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Design, Learn and Play: Designing Engaging Educational Computer Games

1. Objectives

Evidence suggests that computer game-based learning (GBL) environments are effective in increasing students' motivation and supporting learning (de Freitas, 2013; Kiili, Ketamo, Koivisto, & Finn, 2014; Spires, Rowe, Mott, & Lester, 2011). Many intelligent tutoring systems and advanced learning technologies are designed as educational games (Aleven, Beal, & Graesser, 2013; Conati, Jaques, & Muir, 2013; Rodrigo, et al., 2012). This paper presents the lessons learned during the design, implementation and evaluation of an educational game, Heroes of Math Island, for students in grades five through seven. The game was designed and implemented with the purpose of researching (1) affective states that are relevant to learning during gameplay and (2) methods that are better suited for design of engaging educational games. This paper focuses on the second objective.

2. Perspectives

In February 2013, the Learning Solutions magazine published an article with the provocative title "Why Games Don't Teach" (Clark, 2013). The author argued that "advocating games as a main or even frequent instructional strategy is misleading" (p.1) and encouraged the development of a "taxonomy of games or game features that link to desired instructional outcomes" (p.1). Citing an extensive technical report by Hays (2005), she argued that there is "insufficient well-designed experimental research on which to base many conclusions" (Clark, 2013, p. 1). Although Clark's argument for better alignment of game design with learning outcomes is valid, her other statements are wrong: there is tremendous evidence of empirically-validated studies that demonstrate the educational potential and effectiveness of GBL (Barab, et al., 2009; de Freitas, 2013; Kiili, Ketamo, Koivisto, & Finn, 2014; Spires, Rowe, Mott, & Lester, 2011). Several perspectives and theories support GBL: constructivism (Piaget, 1952), constructionism (Papert, 1980), experiential learning (Kolb, 1984) and situated learning (Brown, Collins, & Duguid, 1989). The implementation of learning objectives into a game fosters knowledge construction through experience.

A pioneer in this field, Prensky (2001) argued that games are effective because of their engaging factor involving 12 characteristics: “enjoyment and pleasure”, “intense and passionate involvement”, “structure”, “motivation”, “doing”, “flow”, “learning”, “ego gratification”, “adrenaline”, “creativity”, “social groups” and “emotion” (p. 05-1).

The main goal of an educational game is to advance learning. Situations of negative emotions are common. Confusion and frustration could be unavoidable; however frustration could lead to boredom which is negatively associated with learning (D’Mello, Taylor, & Graesser, 2007). Previous studies indicated that learners who become bored are likely to stay in that state (Craig, Graesser, Sullins, & Gholson, 2004; D’Mello, Taylor, & Graesser, 2007). However, confusion could be beneficial: in a recent study by D’Mello, Lehman, Pekrun and Graesser (2014) confusion was strategically induced in a learning session on difficult conceptual topics via a contradictory-information manipulation. As a result, learners actually performed more effectively when contradictions were successful in confusing them. These findings are in line with Piaget’s (1952) theory of cognitive disequilibrium stating that comprehension occurs when learners confront contradictions. Educational games have a great potential because of their engaging factor: they could reduce boredom and increase motivation through game-like activities.

In order to be effective and respond to the users' cognitive and emotional needs (e.g., clarify situations of confusion when learners become stuck), educational games should provide individualized support and adaptive guidance (Aleven, Beal, & Graesser, 2013; Baker, D'Mello, Rodrigo, & Graesser, 2010; Conati, Jaques, & Muir, 2013). Evaluating the subjective playing experience and engagement in learning is a very important step in the design process of effective educational games that respond to the learners' needs.

Embracing a behaviourist perspective, Linehan, Kirman, Lawson, and Chan (2011) proposed a set of empirically-validated guidelines for designing educational games. According to them, one of the mistakes made by designers is the focus on educational content and the lack of attention to the game mechanics. They proposed the applied behavior analysis (ABA) method developed by behavioral psychologists arguing that ABA "can provide a foundation for the design of educational games, while maintaining those aspects of entertainment games that are crucial to player motivation" (p. 1979). Similarly to practices used in commercial video games, ABA employs techniques like recording and analyzing the behavioral change, providing corrective feedback, offering a variety of rewards for correct performance, and "persistent negative consequences for poor performance, which the player will work to avoid" (p. 1986).

