondary education:

- How are the effects of digital game-based learning (DGBL) on students' engagement in the game described?
- How are the effects of DGBL on students' motivation for the subject described?
- How are the effects of DGBL on students' learning outcomes described?

3.1 Data

We selected literature on game-based learning published from 1999 to 2009 by conducting five searches at the end of 2009:

- 1) The following databases were searched.
 - a) The Eric databases, University of Amsterdam catalogue, UvA-Dare, Picarta and Web of Science. Academic Search Premier and Scopus were searched simultaneously using the University of Amsterdam digital library (<http://digitaal.uba.uva.nl>). We used the search terms Game* and Learn* in the subject field, and Educat* in the field called "all words". We used the asterisk as a joker referring to any combination of subsequent characters.
 - b) The Digiplay online database (<http://digiplay.info/wikindx3/index.php>) of academic and research articles was searched for articles containing the words Learn* or Educat*.
- 2) Four journals on technology and education (three frequently found in step 1 and a recently launched journal) and a handbook on gaming were searched:
 - a) Computers and Education (C&E) using the advanced search option with the search terms Gam* AND Learn* in the Title, Abstract and Keyword fields;
 - b) Simulation and Gaming (S&G) using the advanced search option and the search terms game* and learn* in the Abstract OR Keywords fields AND educat* in all fields.
 - c) Journal of Computer Assisted Learning (JCAL) by reading the abstracts as the journal does not have advanced search options.

- d) Journal of Gaming and Virtual Worlds (G&VW) by reading the abstracts as not many articles had been published then in this relatively new journal (of 2009).
 - e) Handbook of Research on Effective Electronic Games in Education (Ferdig, ed. 2010) by reading the abstracts.
- 3) To find research that had not yet been published, some recent conference proceedings were searched by reading the abstracts.
 - a) M-learn 2008
 - b) ICLS 2008
 - c) ECGBL 2009.
 - 4) The snowball method was used: all the literature reviews found in the previous steps were used to find relevant studies.
 - 5) Studies mentioned in game discussion lists (seriousgames@listserver.dmill.com and GAMESNETWORK@uta.fi) were added if the discussion indicated they might be relevant. Articles continued to be added until June 2010.

3.2 Selection criteria

This literature review focuses on empirical research on the use of digital games in education, which means that anecdotal or opinion-based articles have not been included. To determine the relevance of each study we defined games as organized play, involving one or more players, with goals, constraints, rules, interaction, challenges, pay-offs and their consequences, and aspects of competition (with another player or oneself). A narrative, story or fantasy elements are involved and the game should provide enjoyment and pleasure (based on Dempsey, Lucassen, Haynes, & Casey, 1996; Prensky, 2001). Another element determining the relevance of each study was whether the games had been used in elementary or secondary education. We then selected literature on cognitive learning (not the learning of sensory or motor skills) in the school curriculum of students aged from 4 to 18. Dissertations were only included if we had found no other work by the authors. We have restricted our review to articles written in English, German or Dutch. This literature search resulted in 92 articles.

3.3 Analyses

3.3.1 Minimum quality of each study

As the field of game-based learning is relatively new we included not only peer-reviewed articles, but also for example reports, book chapters and non-peer-reviewed articles. To guarantee a minimum standard we only selected articles that at least report:

- the number of participants and their age or school year;
- the method of data collection, and
- the method of data analysis.

Two raters applied the three categories in a subset of 16 randomly selected articles with a reliability in terms of Cohen's kappa (k) of 0.90 (with a 95% reliability interval of $0.73 \leq k \leq 1$). Then all articles were coded. Of the 92 articles 17 did not meet these criteria and were deleted from our selection, leaving 75 articles¹ in our review.

3.3.2 *Determining possible claims*

Research questions or a problem establish the scope and direction of research and therefore the possibility of finding claims about engagement, motivation or learning. Of the 75 articles that remained after determining the quality of the various studies, 57 articles were selected with at least one relevant research question.

3.3.3 *Determining the relevance of claims*

In the 57 articles we operationalized the 'claims about games' as authors' conclusions based on the research results. We therefore searched the discussion and conclusions sections for claims about motivation or learning. Eleven of the 57 articles were excluded as we could not find any claims on motivation or learning (although they do include research questions that point in this direction).

3.3.4 *Coding the content of claims*

The next step was to indicate the content of a claim. We differentiated between claims about students' motivation and their learning outcomes. Motivation is a broad, multifaceted term (see e.g., Fredricks, Blumenfeld, & Paris, 2004; Perry, Turner, & Meijer, 2006). In this review, we differentiated between students being engaged in the game (enjoying it, having fun, not being distracted, wanting to play) and having a positive attitude towards the game content or the school subject in which the game is used. We refer to these as *engagement in the game* and *motivation for the content* respectively. In the learning outcomes in the context of schooling we distinguished between *factual knowledge*, *cognitive skills* and *metacognitive skills* (cf., Elshout-Mohr et al., 1999; Ettekhoven & Hooiveld, 2010; Omrod, 2011; Presly & Harris, 2006; Schraw, 2006).

We have coded the claims about games by five variables: engagement, motivation, learning factual knowledge, learning cognitive skills and learning metacognitive skills. All the authors' conclusions were coded on the basis of the one or more variables they refer to. In addition each conclusion was coded as referring to a positive, negative or non-significant effect. The combination of these two codes (for the content and for the positive, negative or non-significant direction of the conclusion) formed the claim. When game-based learning was studied by comparing it with other forms of instruction we coded the claim with the term "more" to distinguish

¹ As Habgood's dissertation comprises four empirical studies each with its own group of respondents and description of methods, results and conclusions, we counted this dissertation as four articles.

the claims in these studies from the claims of studies where no control groups had been used.

