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Augmented reality in science laboratories: The effects of augmented reality on university students' laboratory skills and attitudes toward science laboratories

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ABSTRACT

This study investigated the effects of the use of augmented reality (AR) technologies in science laboratories on university students' laboratory skills and attitudes towards laboratories. A quasi-experimental pre-test/post-test control group design was employed. The participants were 76 first-year university students, aged 18–20 years old. They were assigned to either an experimental or a control group. Qualitative and quantitative data collection tools were used. The experimental results obtained following the 5-week application revealed that the AR technology significantly enhanced the development of the university students' laboratory skills. AR technology both improved the students' laboratory skills and helped them to build positive attitudes towards physics laboratories. The statements of the students and the instructor regarding other effects of AR technology on science laboratories, both negative and positive, are also discussed.

1. Introduction

In the broadest terms, augmented reality (AR) can be defined as "a real world context that is dynamically overlaid with coherent location or context sensitive virtual information" (Klopfer & Squire, 2008, p. 205). AR has three main characteristics: (a) a combination of virtual and real objects in a real setting, (b) people working interactively in real time, and (c) an alignment between real and virtual objects (Azuma et al., 2001). AR was first used in the 1990s, when applications were related to the training of pilots (Caudell & Mizell, 1992). Medical educators soon used it as well. The use of AR technology is now becoming increasingly popular in the fields of engineering (Behzadan, Dong, & Kamat, 2015), environmental science (Tsai et al., 2012), and particularly education (Yen, Tsai, & Wu, 2013). Currently, AR technology is used in every level of schooling, from K-12 (Chiang, Yang, & Hwang, 2014b; Kerawalla, Luckin, Seljeflot, & Woolard, 2006) to higher education (Ferrer-Torregrosa, Torralba, Jimenez, García, & Barcia, 2015). Though initially the application of this technology required high-end electronics hardware and sophisticated equipment for educational environments, such as head-mounted displays (HMD), this technology is used more widely now because new AR applications are supported by computers and mobile devices (smartphone, tablet PC, etc.) (Wu, Lee, Chang, & Liang, 2013). Mobile devices with improved hardware properties are available at lower prices, and so the use of AR technology is not as difficult as it once was (Gervautz & Schmalstieg, 2012; Martin et al., 2011; Squire & Klopfer, 2007).

Studies have shown that AR technology can greatly enhance educational outcomes (Chiu, DeJaegher, & Chao, 2015). For instance, AR helps students to engage in authentic explorations in the real world (Dede, 2009). AR enables us to experience scientific experiments, such as chemical reactions, that we cannot easily experience in the real world (Klopfer & Squire, 2008). AR also makes it possible to visualize concepts such as airflow or magnetic fields, and also events, by displaying virtual elements over real objects (Dunleavy, Dede, & Mitchell, 2009; Wu et al., 2013). AR helps students to improve their knowledge and skills, and does so more effectively than other technologies (ElSayed, Zayed, & Sharawy, 2011). It increases students' motivation, and in this way, students gain better investigation skills and do not experience conceptual fallacies (Sotiriou & Bogner, 2008).

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Though it offers many advantages, AR poses some challenges that must be considered. Lin, Hsieh, Wang, Sie, and Chang (2011) reported that students find AR complicated and experience some technical problems while engaging with it. For example, in location-based AR applications, there are sometimes problems with GPS accuracy (Chiang et al., 2014b). Without a good interface design and the provision of extensive guidance, AR technology can be overly complex for students (Squire & Jan, 2007). The use of a variety of devices for AR applications may create even more technical problems (Wu et al., 2013). Also, the resistance of some teachers and faculty to AR technology is an occasional obstacle for AR usage in education (Kerawalla et al., 2006). For students, complicated tasks and large amounts of information to master may increase their cognitive loads and prevent their learning (Cheng & Tsai, 2013; Dunleavy et al., 2009). However, careful consideration all of these challenges during the processes of design and application can help in the development of more effective uses of AR for science education.

2. Theoretical background

The multimedia learning theory provides potential explanations of how AR may improve learning (Chiang, Yang, & Hwang, 2014a; Santos et al., 2014; Sommerauer & Müller, 2014). Multimedia is defined as the presentation of material using both words (e.g., printed or spoken text) and pictures (e.g., graphs, photos, animation, video) (Mayer, 2009). Mayer has shown that certain principles in this theory are directly related to AR annotation applications (Santos et al., 2014). These include the multimedia principle, the spatial contiguity principle, the temporal contiguity principle, and the learner control principle.