3. Methodology

Following the design-based research (DBR) methodology, this study involved iterative design and implementation based on three main stages: (1) theory and brainstorming sessions, (2) revision based on usability studies with one teacher and two instructional designers, and (3) quasi-experimental study with 24 students (13 boys and 11 girls) grades five through seven.

Iterative design and implementation is also characteristic to game development (Salen & Zimmerman, 2004). The game design was discussed and brainstormed with a research group involving two researchers, four educational technology graduate students and two undergraduate students specialized in game design. Based on design specifications and feedback resulted from usability studies, the game was implemented by the undergraduate students under the supervision of the researcher conducting this study.

All participants played the game, were interviewed and videotaped. Additionally, students wrote pre- and post-tests and responded to a questionnaire. A minimum of two observers participated in each experiment; after experiments, observers discussed findings and wrote detailed reports.

4. Data Sources

Important attention was given to aesthetics, game mechanics, story, and player's experience. The game design used a narrative set on an island with a castle as the central site where students got challenges or "quests" from a king or queen, and was based on several game design principles: avatars, non-player characters (monkey, queen, king, etc.), content (a narrative accompanying each task), repeatability (a player will repeat a set of actions for mastering a task), and levels of difficulty. Similarly to Rodrigo et al. (2012), Heroes of Math Island has an agent (the monkey) that uses emotional expressions to respond to the students' performance.

The game was designed with five possible quests; however for this version of the game only the mine quest based on number factorization was functional (see Figure 1).

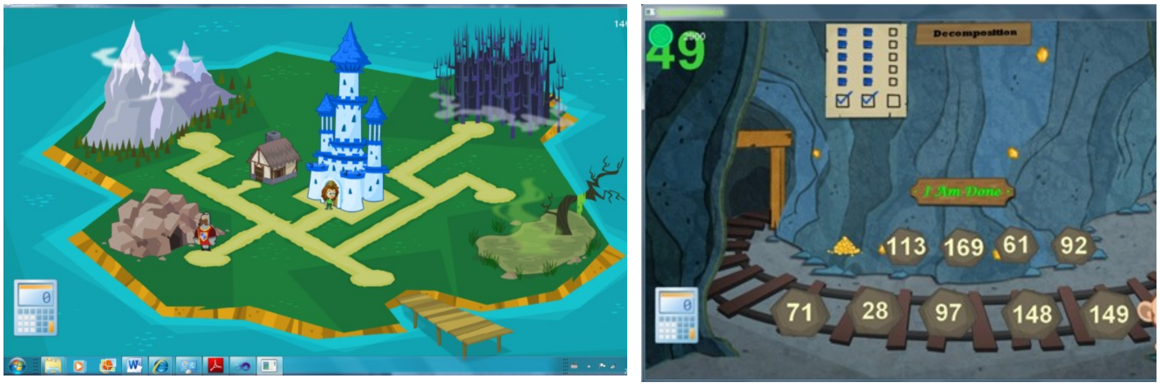

Figure 1: Heroes of Math Island

From Prensky's (2001, p. 05-1) twelve characteristics all but "ego gratification", "creativity" and "social groups" were included. With respect to creativity, although intended, there was not enough time to include creative elements in the game (e.g., students create their own questions); however, students were involved in design by being asked to critique the existing version and suggest future features. The constructionist approach of involving students in making games was successfully explored in previous studies (Druin, 2002; Kafai, 2006; Rusnak, 2009).

Cognitive interactivity or interpretative participation as suggested by Salen and Zimmerman (2004) was included in design: building knowledge of the game's framework, game's rules, mathematical principles and rules of learning.

The game design employed some ABA techniques. In this version rewards were not included; however negative consequences for poor performance were (Linehan, Kirman, Lawson, & Chan, 2011). On the fourth error, the activity restarted. Experiments indicated that this technique prevented "gaming the system" (guessing the correct answer), however some students reported frustration.