3.3.5 *Checking the quality of the claims*

To determine the rigor of the claims, we checked whether the claims are:

- grounded in design (match between results and design);
- grounded in analysis (match between results and the analyses performed), or
- grounded in results (match between the authors' conclusions and results).

3.3.6 *Summarizing the results*

Only the claims that are grounded (as stated immediately above) in the 46 articles that ultimately remained in our review have been included in the results. We have summarized these results by identifying the claims, the games used and the school subjects. If the authors specified their results for specific groups of students, we have included this in our summary, even when they only specify these groups in their results and not in the formulation of their claim.

4. RESULTS

Ninety-three claims about games were made in the 46 articles included in this literature review. Table 1 gives an overview of these claims. In total 81 of the 93 claims could be considered as grounded, leaving 41 articles in this review. The other claims were not grounded in the results except for one that was not grounded in the design. Reasons for considering claims not to be grounded included authors' generalization to too large a population, insufficient information to decide whether the claim was grounded or not, and the inclusion of non-significant results.

The following sections present the results on claims about games on engagement in game-play, motivation for the content or school subject, and learning factual knowledge, cognitive skills and metacognitive skills. The results are based on the 81 claims that can be considered as grounded.

Table 1. Number of claims

Type of claims	Grounded	Not grounded in design	Not grounded in analysis	Not grounded in results	Total
Motivation (n=35)					
Engagement in game	21	0	0	1	22
Motivation for content	12	0	0	1	13
Learning (n=58)					
Factual knowledge	8	0	0	0	8
Cognitive skills	38	1	0	8	47
Metacognitive skills	2	0	0	1	3
Total	81	1	0	11	93

4.1 Claims on engagement in the game

Table 1 of the Appendix presents the studies with claims about games on engagement in playing games. Three of the studies are about engagement in *making* games. Playing or making games to engage students is used in a wide variety of subjects, but mostly in math.

Engagement is understood as the appeal of the game (Papastergiou, 2009; Serrano & Anderson, 2004), fun while playing it (Habgood, 2007; Jonker, Wijers, & Van Galen, 2009; Muwanga-Zake, 2007; Rosas, et al., 2003; Solomou & Vrasidas, 2008; Tuzun, 2008; Ulicsak, 2004; Verheul & Van Dijk, 2009), student satisfaction (Cheung, 2008), time spent playing the game (Habgood, 2007; Virvou & Katsionis, 2008), playing the game voluntarily in or out of class (Arici, 2008; Greenhill, Pykett & Rudd, 2008; Jonker et al., 2009; Owston, Wideman, Ronda & Brown., 2009), time spent on the task or proportion of on-task behavior (Annetta, 2009; Arici, 2008; Greenhill et al., 2008; Ota & Du Paul, 2002), being absorbed in the game or experiencing a state of flow (Lim, 2008; Papastergiou, 2009) and feelings of enthusiasm (Arici, 2008; Barab, Sadler, Heiselt, Hickey, & Zuiker, 2007; Greenhill et al., 2008; Papastergiou, 2009; Robertson & Howels, 2007; Solomou & Vrasidas, 2008). All the claims show that students found the use of games engaging. We found six studies which compared students using games with another group of students, mostly non-gaming students. Four of these studies make a positive claim, one a negative claim and one is non-significant.

The authors provide several explanations for their claim that the use of games in education is engaging. In their study on game-making, Greenhill et al. (2008), for example, mention five key sources of engagement: authorship, ownership, playful/experimental learning, the social value of the game, and involvement in real research and development activities (Greenhill et al., 2008, pp. 38-39). Other explanations are the challenge of the tasks or game (Robertson & Howels, 2008), and competing against each other (Habgood, 2007; Owston et al., 2009). Teachers in Owston

et al.'s study (2009) reported that making games for a particular target group and playing each other's games motivated students. Moreover, promising to make games later stimulated students to persist with other non-game work. Lim (2008) saw an increase in engagement after the third lesson with Quest Atlantis and hypothesizes that this might be caused by the additional scaffolding provided by teachers after this session, immersion in the story and familiarization with the Quest Atlantis space. Ang and Rao (2008) show that children want to play games because they want to solve puzzles, to complete missions and to know what happens at the end of a game. Comparing the intrinsic version (learning content by playing) of *Zombie Division* with the extrinsic one (learning content in a separate quiz), Habgood (2007) found that the recurring reasons for children preferring one version to the other were quick progress, the ease of the game, fun and learning. Having to read instructions is a less engaging aspect of educational games, which is therefore frequently ignored (Habgood, 2007; Ulicsak, 2004).

A few authors analyze their general claims on engagement in relation to differences between boys and girls. Ke (2008b) and Papastergiou (2009) found no significant gender differences in engagement in game-play. In his third study, Habgood (2007) did find some minor gender differences. Although both boys and girls prefer the intrinsic version of the game *Zombie Division* to the extrinsic version (in which questions are not integrated into game-play), girls played the intrinsic version for significantly longer than boys did. In Habgood's second study, boys played both versions significantly longer than girls did.

