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The effectiveness of adaptive difficulty adjustments on students' motivation and learning in an educational computer game

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ABSTRACT

Computer games that adaptively adjust difficulty are used to continuously challenge players according to their abilities. The adjustment of difficulty occurs automatically in response to a game's ongoing assessment of a player's performance. This approach to difficulty adjustment is likely to be of value in educational computer games as a means of scaffolding learning for students. However, there is limited research evaluating the effectiveness of educational computer games with adaptive difficulty adjustment when compared to non-adaptive difficulty adjustment. To expand on this research a quasi-experimental study was designed to isolate the impact of the difficulty adjustment game element on motivation and learning. A total of 234 secondary school students were allocated to one of three activities involving learning about Spanish cognates: an adaptive difficulty adjustment game, an incremental difficulty adjustment game that was non-adaptive, and a written activity. The three learning activities were designed following the same learning and motivation theories. The two games were identical apart from the difficulty adjustment mechanism. The results for motivation indicated that all students experienced high levels and there was no significant difference between the three learning activities. The pre- and post-tests results for learning indicated that significantly higher learning outcomes were achieved by students who played the adaptive game. Analysis of a game log recording the correctness of students' responses indicated that the adaptive difficulty adjustment game, in contrast to the non-adaptive incremental difficulty adjustment game, provided a scaffolding structure to enhance student learning.

1. Introduction

Educational computer games have become a popular teaching tool because of their ability to increase students' motivation (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012; Egenfeldt-Nielsen, 2007; Hays, 2005; Kirschner, Sweller, & Clark, 2006; Squire, 2005). This increase in motivation has been identified when educational computer games are not only educational but also fun to play (or intrinsically motivational) (Berns, Gonzalez-Pardo, & Camacho, 2013; Brom, Preuss, & Klement, 2011; Reinders, 2012). In education, students that are intrinsically motivated and whose levels of perceived competence are high often engage in academic behaviours that lead them towards higher learning outcomes (Cordova, 1983). Conversely, a lack of motivation is more likely to hinder learning.

One way to make educational computer games intrinsically motivational is to provide an optimal level of challenge. An optimal level of challenge is one where players are able to solve tasks that are neither too easy nor too difficult (Aponte, Levieux, & Natkin, 2011; Johnson, Vilhjalmsson, & Marsella, 2005). Learning activities that optimally challenge students and also recognise when they struggle and provide support are said to incorporate a scaffolding strategy (Van Der Stuyf, 2012). Learning activities implementing scaffolding have resulted in better learning outcomes than using the same activities without scaffolding (Chang, Sung, & Chen, 2001; Chang, Wernhuar, & Shin, 2009; Murphy & Messer, 2000). Of the multiple game elements that comprise an educational computer game, difficulty adjustment seems most likely to provide students with an optimal level of challenge and a scaffolding strategy. In particular,

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adaptive difficulty adjustment can be used to monitor the correctness of players' responses and continuously alter the level of challenge up and down as necessary.

Whilst educational computer games with adaptive difficulty adjustment would seem to have the necessary capabilities to promote student learning there is little research evaluating their effectiveness (Koidl, Mehm, Hampson, Conlan, & Gobel, 2010; Rodriguez, Cheng, & Basu, 2007). In particular, there are few studies comparing an educational computer game with adaptive difficulty adjustment with an equivalent game with non-adaptive difficulty adjustment (Bauer, Brusso, & Orvis, 2012; Orvis, Horn, & Belanich, 2008). Therefore, the aim of the study reported in this paper was to evaluate the effectiveness of an educational computer game with adaptive difficulty adjustment on students' motivation and learning outcomes when compared to both an educational computer game with non-adaptive difficulty adjustment and a traditional written activity.

2. Background

2.1. Motivation and learning theories

A number of motivation and learning theories were used in the design of the learning activities reported in this paper, including the educational computer games.

The adaptive difficulty adjustment game used in the study was intended to scaffold students' learning. Scaffolding is a learning theory focused on tailoring teaching within the students' zone of proximal development (ZPD). The ZPD refers to what a learner can achieve alone and what can be accomplished with assistance (Rodgers & Rodgers, 2004; Vygotsky, 1978). Scaffolding student learning involves supporting students' ability to build on prior knowledge and internalise new information by providing them with learning activities that are just beyond the current level of what they can achieve by themselves (Olson & Platt, 2000; Van Der Stuyf, 2012; Vygotsky, 1978). A learning activity can be designed to scaffold instruction by recognising the point at which difficulty occurs and structuring supports at that time (Rodgers & Rodgers, 2004).