The multimedia principle states that students learn better from words and pictures than from words alone. As Mayer stated, "when words and pictures are both presented, students have an opportunity to construct verbal and pictorial mental models and to build connections between them" (Mayer, 2009, p. 63). According to Sommerauer and Müller (2014), AR provides opportunities based upon this principle by combining printed text with virtual content (e.g., integrating videos into a textbook) or by augmenting physical objects with virtual text (e.g., displaying informative text at the top of a screen-image of an historical building).

The spatial contiguity and temporal contiguity principles state that students learn better when corresponding words and pictures are presented near to one another and simultaneously (Mayer, 2009). Incorporating these two principles, AR superimposes virtual content onto physical objects in real-time, and thereby spatially and temporally aligns real and virtual objects (Sommerauer & Müller, 2014). AR technology also links real-world contexts with virtual content at the right place and at the right time (Chiang et al., 2014a).

Finally, the learner control principle suggests that the learner should be given control over the instructional material, for example, over the pace and/or sequence (Mayer, 2014). According to Fowler (1983) and Newkirk (1973), giving the learner this control can improve the students' attitudes about a topic. Embodying the learner control principle, AR helps learners to take control of their learning and enables them to work independently, at their own pace (Kamarainen et al., 2013).

2.1. Technology and science laboratories

Technology develops continuously and is increasingly prevalent in classrooms. Wikis, forums, chat rooms, virtual worlds, and cloud computing technology now are used in traditional classrooms (Zhang, Ma, Wu, de Pablos, & Wang, 2014). Technology allows students to access educational resources from nearly any location, at any time (Zhang, de Pablos, & Xu, 2014). Students are also more comfortable with learning when using technologies such as video and animation (Zhang, Liu, de Pablos, & She, 2014).

As in traditional classrooms, technology is of course also used in laboratories (Chiu et al., 2015). The use of technology in science labs presents helpful opportunities to students, who can participate in high-budget, dangerous, and complex experiments that would be difficult to conduct otherwise. Research on technology use in science laboratories has revealed that it has yielded positive outcomes (Olympiou & Zacharias, 2013; Trundle & Bell, 2010).

On the other hand, some studies report that the use of educational technology does not significantly influence the effectiveness of science laboratories (Klahr, Triona, & Williams, 2007; Wiesner & Lan, 2004). Moreover, students' constant uses of hardware, such as a computer mouse and keyboard, instead of real laboratory equipment to conduct their experiments may hinder the development of their practical laboratory skills. Research has proven that an approach in which physical and virtual experiences are combined yields the best results because students can make use of opportunities offered by the educational technology in their science labs, and they are not thereby separated from the real laboratory environment and equipment (Zacharia, 2007; Zacharia & Olympiou, 2011). Students must train themselves in practical and motor skills, and acquire hands-on experience with physical equipment in order to master experimental procedures and learn science content (De Jong, Linn, & Zacharia, 2013). With the proper integration of the educational technology into the real lab environment, the students can optimize their learning (De Jong et al., 2013; Lui & Slotta, 2013). To sum up, educational technology should not keep students completely separated from the real laboratory environment and equipment.

3. Research purposes

Cheng and Tsai (2013) conducted a literature review on the use of AR technology in education. They reported that studies on AR in science education are few in number and that the field is in its infancy. The existing research focuses on issues such as development, usability, and initial implementation (Blake & Butcher-Green, 2009; El Sayed et al., 2011; Kaufmann & Schmalstieg, 2003). Students' laboratory skills and learning outcomes have been ignored to a great extent (Cheng & Tsai, 2013). The effect of AR technology on university students' laboratory skills should be investigated in science education. Thus, the first purpose of this study is to investigate whether there is a significant difference between the lab skills of students who use AR technology in their science labs and those who do not.

Attitude is important when learning science. University students should have positive attitudes towards science laboratories when acquiring lab skills and science content (Bal, 2012). Attitudes toward science labs affect the efficiency of lab training (Palic & Pirasa, 2012), and are also important in relation to continuing science research and to pursuing a career in the field (Cavallo & Laubach, 2001; Jarvis & Pell, 2005). Attitude is also a factor that influences students' achievements in science (Gönen, 2008; Osborne, Simon, & Collins, 2003). Research on the effects of new educational technologies used in science labs on students' attitudes towards these labs should provide more information about the educational outcomes related to these technologies. The second purpose of this study is to determine whether there is a significant difference between the attitudes of students using AR technology in their science labs compared to those who do not.

The opinions and suggestions of the users must be ascertained in order to determine the positive and negative aspects of AR and to