4.2 Claims on motivation for the game content or school subject

As shown in Table 2 in the Appendix, all the claims about games on motivation are formulated in a positive way, except for three of the studies using a control group. In these three studies, no significant differences were found (Huizenga, Admiraal, Akkerman, & Ten Dam, 2009; Ke, 2008a; Verheul & Van Dijk, 2009). Six of the 11 articles (Huizenga et al., 2009; Lim, 2008; Ke, 2008a, 2008b, 2008c; Ke & Grabowski, 2007) cover students' motivation for the school subject and the other five articles are about motivation for the learning tasks or the content of the game. Lim's (2008) is the only study that measured both kinds of motivation showing that motivation to learn the content of the games had improved from pre-test to post-test, but motivation for the subjects English, math and science and motivation for learning in general did not change significantly. Three of Ke's studies (Ke & Grabowski, 2007; Ke, 2008a, 2008c) on motivation for a school subject compare game-based learning and 'regular' learning. In two of these studies, the author found a significant difference. One of Ke's studies (2008c) compared students in three computer-game conditions (individualistic, competitive and cooperative classroom) with students in three similar paper-and-pencil drill groups. In the second study Ke and Grabowski (2007) compared two groups of game-playing students (cooperative and competitive) with a control group. In both studies, students in the computer-game condition showed the highest motivation for math. These differences were completely due to the cooperative game-playing condition. In Ke's third study (2008a),

she claimed that there was a non-significant effect as the educational game by itself did not reinforce motivation for math; only game-based learning in combination with the cooperative classroom condition did. So cooperative learning seems to be one of the design principles that make game-based learning motivating.

Four studies formulate claims about games on motivation for particular groups of students. No differences were found between boys and girls (Ke & Grabowski, 2007; Ke, 2008a, 2008c) and between students with and without gaming experience (Verheul & Van Dijk, 2009). In one study (Ke, 2008c), prior ability was found to be related to learning outcomes including motivation, but the article did not state whether the direction of this relation was positive or negative and there was no interaction effect with the six treatment conditions. Finally, one study (Ke & Grabowski, 2007) did find an interaction effect of social-economic status. Economically disadvantaged students showed a higher motivation for math (corrected for the pre-test) in the cooperative game-playing condition than in the competitive and individualistic game-playing and control conditions (Ke & Grabowski, 2007). Moreover, the competitive game-based learning condition was the least effective in promoting math motivation for them, whereas no significant difference has been found for students without an economic disadvantage.

4.3 Claims on learning factual knowledge

The studies summarized in Table 3 in the Appendix all formulated positive claims about games on learning factual knowledge. These claims address a variety of school subjects. Examples of factual knowledge learned by using games in geography lessons are topological knowledge about countries, knowledge about population and language of countries, and other cultural characteristics (Tüzün, Yılmaz-Soylu, Karakus, Inal, & Kizilkaya, 2008, p. 7) and historical knowledge about sites and buildings of medieval Amsterdam (Huizenga et al., 2009) and facts about Greek heroes (Solomou & Vrasidas, 2008) in history lessons.

Two studies formulated claims about students with different cognitive abilities learning factual knowledge. Virvou, Katsionis and Manos (2005) found that poor-performing students learned more facts by using games compared to high-performing students. Huizenga et al. (2009) found the opposite. Games proved to be most effective for students with higher cognitive ability, which led to the authors concluding that the game might have been too difficult for the other students.

Papastergiou (2009) paid a lot of attention to the design of the game she studied. The game (LearnMem1) has rules, clear but challenging goals, a fantasy linked to the student activity, progressive difficulty levels, interaction and a high degree of student control, uncertain outcomes, and immediate, constructive feedback. Every time students answer a question, they are not only given feedback; if they give a wrong answer; a life is subtracted from their score to encourage reading, thinking and then trying, instead of a trial and error approach. The game is realistically designed, but heavy 3D graphics were avoided to deal with the practical limitations of gaming in a school environment. In addition, the overall complexity is relatively low and the plot comparatively simple. Papastergiou states that it is important to look for

“an optimal balance between, on the one hand, the level of sophistication and complexity of a game (in terms of multimedia design and storyline) and, on the other hand, its learning effectiveness and motivational appeal” (Papastergiou, 2009, p.11).

4.4 *Claims on learning cognitive skills*

Table 4 in the Appendix summarizes the 28 studies making claims about digital game-based learning and learning outcomes with respect to cognitive skills. Eight of these 28 studies address science and 14 address math. They focused on the math skills of addition, subtraction, multiplication and division, but also comparing and simplifying expressions, solving quadratic equations (Redfield, Gaither, & Redfield, 2007), comparing quantities and magnitudes, locating and identifying points on a coordinate plane (Ke & Grabowski, 2007; Ke, 2008a; Ke, 2008c), and algebraic thinking, such as describing and analyzing patterns, relationships, graphs, symbols, and functions (Vogel, Greenwood-Ericksen, Cannon-Bowers, & Bowers, 2006). Other cognitive skills not related to math include critical thinking, reasoning, socio-scientific inquiry (Arici, 2008; Chuang & Cheng, 2009; Hickey, Ingram-Goble, & Jameson, 2009; Solomou & Vrasidas, 2008) understanding science concepts (Arici, 2008; Hickey et al., 2009; Squire, Barnett, Grant, & Higginbotham, 2004; Zuiker, Anderson, Lee, & Chee, 2008) and digital literacy skills (Owston et al., 2009).

