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Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness

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ABSTRACT

Educational researchers have recognized Augmented Reality (AR) as a technology with great potential to impact affective and cognitive learning outcomes. However, very little work has been carried out to substantiate these claims. The purpose of this study was to assess to which extent an AR learning application affects learners' level of enjoyment and learning effectiveness. The study followed an experimental/control group design using the type of the application (AR-based, web-based) as independent variable. 64 high school students were randomly assigned to the experimental or control group to learn the basic principles of electromagnetism. The participants' knowledge acquisition was evaluated by comparing pre- and post-tests. The participants' level overall-state perception on flow was measured with the Flow State Scale and their flow states were monitored throughout the learning activity. Finally, participants' perceptions of benefits and difficulties of using the augmented reality application in this study were qualitatively identified. The results showed that the augmented reality approach was more effective in promoting students' knowledge of electromagnetic concepts and phenomena. The analysis also indicated that the augmented reality application led participants to reach higher flow experience levels than those achieved by users of the web-based application. However, not all the factors seem to have influence on learners' flow state, this study found that they were limited to: concentration, distorted sense of time, sense of control, clearer direct feedback, and autotelic experience. A deeper analysis of the flow process showed that neither of the groups reported being in flow in those tasks that were very easy or too difficult. However, for those tasks that were not perceived as difficult and included visualization clues, the experimental group showed higher levels of flow that the control group. The study suggests that augmented reality can be exploited as an effective learning environment for learning the basic principles of electromagnetism at high school provided that learning designers strike a careful balance between AR support and task difficulty.

1. Introduction

Interactive technologies such as 3D virtual worlds (3DVWs) and augmented reality (AR) are potentially effective in promoting learning benefits (Conole & Dyke, 2004); they act through the mediation of usability and psychological states on learning outcomes (Choi & Baek, 2011; Dalgarno & Lee, 2010; Dickey, 2005; Dunleavy, Dede, & Mitchell, 2009; Kye & Kim, 2008; Lee, Wong, & Fung, 2010; Wu, Lee, Chang, & Liang, 2013). Therefore, an active area of research is the exploration of learning affordances offered by these emerging technologies in different knowledge areas (Dalgarno & Lee, 2010; Mikropoulos & Natsis, 2011).

Augmented reality refers to technologies that enhance the sense of reality allowing the coexistence of digital information and real environments (Azuma, 1997). These technologies enable learners to interact with real objects in ways still to be discovered (Bujak et al., 2013; Cuendet, Bonnard, Do-Lenh, & Dillenbourg, 2013). However, high-quality user experiences are difficult to achieve and interaction with the learning environment should help, not hinder the teaching-learning process (Dunleavy et al., 2009; Zaharias, 2003). Many studies

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have reported that once high-quality interaction with the learning environment is achieved, students' emotional states contribute to improved learning effects (Billinghurst, 2003; Dalgarno & Lee, 2010; Kye & Kim, 2008; Lee et al., 2010). Furthermore, researchers have shown that AR features might increase students' motivation, engagement and their satisfaction on performing learning activities. In this regard, B. Kye and Y. Kim's conceptual model (2008) states that AR's media characteristics namely sensory immersion, navigation and manipulation might foster feelings of presence, flow state and satisfaction. Their model is similar to B. Dalgarno and M. Lee's model of learning in 3d virtual learning environments (2010) and both conclude that a positive impact of AR on emotions would improve students' cognitive processes and performance. What is lacking, however, is empirical studies to support or refute these theoretical claims (Cheng & Tsai, 2012; Dalgarno & Lee, 2010; Kye & Kim, 2008).

A full history of emotional states that emerging technologies might foster on learning activities is beyond the scope of this work. We concentrate our efforts on the observation the "optimal experience" or "flow" (Csikszentmihalyi, 1990). Flow describes a state of complete absorption or engagement in an activity that acts as a motivating factor in daily activities such as work, sport, and education (Chan & Ahern, 1999; Choi & Baek, 2011; Kye & Kim, 2008; Pearce, Ainley, & Howard, 2005). The motivation promoted by the flow state enables learners to engage in activities without receiving any apparent reinforcement (Davis, Bagozzi, & Warshaw, 1992). As this self-motivated learning is considered the best way to learn (Ghani & Deshpande, 1994), a main challenge in education is to foster learners' flow state. In this regard, research in web-based learning environments has shown that there is a positive correlation between the flow state that students might reach when using these environments and their learning outcomes (Liao, 2006; Shin, 2006; Webster, Trevino, & Ryan, 1993). Positive results have also been highlighted by studies that analyzed the performance of students within multi-user virtual environments and game-based learning environments (Faiola, Newlon, Pfaff, & Smyslova, 2013; Papastergiou, 2009). Therefore, it is reasonable to expect that an emergent technology such as AR may also promote learners' flow state and consequently help them to achieve better learning outcomes. Based on these concerns, this study aimed to research on the impact of AR on learners' flow state in the context of electromagnetism, a domain area that underpins the operation of much of today's technologies.