During stages one and two, the design document and the software implementation were revised based on discussions with the research group, observations, and recommendations provided by the teacher and the instructional designers. During stage three, there were no changes in the game; however design issues were addressed in students' interviews.

5. Results

Designing GBL environments is challenging. During the design process, pedagogical and game design principles proven to be contradictory. For example, the pedagogical principle of freedom of exploration contradicts the nature of a game based on levels of difficulty mastered before progressing. Similarly, negative consequences following poor performance resulted in frustration.

The DBR approach combining theory and iterative steps was effective. The teacher and the instructional designers provided significant feedback with respect to mathematical content, interface design, game mechanics and the hint system. In interviews, students welcomed design questions and were very enthusiastic to share their experience, feedback and ideas. Observing the students' interaction during gameplay and exploring their subjective views provided rich data and valuable design ideas. Several themes emerged: goals (including avatars and collecting objects), ego gratification and competition (providing achievements, leaderboards and rewards), social groups (interacting with other players), multiplayer modes (challenging other players in real-time competitions), and gender issues (including a girls' version).

Learning

Several post-questionnaire statements addressed the students' perception of learning gains with respect to gameplay, task accomplished ("I learned math when I finished the quest"), game design (hints, harder questions), mistakes, and social norm ("I learned math when I helped the miners”). Data indicate that students felt that learning happened. The students’ perceptions were confirmed by test results indicating significant improvement from pre-test (M = 75.3%; SD = 9.3%) to post-test (M = 80.2%; SD = 8.7%), t (22) = 2.07; two-tailed $p < 0.004$). Generally, students demonstrated good attitude and interest. 87.5% of participants agreed or strongly agreed with the statement “I learned math when I played the game”, and the rest 12.5% were neutral. One of the students who responded neutral was completely uninterested in mathematics; another was too advanced for this game. Even if his response was neutral, the third student indicated in interview that the game helped him learn and represented a better learning tool than a textbook.

Motivation to Play

The design heuristics included in this game (e.g., quests, monkey, island, castle, helping miners, etc.) were adequate to the age group and provided engagement and enjoyment. Participants did not report boredom and generally indicated increased curiosity in the subject matter. Difficult questions were welcomed: when students were asked to stop or repeat an easier task all but two students refused. I argue that finishing the quest was more important than being tired or overwhelmed by the task. Completing the quest was a strong motivator. Determination to accomplish tasks and finish quests ought to be considered among heuristics of educational game design.

Gender Issues

Some female students disliked and even some male students commented on the male-oriented narrative of the mine quest. According to Schell (2008) videogame players enjoy: if male, mastery, competition, destruction, spatial puzzle, and trial and error; if female, emotion, real world, nurturing, verbal puzzles, and learning by example. However, this study did not confirm Schell's model: e.g., some girls were competitive and some cautious boys did not use trial and error.

6. Significance

The current study provided rich data that will be used to incorporate adequate individualized support and adaptive interaction. Algorithms aimed at detecting when help is needed and the predictive algorithms responsible for game adaptation to level of difficulty and student's learning style involve artificial intelligence aspects of student modeling, machine learning and adaptive interfaces that will be included in future re-designs of the game.

Gender is important for various reasons in game deign. Even with its mathematics content, the interaction offered by narratives and quests, Heroes of Math Island can be designed to address hidden gender cues and explore cultural and environmental factors that affect gaming and learning. More research is needed on the role that affective or pedagogical agents play in reinforcing or contradicting gender norms.

Although the game designed and evaluated in this study has the promise of a great pedagogical tool, it is also restricted by important limitations that govern games based on mastery and levels of difficulty. Freedom of exploration, a fundamental learning principle is in contradiction with the control imposed by the current game mechanics which restrict creative and constructivist involvement in learning.

Designing the game was a creative and collaborative process. The teacher, the instructional designers and especially students were very enthusiastic to offer feedback. The constructionist approach to learning by including young students in design of educational games was proven to be very energizing, motivating, and satisfying and should be explored further. Students felt empowered to critique and provide personal ideas, and indicated that they would like to return and continue the design.

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