Five authors explicitly stress the role of the teacher (Annetta et al., 2009; Owston et al., 2009; Robertson & Howels, 2008; Squire et al., 2004; Solomou & Vrasidas, 2008). The teachers' role, for example, should change from instructor to coach or facilitator; they should teach the students the skills they need to perform their tasks and guide conversations. Moreover, some studies emphasize the need for feedback. This may be feedback from the teacher, but can also be feedback built into the game and which is therefore an important design element. The feedback should be formative and not only summative and students should be encouraged to use it (Hickey et al., 2009; Jonker et al., 2009; Ke, 2008a). Hickey et al. (2009) made some changes in their game to improve the feedback from the Lab Technician and the teachers were given a three-point rubric with examples of feedback to use in the ranger Bartle role. Habgood (2007), in his fourth study, concludes that student reflection on the game-play and outcomes was beneficial to the learning gains. Squire et al. (2004) used logsheets and structuring from the teacher to promote critical thinking and Sedig (2008) fostered learning by providing scaffolding (an arc and ghost image) with Super Tangrams and started with playful gaming (with no need for understanding) with a gradual shift later towards representations of the educational concept (requiring understanding). Several other authors have stressed balancing play and learning. Vogel et al. (2006) state that the learning materials must be presented in an organic manner and should not be disruptive to the game (and that it probably was disruptive in their study, resulting in worse scores in the GBL condition), whereas Annetta et al. (2009) stress attention to the embedded instructional content and less emphasis on animation, text and audio that do not assist learning. Jonker et al. (2009) agree by stating that the game and goals should be aligned.

Four studies formulate the effects of games on the learning of cognitive skills by students with different cognitive abilities and/or prior knowledge, with ambiguous conclusions. In Banerjee et al.'s study (2007), the weaker students improved the most in math, whereas in Greenhill et al.'s study (2008) the moderate students learned the most about understanding the concepts of gravity, friction and electric charges. Bottino (2007) found that the poor-performing students achieved *less* well in medium-level exercises compared to other students. Ke (2008c) reports that students with less prior knowledge about the game content especially needed the support of an instructor or facilitator. No effect of socioeconomic status (SES) was found (Ke & Grabowski, 2007; Ke, 2008c), except for a weak interaction effect between treatment and SES. The economically disadvantaged students in the cooperative and the competitive game-based learning groups had significantly higher math scores (corrected for the pre-test) than those in the control group. For students without this disadvantage, the individualistic game-based learning condition worked significantly better (corrected for the pre-test) than the other learning conditions (Ke, 2008a).

4.5 Claims on learning metacognitive skills

In Table 2 claims of Ke's study (2008c) are presented. This study is the only one with grounded claims on metacognitive skills. These skills (e.g. self-monitoring) were measured by thinking-aloud procedures and by the Junior Metacognitive Awareness Inventory (version A), a 12-item self-report questionnaire. Although no significant differences in metacognitive awareness were found between students using computer games and students who did paper-and-pencil drills, the think-aloud data show that game-playing students were relatively more frequently engaged in metacognitive regulation processes.

Table 2. Claims on metacognitive skills (with + for claims indicating a positive effect, - for claims indicating a negative effect and 0 for claims indicating a non-significant effect)

Study	Name and type of game	Subject	Age/grade and number of participants	Direction of the claim	Compared to control group
Ke (2008c)	ASTRA EAGLE: a series of Web-based games designed as drill-and-practice programs for math	Math	358 students from 18 fifth-grade classes	+	0

5. TWO EDUCATIONAL GAMES FROM THE STUDIES IN THE REVIEW

To illustrate the kind of games that are used in educational settings and whose effects have been studied, we will describe two games in more detail. These descrip-

tions, including the main results, are based on two dissertations included in the current review (Arici, 2008; Habgood, 2007).

5.1 *Quest Atlantis*

The game environment of *Quest Atlantis* was the subject of research by several authors in our review. It is a 3D multi-user environment and designed for use in education (by students aged 9-12). The goal is to introduce students to the socio-scientific complexity underlying many scientific decisions that take place outside the laboratory, “in real-world contexts where people, opinions and stakeholders are enmeshed in scientific issues. In the process, Questers encounter scientific domain concepts such as pH, turbidity, eutrophication, etc.” (Arici, 2008, p.55). Figure 1 shows a screenshot of the main page of the game.

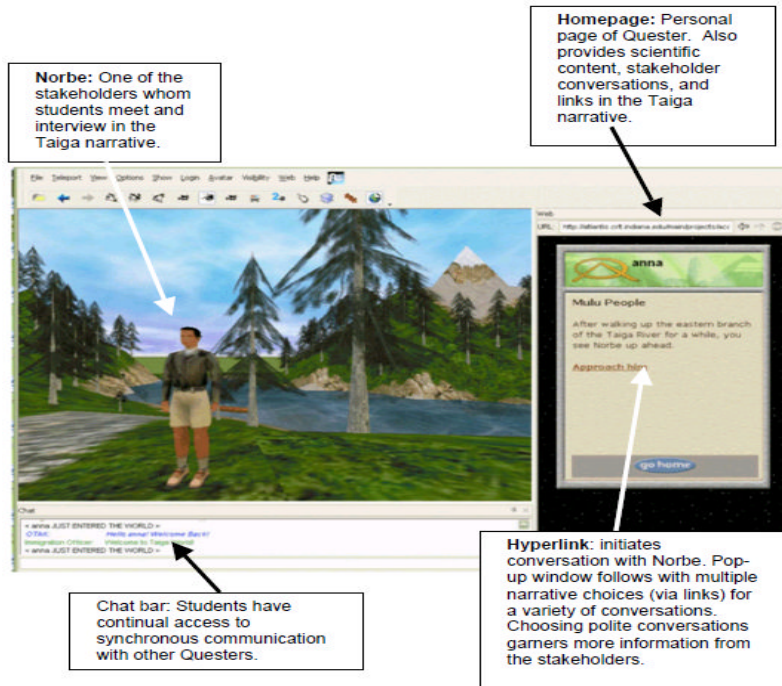


Figure 1. Screen capture of the 3D virtual environment in *Quest Atlantis*: the Taiga Park environment (from Arici, 2008).