The design of educational computer games can be enhanced through the incorporation of motivation and learning theories (Kickmeier-Rust et al., 2007; Koidl et al., 2010). For the game presented in this study, Malone's motivational theory and Csikszentmihalyi's flow theory were used to enhance the motivational aspect (Csikszentmihalyi, 1990; Malone, 1981), and the cognitive load and perceptual learning theories were used to enhance the educational aspect (Colvin, Nguyen, & Sweller, 2006; Goldstone, 1998). The principles underpinning these learning and motivation theories were incorporated in a set of guidelines used for the game design (see Section 4.1).

Malone's motivational theory emphasises how to make educational computer games motivational and fun to play through the use of elements such as: *challenge, goals, feedback, uncertain outcomes, self-esteem, player skills, curiosity, control* and *fantasy* (Malone & Lepper, 1987). Similarly, the Flow theory relates to elements that make an activity enjoyable such as: *completion, challenge, player skills, goals, feedback, concentration and control* (Sweetser & Wyeth, 2005). These elements were included in the learning activities of this study. For example, the element of *challenge* was included in the game by increasing the difficulty of both the educational content and the gameplay. In addition, the level of challenge was tailored according to the students' skills using adaptive difficulty adjustments. Due to space constraints, it is not possible to present how each one of the motivational elements was incorporated into the game and the written activity. The details are instead available in Sampayo-Vargas (2012).

The cognitive load theory specialises on methods to design and deliver instructional environments in ways that best utilise human cognition. The cognitive load theory follows a set of principles such as: *redundancy* – to minimise redundant teaching material; *modality* – to facilitate learning by providing audio explanations of visuals rather than text explanations; *multimedia* – to present the content as words and graphics rather than words alone, *etc*. Moreover, the learning theory of perceptual learning involves repetition to stimuli and long lasting changes to improve the ability to respond to those stimuli. Perceptual learning is based on mechanisms to better respond to stimuli such as: *attention-weighting, categorical perception, stimulus-imprinting, differentiation and unitisation.* These principles and mechanisms were used to design the learning activities of this study. For example, the principle of *modality* was included in the game using short, relevant and clear audio of the correct Spanish pronunciation when the English word was translated into Spanish. Again, due to space constraints, it is not possible to present the details of how each one of the learning principles and mechanisms were incorporated into the game and written activity. The details are instead available in Sampayo-Vargas (2012).

2.2. Difficulty adjustment

The definition of difficulty refers to something laborious, not easy to do or understand, which requires an effort to be accomplished (Nicholls & Miller, 1983). Following that definition, in this paper difficulty refers to the effort required to overcome the challenges presented in the learning activities of the empirical study.

There are two broad approaches to adjust difficulty in educational computer games: non-adaptive and adaptive difficulty adjustment. Non-adaptive difficulty refers to either the use of the same difficulty settings throughout a game or to adjustment based on game settings that are unrelated to the players' performance. An example of the latter is a game that incrementally increases difficulty after pre-defined intervals of time. In contrast, an adaptive difficulty mechanism adjusts the game difficulty according to the players' performance during gameplay (Andrade & Corruble, 2005).

In educational computer games the challenges are related not only to the difficulty of the gameplay but also to the difficulty of the educational content. The difficulty of the gameplay refers to the complexity of the game mechanics and settings. For example the number of objects to manoeuvre, speed, time limit to respond, etc. The difficulty of the educational content can be categorised depending on its complexity. Difficulty adjustments can be applied to the gameplay, the difficulty of the content or both. Thus adaptive difficulty adjustment can be used to provide an optimal level of challenge not only to the gameplay but also to the educational content. One possibility to support scaffolding is for an adaptive difficulty mechanism to reduce the difficulty of the gameplay when the students' responses indicate that they are having difficulty with the level of challenge of the content. The reduction in the difficulty of the gameplay would allow students more time to learn the content.