Electromagnetism is abstract and cognitively demanding, thus it is one of the most difficult subjects for students to master (Dori & Belcher, 2005). To understand abstract scientific concepts, students are required to build mental models where they internalize and organize knowledge structures (Dede, Salzman, Loftin, & Sprague, 1999). Unlike what happens in other Physics' conceptual areas, when dealing with electromagnetism, students' mental models should include abstractions and invisible factors for which students have no real-life references (Maloney, O'Kuma, Hieggelke, & Van Heuvelen, 2001). The relevance of presenting learning materials not only through words but also through visual assets to fully understand the nature of scientific phenomena and processes was reported by Dori, Hult, Breslow, and Belcher (2007). Indeed, these concerns were already addressed in the MIT Technology Enabled Active Learning (TEAL)/Studio Project where students developed much better intuition about, and conceptual models of, physical phenomena through the use of visualization in an electricity and magnetism course using web-based technologies (Belcher & Bessette, 2001; Dori et al., 2007). Consequently, developing effective pedagogical strategies and using emergent technologies for helping students in this endeavor will be a step ahead to validate TEAL Project findings when using AR technology. In this regard, augmented reality has been recognized as a technology with great potential for science learning (Bujak et al., 2013; Cheng & Tsai, 2012; Wu et al., 2013) as it provides new ways of tactile and visual interactions which could be useful to improve learning outcomes (Cheng & Tsai, 2012; Gilbert, 2005; Rapp, 2005). Visualization features of AR have been successfully used to improve spatial abilities in science and engineering (Dünser, Steinbügl, Kaufmann, & Glück, 2006; Martín-Gutiérrez et al., 2010). However, few studies have explored the visualization benefits of AR in science in general and physics in particular (Cuendet et al., 2013; Wu et al., 2013).

In response to the aforementioned issues, the aim of this study was to assess the learning effectiveness of an augmented reality experimental lesson for learning the basic principles of electromagnetism and the level of enjoyment of high school students. The lesson was designed according to the curricular objectives and subject matter of the Spanish high school Physics curriculum, and compared to a similar web-based lesson which encompasses identical learning objectives and content. Both AR and web based lessons guided the students through the building of an electromagnetic circuit representing a problem to solve which involved basic principles of electromagnetism. Each building stage offered students the possibility to review (or learn) concepts related to the proposed learning task. The AR-based lesson guided the learning workflow by leading students to build a circuit while allowing them the visualization of the forces involved and the exploration of their circuit behavior. The following research questions shaped this study:

1. Do students who use an augmented reality based lesson develop deeper understanding of the embedded basic principles of electromagnetism compared to peers who use a similar web-based lesson?
2. Do students who use an augmented reality based lesson experiment reach a flow experience higher than the one achieved by peers using a similar web-based lesson?

The study is unique in that it investigates the use of AR technology within real school settings for teaching electromagnetism at high school level, while also comparing an AR-based application with a web-based application. The study can help us to learn whether AR technology can be effective in promoting student flow, and to gain understanding on which activities maintain students' engagement in AR-based learning environments. Furthermore, this empirical research might contribute to a better understanding of the impact of AR on learning outcomes, mainly those requiring the understanding of electromagnetic invisible forces. In addition, it can provide insight into what benefits and difficulties students found when interacting with an AR-based learning environment.

2. Learning affordances of augmented reality

Each interactive technology has a set of features that facilitates particular approaches to educational practice (Choi & Baek, 2011; Conole & Dyke, 2004; Dalgarno & Lee, 2010; Dickey, 2005; Dunleavy et al., 2009; Kye & Kim, 2008; Lee et al., 2010; Wu et al., 2013). For instance, three-dimensional virtual world (3DVW), an interactive technology that shares relevant characteristics with augmented reality, offers representational fidelity and learning interaction as technical features (Chittaro & Ranon, 2007). These features potentially promote learners' psychological states such as the construction of identity, sense of presence, and co-presence, and foster the flow state (Choi & Baek,