The back-story of the game is that knowledge has been lost in Atlantis and the players have to help the Council to restore the lost knowledge. Players can travel to virtual places and talk with each other through the chat bar, or they can talk to Non-Player Characters (NPCs). An NPC is a bot (a computer program) pre-programmed to say and do specific things to guide and structure the game. One of the NPCs in

Quest Atlantis is Norbe, who is depicted in Figure 1. A hyperlink initiates the conversation with him.

Quest Atlantis has several virtual worlds. One of these worlds is about a virtual aquatic habitat called Taiga. Here the students receive a letter from the NPC ranger Bartle describing a recent decline in fish in the Taiga Park. Students are asked to help. By investigating the cause of the fish decline students learn about water quality. In the Taiga scenario the students take the role of scientists and engage in processes like water sampling and data analysis. They can test the water sample by clicking on a machine, which generates a pop-up window with a complete data table.

Arici (2008) examined Quest Atlantis and reported two claims relevant to this review. The first claim is about engagement. The Quest Atlantis context engaged students more than the regular curriculum. The second is about learning. The author concludes that the Quest Atlantis multi-user environment (MUVE) effectively supports learning science concepts, compared to traditional teaching. Students in the Quest Atlantis MUVE condition showed significantly more cognitive skills learning, both in the post-test and the retention test.

5.2 *Zombie Division*

Zombie Division is a game for learning math, division in particular, by game-playing (for students aged 7-11). Habgood (2007) examined two versions of the game: one where the educational content is integrated into the game (intrinsic version) and one where it is included in a multiple-choice quiz at the end of each level (extrinsic version). The back-story is about an ancient Olympic curse on athletes. The skeletons are the cursed athletes; their curse can only be dispelled by magical attacks by the player.



Figure 2: Intrinsic version of *Zombie Division*: screenshot of a divisor-based question in the challenge level (from Habgood, 2007).

Figure 2 shows a screenshot of a typical situation in the game. Skeletons have numbers displayed on their chest which indicate the number of magic bones they have. To defeat them the player uses one of the three available weapons (see Figure 2, top left) to divide the number of magic bones into groups of equal size. (For example, in Figure 2 the player must choose weapon 2 to divide the skeleton's 18 magic bones equally, which is not possible with weapons 5 or 10.) This restores their magical balance so that their souls can finally rest in peace. However, if the player tries to divide them into unequal groups, they attack with increased strength. In the intrinsic version, a multiplication grid helps the player choose the right weapon. (For example, in Figure 2, the multiplication grid shows which numbers can be divided by 5.) The player also can leave via an unlocked door, but is then prevented from making progress. The game progresses from being able to ignore a skeleton and having enough time to think about what action to take, to being pursued by several skeletons simultaneously.

Habgood (2007) has conducted four experimental studies of *Zombie Division*, two on learning cognitive skills and two on engagement. In study 1 there was no significant difference between the groups (intrinsic, extrinsic, control) in learning math. All the students improved significantly, but only on the conceptual questions. Studies 2 and 3 are about engagement in the game, measured as time-on-task for different versions of the game. In study 2 there were no significant differences in

engagement in the intrinsic or extrinsic version. Students could also play a non-educational game, but chose to play *Zombie Division* for 65% of their optional playing time, with boys playing significantly longer than girls. In study 3 the children could only choose between the intrinsic and extrinsic versions and here the intrinsic version proved to be significantly more engaging for both boys and girls, but the girls played the intrinsic version for significantly longer than the boys. Study 4 was also about learning and there were significant learning gains for all groups (extrinsic, intrinsic and control), but the intrinsic group's percentage scores were significantly higher than either of the other two groups in the delayed post-test. Moreover, only the intrinsic group performed significantly better than the control group in percentage scores for dividend-based questions. This is an indication that the intrinsic version might be best for learning.

Between study 1 and the other studies several changes were made to the game and methodology to improve the game's potential and measurements. These changes include the use of a multiplication grid; an improved save-game system allowing students to easily resume where they left off; a computer-based testing system to reduce the possibility of high pre-test scores; a game-based transfer test to provide a direct comparison between questions in the test and game conditions; and a delayed test to measure long-term gains.

6. DISCUSSION AND CONCLUSIONS

The use of digital game-based learning seems to provide a solution for tackling student disengagement, which is one of the most pressing problems confronting education today. Moreover, many authors argue that digital game-based learning improves the learning results of students. Although it is widely claimed that games in education provide excellent ways of combining meaningful learning with fun, a systematic review of the empirical basis of this claim is still lacking. In this article we have reviewed claims about engagement in game-play, motivation for the content of the game and the school subject, and learning outcomes. The review is based on studies which meet basic criteria of rigor. In general, these studies confirm the claims that using games in elementary and secondary education does engage students. Using games triggers enthusiasm, and supports students' on-task concentration. Instructional design elements mentioned in relation to why games are engaging emphasize students' authorship and ownership, stimulating playful/experimental learning, accentuating the social value of the game and involving students in authentic research and development activities, including challenging tasks and competitive elements, making games for a particular group and the possibility of playing each other's games.

The results regarding the claims about games on students' motivation for the content or school subject proved to be more ambiguous. Several studies seem to provide evidence that using games in education triggers student motivation, but this is not always confirmed in studies which compare a game intervention with other educational interventions. Ke's studies indicate that cooperative learning is a design principle that contributes to motivation for math through game-based learning.

