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Learning with desktop virtual reality: Low spatial ability learners are more positively affected

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A B S T R A C T

This study aims to verify the learning effectiveness of a desktop virtual reality (VR)-based learning environment, and to investigate the effects of desktop VR-based learning environment on learners with different spatial abilities. The learning outcome was measured cognitively through academic performance. A quasi pretest–posttest experimental design was employed for this study. A total of 431 high school students from four randomly selected schools participated in this study where they were randomly assigned to either experimental or control groups based on intact classes. Findings indicate a significant difference in the performance achievement between the two groups with students performed better using desktop virtual reality. A possible explanation is that the desktop virtual reality instructional intervention has helped to reduce extraneous cognitive load and engages learners in active processing of instructional material to increase germane cognitive load. A significant interaction effect was found between the learning mode and spatial ability with regard to the performance achievement. Further analysis shows a significant difference in the performance of low spatial ability learners in the experimental and control groups, but no statistically significant difference in the performance of high spatial learners in both groups. The results signify that low spatial ability learners' performance, compared with high spatial ability learners, appeared to be more positively affected by the desktop VR-based learning environment which is supported by the ability-as-compensator hypothesis, and can be explained by the cognitive load theory.

1. Introduction

There is a growing trend to use virtual reality (VR)-based learning in schools and colleges (Huang, Rauch, & Liaw, 2010; Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014; Mikropoulos & Natsis, 2011; Stull, 2009). De Jong, Linn, and Zacharia (2013) has elaborated the use and advantages of virtual laboratories in science and engineering education in the recent decade. Nevertheless, research finding is mixed with regard to the learning effectiveness of VR-based learning. Positive research outcomes have been reported with VR-based learning such as better performance in business knowledge application (Cheng & Wang, 2011); improved anatomy learning (Petersson, Sinkvist, Wang, & Smedby, 2009); greater efficiency in matching diagrams and models (Stull, Barrett, & Hegarty, 2013); improved calligraphic writing skills (Wu, Yuan, Zhou, & Cai, 2013); improved spatial thinking (Cohen & Hegarty, 2014; Dünser, Steinbügl, Kaufmann, & Glück, 2006; Hauptman, 2010); enhanced spatial abilities for "sensing" and kinesthetic learning style learners (Hauptman & Cohen, 2011) and for low visual spatial ability learners (Meijer & van den Broek, 2010); and the ability to accommodate learners with different learning styles in cognitive outcomes (Chen, Toh, & Wan, 2005; Lee, Wong, & Fung, 2010b) and affective outcomes (Lee et al., 2010b)

On the other hand, Urhahne, Nick, and Schanze (2009) found no difference in understanding chemical structures and their properties for freshman students using three-dimensional (3-D) simulations and two-dimensional (2-D) images. Similarly, in the study of Merchant et al. (2013), the hypothesis that 3-D virtual environment can enhance chemistry learning among undergraduate students was not supported.

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Besides, students did not demonstrate greater understanding of the genetics concepts in the study of Annetta, Minogue, Holmes, and Cheng (2009). Therefore, VR might not work for all kinds of learning. Learner characteristics or individual differences can account for different learning results in VR-based learning environment (Chen, 2006; Hauptman & Cohen, 2011). In recent years, there is more focus on the role of learner characteristics or individual differences on learning with visual representations (Höffler & Leutner, 2011). The importance of considering individual differences in visual representations is also emphasized by Meijer and van den Broek (2010). The effects of learner characteristics on learning outcomes would enable instructor to adapt the nature of instruction to accommodate individual differences to improve learning outcomes.

This study therefore aims to verify the learning effectiveness of a desktop VR-based learning environment in biology education, and to investigate the effects of VR-based learning environment on learners with different spatial abilities. We intend to provide an answer to these questions: (1) Is there any difference in the learners' performance achievement between a desktop VR-based learning environment and a conventional classroom learning practice? (2) What is the interaction between learners' spatial ability with the learning environment with regard to their performance achievement?