We have distinguished various types of learning outcomes regarding the claim about games on learning outcomes. In our review, the claims that using games improves factual knowledge can be confirmed, as all the studies include empirically grounded claims. However, the claims that using games in education improves students' cognitive skills cannot be fully confirmed. Only 81% of the claims were based on studies that were rigorous enough, and of these 39 claims only 26 were based on significant effects. One of these claims was that children in the GBL condition learned significantly *less*. The claims about metacognitive skills appear to be under-researched, as only one study (with two claims) examined metacognitive skills. For learning it is important that there is a good balance between game elements and learning elements. The game must be fun but it is important that game elements do not distract from learning. Useful feedback is necessary and the constraints of the educational environment should be addressed.

Some studies present claims that are specific to particular groups of students. In spite of what is often assumed, gender does not seem to influence the effects of games on engagement, motivation and learning, with no differences being reported between boys and girls. Cognitive ability only mattered for learning outcomes, albeit with unclear results. In some studies games appear to work best for poor-performing students, in others for the well-performing students. Two studies reported significant interaction effects regarding social-economic groups depending on whether the game was individualistic, cooperative or competitive.

6.1 Some critical remarks

Strengths of this review study include the empirical underpinning of claims about games regarding engagement, motivation and learning results. Nevertheless, some critical remarks should be made concerning the generalization of our conclusions on the use of game-based learning in education. Firstly, the use of games in education is burgeoning, and most empirical research has been published recently. There was a significant increase in research publications on game-based learning at the end of the period covered by our review (1999-2009). A systematic review requires a considerable amount of time and our findings should be understood in this context. However, on the basis of recently published articles in journals, such as *Computers & Education* and *Computers in Human Behavior*, and listserves, such as *Gamesnetwork*, we are of the opinion that our conclusions still hold. Secondly, we had to base our analyses on authors' texts which are published in peer-reviewed journals and dissertations. As a result some manuscripts that omit crucial information about the method or results (in tables or in the text) were not selected because of our criterion of methodological rigor. Thirdly, non-significant results are under-represented. When analyzing whether the conclusions of the studies in our review were substantiated we noticed that many authors do not include their non-significant results in the discussion and conclusions sections. Owing to the omission of these results from the conclusions, they were not coded as claims, therefore resulting in the under-representation of claims with non-significant results mentioned above.

Regarding the question what makes ‘game-based learning’ work, we were limited by the information given in the articles. Very often we could not ascertain how long the interventions lasted. (Sometimes only the period was mentioned, sometimes only how long one session lasted.) When time was mentioned we were often unsure whether this was purely game-playing time or that maybe teachers intervened in this time too and if so, we did not know how. This would be valuable information for determining whether game-based learning is effective or not. Moreover, in most cases no effect sizes were mentioned and hence we had no idea whether the effects were substantial or not. We were also not certain whether the effects found were due to using games in education or due to introducing something new – a novelty effect – as barely any long-term studies were included. In some cases the studies were possibly too short to find effects. Nevertheless, we hope that this review has contributed to a better understanding of the learning and motivational effects of DGBL and the state of research.

6.2 Implications and future research

It is clear that games for use in education have to be well designed from an instructional point of view. To engage students in a game - which seems to be a prerequisite for motivating them and for their learning – students should feel ownership and authenticity and they should perceive sufficient challenges and possibilities for competition. But technology alone does not seem to be enough to trigger effects on students’ learning. Students need input from teachers in the form of instructions, guidance and feedback, and enough opportunities for reflection. It is also necessary to be aware that too many embellishments in the game design can distract students’ attention from learning.

To utilize the full potential of games we need to know more about *how* games work and for *whom*. One way would be to systematically manipulate design elements to examine their impact on engagement, motivation and learning. Moreover, longitudinal research could establish retention effects. Finally, research is needed on how game-based learning works for different school subjects and different groups of students. Only when we have this information can we safely conclude that students are engaged and motivated while playing games and do indeed learn more than in regular instructional settings.

APPENDIX

Table 1. Claims on engagement in game-play (with + for claims indicating a positive effect, - for claims indicating a negative effect and 0 for claims indicating a non-significant effect).

Study	Name and type of game	School subject	Age/grade and number of participants	Direction of the claim	Compared to control group
Annetta et al. (2009)	A teacher-created Multiplayer Educational Gaming Application (MEGA)	Biology	4 general biology classes at a single high school. N= 129 (66 game, 63 control), aged 14-18		+
Arici (2008)	Quest Atlantis: a 3D MUVE (multi-user environments and virtual world) video game designed for education (Taiga).	Science content	Approx.120 students, aged 11-12		+
Barab et al. (2007)	Quest Atlantis: a 3D MUVE (Taiga)	Science: socio-scientific inquiry	28 students (16 females) in a fourth-grade gifted class	+	
Cheung et al. (2008)	Farmtasia: an online game based on VI-SOLE (a Virtual Interactive Student-Oriented Learning Environment, VR)	Interdisciplinary: biology, government, economics, technology, production system and natural environment	16 secondary-four students (comparable with K-10)	+	
Greenhill et al. (2008)	Newtoon: mobile microgame creation	Science: physics	1 year-seven class	+	
Habgood (2007) Study 2	Zombie Division: action-adventure game, attacking skeletons	Math	46 mixed-ability students, aged 7 years 10 months - 8 years 8 months (mean 8 years 2 months), 18 females and 28 males (data on 2	(+)	0

Habgood (2007) Study 3	Zombie Division: action-adventure game, attacking skeletons	Math	students lost owing to damaged data storage) 16 students, aged 9 years 10 months - 11 years 2 months (mean 10 years 4 months) in an after-school club	+
Jonker et al. (2009)	Crack the Number Safe: a mini-game designed for exploring division	Math	18 fourth and sixth-grade students	+
Lim (2008)	Quest Atlantis: a 3D MUVE	English, math and science	80 fifth-grade students at a school open to technological innovation	+
Muwanga-Zake (2007)	Zadarh: an adventure game that explores photosynthesis, respiration, genetics and evolution	Biology	26 teachers and 129 twelfth-grade students	+
Ota & Du Paul (2002)	Math Blaster: commercial math software with game format	Math	3 male, Caucasian, fourth, fifth, and sixth-grade students exhibiting ADHD behaviors	+
Owston et al. (2009)	Education Games Central: a game-shell for making games	Social studies	Fourth-grade classes at nine public elementary schools	+
Papastergiou (2009)	LearnMem1: computer game on basic computer memory	Computer science	88 students at two high schools, 46 males and 42 females, aged 16-17	+
Robertson & Howels (2008)	Neverwinter Nights game-making toolset: NWN is a Dungeons and Dragons style 3D role-playing game	Interdisciplinary: Scotland's curriculum for excellence	Class of 30 students, aged 9-10	+
Rosas et al. (2003)	Simple low cost video-game platform, gameboy appearance	Math and reading (also tests spelling)	1274 first and second-grade students	+
Serrano & Anderson (2004)	Food Pyramid Games (and songs): a bilingual nutrition software program for Mac	Nutrition	115 students from four schools and nine fifth-grade classes	+
Solomou & Vrasidas (2008)	Age of Mythology: a commercial strategy simulation computer game	History	24 sixth-grade students	+
Tüzün et al. (2008)	Quest Atlantis: a 3D MUVE (Global Village):	Geography	24 fourth and fifth-grade students at a K-8 elementary school	+
Ulicsak (2004), only final study in review	Astroversity: game for 12-14 year olds, extension Virtual Multi-User Learning Environments project	Cross-curricular with science focus	Year-nine (top) class, 8 females and 10 males	+

Verheul & Van Dijk (2009)	Oblivion: a single-player offline RPG (COTS)	Vocational education (one subject being English)	43 students (but a pre-test and post-test for only 34), aged 16-26, the majority aged 16-19	-
Virvou & Katsionis (2008)	VR-ENGAGE: a virtual reality educational game (similar to DOOM)	Geography	50 students aged 11-12 (15 novice, 20 intermediate, 15 expert)	+

Table 2. Claims on motivation for the subject (with + for claims indicating a positive effect, - for claims indicating a negative effect and 0 for claims indicating a non-significant effect).

Study	Name and type of game	Subject	Age/grade and number of participants	Direction of the claim	Compared to control group
Ang & Rao (2008)	Reconstructors: a web-based educational game	Drugs	100 students, 50 aged 15-18 and 50 aged 19-35		+
Huizenga et al. (2009)	Frequency 1550: a mobile location-based game	History	458 students in first year of secondary education, aged 12-16, mostly 13		0
Ke (2008a)	ASTRA EAGLE: a series of web-based games designed as drill-and-practice programs for math	Math	160 participants from 8 fifth-grade classes		0
Ke (2008b)	ASTRA EAGLE: a series of web-based games designed as drill-and-practice programs for math	Math	15 students enrolled in a summer math program, aged 10-13	+	

Ke (2008c)	ASTRA EAGLE: a series of web-based games designed as drill-and-practice programs for math	Math	358 students from 18 fifth-grade classes	+
Ke & Gradowski (20007)	ASTRA EAGLE: a series of web-based games designed as drill-and-practice programs for math	Math	125 fifth-grade students from six classes	+
Lim (2008)	Quest Atlantis: a 3D MUVE	English, math and science	80 fifth-grade students at a school open to technological innovation	+
Sedig (2008)	Super Tangrams: interactive game on geometry concepts, based on Chinese Tangrams puzzle activity	Math	58(/59) sixth-grade students, 20 from a control group at another school	+
Solomou & Vrasidas (2008)	Age of Mythology: a commercial strategy simulation computer game	History	24 sixth-grade students	+
Tüzün et al. (2008)	Quest Atlantis: a 3D MUVE (Global Village)	Geography	24 fourth and fifth-grade students at a private K-8 elementary school	+
Verheul & Van Dijk (2009)	Oblivion: a single-player offline Role Playing Game (COTS)	Vocational education (one subject being English)	43 students (a pre-test and post-test for only 34 students), aged 16-26, the majority aged 16-19	0

Table 3. Claims on factual knowledge (with + for claims indicating a positive effect, - for claims indicating a negative effect and 0 for claims indicating a non-significant effect).

Study	Name and type of game	Subject	Age/grade and number of participants	Direction of the claim	Compared to control group
Chuang & Chen (2009)	Fire Department 2, Fire Captain: a 3D, real-time strategy computer-based video game	Fire-fighting	115 third-grade students, 61 males , and 54 females		+
Cheung et al. (2008)	Farmtasia: an online game based on VISOLE (a Virtual interactive student-oriented learning environment, VR)	Interdisciplinary: biology, government, economics, technology, production system and natural environment	16 secondary-four students (comparable with K-10)	+	
Huizenga et al. (2009)	Frequency 1550: a mobile location-based game	History	458 first-year secondary students, aged 12-16, mostly aged 13		+
Papastergiou (2009)	LearnMem1: computer game on basic computer memory	Computer science	88 students at two high schools, 46 males and 42 females, aged 16-17		+
Serrano & Anderson (2004)	Food Pyramid Games (and songs): a bilingual nutrition software program for Mac	Nutrition	115 students from four schools and nine fifth-grade classes	(+)	+
Solomou & Vrasidas (2008)	Age of Mythology: a commercial strategy simulation computer game	History	24 sixth-grade students	+	
Tüzün et al. (2008)	Quest Atlantis: a 3D MUVE (Global Village)	Geography	24 fourth and fifth-grade students at a K-8 elementary school	+	
Virvou et al. (2005)	VR-ENGAGE: a virtual reality educational game (similar to DOOM)	Geography	90 students aged 9-10 in first part of the experiment, 30 good students in second part, 30 mediocre in third part and 30 poor in fourth part (no overlap)		+

Table 4. Claims on cognitive skills (with + for claims indicating a positive effect, - for claims indicating a negative effect and 0 for claims indicating a non-significant effect).