2. What is virtual reality?

VR is a way of stimulating or replicating an environment that can be explored and interacted with by a person (Ausburn & Ausburn, 2004; Chuah, Chen, & Teh, 2008; Inoue, 2007). VR computer simulations could take many forms, ranging from computer renderings of 3-D geometric shapes on a desktop computer to highly interactive, fully immersive multisensory environment in laboratory (Ausburn & Ausburn, 2004; Mikropoulos & Natsis, 2011; Strangman & Hall, 2003). Unlike static picture, the VR computer image is dynamic, a mimic of a real object and can be rotated to different orientations with a handheld device (Stull, 2009). Education has moved to the use interactive technologies to help impart knowledge and understanding as an alternative to books, pencils and pens (e.g. Aoki, Oman, Buckland, & Natapoff, 2008; Cheng & Wang, 2011; Kebritchi, Hirumi & Bai, 2010).

There are basically two types of VR: Immersive VR and Non-immersive VR. Due to the technological advancements, today's VR system can run on a relatively cheap system such as desktop personal computer, which is known as "non-immersive" or "desktop" VR (Chen, Toh, & Wan, 2004; Lee, Wong, & Fung, 2009; Merchant et al., 2014; Strangman & Hall, 2003). Non-immersive VR or desktop VR is a 3-D image that generated in a multimedia environment on a personal computer, which can be explored interactively by using keyboard, mouse, joystick or touch screen, headphones, shutter glasses, and data gloves (Chen et al., 2004; Gazit, Yair, & Chen, 2006; Strangman & Hall, 2003). The desktop VR-based learning environment could be games, simulations or virtual worlds. The advancement of web technologies has enabled multiple users to work collaboratively in a virtual environment such as Second Life®. Though desktop VR is considered less immersive; however, Dalgarno, Hedberg, and Harper (2002) argue that "the sense of presence or immersion in a virtual environment is induced by the representational fidelity and the high degree of interaction and control of user, rather than just a unique attribute of the environment". Immersive VR environments are presented on multiple, room-size screen or through a stereoscopic, head-mounted display unit (Chen et al., 2004; Dalgarno et al., 2002; Strangman & Hall, 2003). Lee and Wong (2008) has articulated the three levels of immersive VR classified by Allen et al. (2002): partially or semi immersive VR; fully immersive VR; and augmented reality or mixed reality. Due to the high cost of immersive VR systems and the inherent problems associated with them such as simulator sickness, desktop VR provides an alternative to immersive VR systems because it retains the benefits of real time visualization and interaction within a virtual world (Chen et al., 2004; Chuah et al., 2008; Huang et al., 2010; Merchant et al., 2012, 2014).

3. Theoretical background

3.1. Aptitude-by-treatment interaction

Aptitude-by-treatment interaction (ATI) research refers to the concept that instructional strategies are more effective when they are adapted to the specific abilities and/or attributes of the learners (Fletcher & Tobias, 2005, p. 130; Plass, Kalyuga, & Leutner, 2010). Ausburn and Ausburn (2004) have called for the application of the ATI model in new studies in VR in education because the ATI model is more multi-factor in concept which involves not only independent and dependent variables but also moderating variable as well. In this model, the interest is not on the effect of an instructional method, if it works or is better, but on the interactions between various instructional methods and learners' aptitudes or characteristics. Interaction between aptitude and treatment occurs when the effect of treatment differs depending on the level of aptitude measure. Such a research model will enlighten educators for what purposes and for whom an instructional method may be effective (Ausburn & Ausburn, 2004). There is limited research that investigates the statistical effect of ATI between instructions and spatial ability (Wang, Chang, & Li, 2007).

3.2. Spatial ability and VR

Spatial ability refers to a group of cognitive functions and aptitudes that is crucial in solving problems that involve manipulating and processing visuo-spatial information (Lajoie, 2008). Spatial visualization ability is a measure of the ability to mentally restructure or manipulate the components of visual stimulus and involves recognizing, retaining, recalling configurations when the figure or parts are moved (McGee, 1979). It is believed that spatial visualization ability is the primary cognitive factor that causes the differences in performance and has an impact on comprehension of 3-D computer visualization (Huk, 2006). Students with different spatial ability will benefit differently when learning with interactive 3-D animation or simulations (Höffler & Leutner, 2011; Huk, 2006) which depends on their ability to extract relevant information and then to reconstruct or incorporate the information into their existing mental models.

The study of Merchant et al. (2012) reported that spatial orientation mediates the relationships between 3-D virtual learning environment features and chemistry learning outcomes. Lee, Wong, and Fung (2010a) have also found that control and active learning in a VR learning environment is a more concern factor for the high spatial ability learners. High spatial ability learners are more likely to perform