Study	Name and type of game	Subject	Age/grade and number of participants	Direction of the claim	Compared to control group
Annetta, et al.(2009)	a teacher-created Multiplayer Educational Gaming Application (MEGA)	Biology	4 general biology classes at a single high school. N= 129 (66 game, 63 control), aged 14-18		0
Arici (2008)	Quest Atlantis: a 3D MUVE video game designed for education (Taiga)	Science content	Approx.120 students, aged 11-12	(+)	+
Banerjee et al. (2007)	CAL: year 1 internally developed and COTS educational games, year 2 additional company-developed software	Math (& language, but this is not a target of CAL)	The CAL intervention in 2002-2003 in 55 schools in grade 4, 56 comparison, crossover design with switch in 2003-2004		+
Barab et al. (2007)	Quest Atlantis : a 3D MUVE (Taiga)	Science: socio-scientific inquiry	28 students (16 females) in a fourth-grade gifted class	+	
Chuang & Chen (2009)	Fire Department 2, Fire Captain: a 3D, real-time strategy computer-based video game	Fire-fighting	115 third-grade students, 61 males and 54 females		+
Din & Caleo (2000)	Light Span (Sony PlayStation) with CDs	Tests math, spelling & reading	47 students, aged 5-6		0
Greenhill et al. (2008)	Newtoon: mobile microgame creation	Science: physics	1 year-7 class	+	0
Habgood (2007) study 1	Zombie Division: action-adventure game, attacking skeletons	Math	64 students, aged 7 years 6 months - 9 years 7 months (mean 8 years 8 months), 32 females and 32 males	(+)	0

Habgood (2007) study 4	Zombie Division: action-adventure game, attacking skeletons	Math	58 students, aged 7 years 1 month - 8 years 10 months (20 intrinsic condition, 20 extrinsic and 18 control)	+	+
Hickey et al. (2009)	Quest Atlantis	Science	8 classes, including 2 control classes	+	0
Jonker et al. (2009)	Crack the Number Safe: a mini-game designed for exploring division	Math	18 fourth and sixth-grade students	+	
Ke (2008a)	ASTRA EAGLE: a series of web-based games designed as drill-and-practice programs for math	Math	160 participants from eight fifth-grade public school classes		+
Ke (2008c)	ASTRA EAGLE: a series of web-based games designed as drill-and-practice programs for math	Math	358 students from 18 fifth-grade classes		0
Ke & Grabowski (2007)	ASTRA EAGLE: a series of web-based games designed as drill-and-practice programs for math	Math	125 fifth-grade students from six classes		+
Ota & Du Paul (2002)	Math Blaster: commercial math software with game format	Math	3 male, caucasian, fourth, fifth and sixth-grade students exhibiting ADHD behaviors	+	
Owston et al. (2009)	Education Games Central: a game-shell for making games	Social studies	Fourth-grade classes at nine public elementary schools, either two fourth-grade classes or only one fourth-grade class and one with third and fourth-grade students	+	+
Redfield et al. (2007)	Math Blaster Algebra: a game package focusing on using many types of numbers	Math	42 ninth-grade algebra students	0	
Robertson & Howels (2008)	Neverwinter Nights game-making toolset: NWN is a Dungeons and Dragons style 3D role-playing game	Interdisciplinary: Scotland's curriculum for excellence	Class of 30 students, aged 9-10	+	
Rosas (2003)	Simple low-cost video-game platform, gameboy appearance	Math and reading (also tests spelling)	1274 first and second-grade students		0

Sedig (2008)	Super Tangrams: interactive game on geometry concepts, based on Chinese Tangrams puzzle activity	Math	58(/59) sixth-grade students, 20 from a control group at another school		+
Serrano & Anderson (2004)	Food Pyramid Games (and songs): a bilingual nutrition software program for Mac	Nutrition	115 students from four schools and nine fifth-grade classes		+
Solomou & Vrasidas (2008)	Age of Mythology: a commercial strategy simulation computer game	History	24 sixth-grade students		+
Squire et al. (2004)	Supercharged!: an electromagnetism 3D simulation game	Science: physics (electrostatics)	96 students in five different classes all with the same 8 th grade teacher (35 in control, 61 in experimental group)		+
Sung et al. (2008)	SoRT: Software for Rebuilding Taxonomy, several multimedia games	Taxonomic concepts	60 students, aged 3½-5½	(+) (+) (0)	+ + 0
Verheul & Van Dijk (2009)	Oblivion: a single-player offline RPG (COTS)	Vocational education (one subject being English)	43 students (but a pre-test and post-test for only 34) aged 16-26, the majority aged 16-19	+	
Vogel et al. (2006)	A Virtual Reality learning program based on a computer-assisted instruction program	Math	44 students, aged 7-12 at a public school (25 females, 19 males)		- 0
Wilson et al. (2006)	The Number Race: an adaptive computer game for remediation of dyscalculia	Math	Final sample 9 students aged 7-9 from 3 schools		+
Zuiker et al. (2008)	Escape from Centauri: a multi-user serious game; students assume the role of stranded astronauts	Science: physics	36 males, volunteers, aged 14-15, private all-boys secondary school		+
