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Learning in simulated environments: An assessment of 4-week retention outcomes

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ABSTRACT

Simulations offer the benefits of a safer and more accessible learning environment, where learners can practice until the point of proficiency. While research into the effectiveness of simulations as learning tools has found tangible benefits, fewer studies have examined retention and differences between high and low fidelity simulations. This research sought to supplement the literature in this domain by investigating whether participants who learned to construct an electrical circuit using a 2D or 3D breadboard simulation could achieve comparable learning, transfer, and retention outcomes to those who learned using a physical breadboard. The influence of learner characteristics - cognitive ability and goal orientation - were also evaluated. This study had two parts: a cross-sectional portion that examined learning and transfer outcomes and a longitudinal portion that examined retention outcomes after a 2 and 4-week period. The cross-sectional analysis included 70 participants and the longitudinal analysis included 40 participants. The results found that the physical fidelity of the learning environment significantly impacted several transfer outcomes (construction and construction time) but not retention outcomes. Cognitive ability was a significant predictor of learning (gain score, circuit design score) and retention (posttest scores, construction time) outcomes. Learning goal orientation significantly predicted circuit construction over time and measurement occasion significantly predicted posttest scores and interacted with fidelity to predict circuit design score. The study demonstrated that simulated environments can lead to comparable, or better, proficiency than physical environments. These findings have implications for the design and implementation of simulated environments, specifically for courses delivered in an online setting.

1. Introduction

The use of technology has led to unprecedented changes in secondary, higher, and workforce education. Virtual schools have allowed high school students to complete their diplomas online, online degree programs have become commonplace in higher education, and organizations have leveraged online courses and webinars to provide their employees with continuing and just-in-time educational opportunities. Prior research that has compared learning outcomes in online environments, including simulation technology, has found promising results (Campbell et al., 2002; Jaakkola and Nurmi, 2008; Zacharia and Olympiou, 2011). However, presenting course material in an online setting necessitates adaptation and there is still a need to develop and evaluate online education technologies and pedagogies, specifically for technical skills (Bernard et al., 2004). For technical skills, this adaptation has included the use of simulations to substitute or supplement hands-on practice and application (Finkelstein et al., 2005). Despite the increased use of simulations in education, the adoption of technology supersedes the empirical evidence demonstrating its efficacy (Goode et al., 2013). Theoretically, simulated environments are believed to support learning through active exploration, as opposed to direct instruction, that allows learners to develop conceptual understanding and mental models (Dalgarno, 2002). Constructivist theory also suggests that immediate feedback provided by the interactivity of simulated environments allows learners to test different theories and models of the phenomena under study and integrate it into their existing knowledge structure. The studies that have investigated and compared learning in 2D and 3D simulations have focused on conceptual gains, with few specifically evaluating transfer and retention outcomes or examining the role of learner characteristics (Campbell et al., 2002; Finkelstein et al., 2005; Zacharia and Olympiou, 2011; Jaakkola et al., 2011).

The model of transfer developed by Baldwin and Ford (1988) suggests that instructional outcomes, such as acquisition, and transfer outcomes, such as application, are affected by instructional design elements, including the learning environment, as well as learner

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characteristics (Baldwin and Ford, 1998). This interaction was also proposed by aptitude-treatment interaction theories, which argued that different learning environment may be more or less effective depending on the aptitude of the learner (Snow, 1989). The design of the simulations, including the physical fidelity, represents a design element that can facilitate or impede learning and application along with learner characteristics such as engagement, intelligence, and prior knowledge. This research sought to investigate whether individuals who learned a hands-on task in a 2D or 3D simulated environment achieve comparable learning, transfer, and retention outcomes as those who learned in a physical environment. Learner characteristics were also considered.

2. Background

2.1. Learning in simulated environments

When compared to learning in a physical environment, learning in both 2D and 3D simulated environments can offer several advantages. Simulations provide a safe, accessible environment where learners can explore and practice at their own pace (Jaakkola and Nurmi, 2008). Researchers have suggested that when simulations incorporate interactivity, animation, and a meaningful context, they can create a “powerful learning environment” (Adams et al., 2008, pg. 418). Simulations can help students learn complex relationships and develop a better conceptual understanding by illustrating unseen phenomena - such as the flow of electricity – and fostering students' sense of exploration (Adams et al., 2008; Finkelstein et al., 2005; Jaakkola et al., 2011). Simulations also provide an ideal environment where students can develop a theoretical understanding without the complications associated with malfunctioning laboratory equipment (Finkelstein et al., 2005; Jaakkola and Nurmi, 2008). Additionally, Mikropoulos and Natsis (2011) noted that 3D simulations can help facilitate learning by expanding human capabilities by providing zooming features, multiple vantage points, and accurate scientific visualizations.

One criticism of simulated laboratories, however, is that they force students to learn in an environment that is fundamentally different from the environment in which they may ultimately work (Jaakkola and Nurmi, 2008). Simulations lack the physicality, or the touch of real components, which is believed to support science learning (Zacharia and Olympiou, 2011) and may also lack the nuances and the sensory feedback that exist in the real world; oversimplifying complex systems. While potentially beneficial for learning, simulations can create issues for learners when they encounter real issues or problems that were not experienced in the simulation (Alfred et al., 2016). Learners may maintain doubts that the principles demonstrated in a simulation are applicable in the real world (Couture, 2004).

The fidelity of a simulation is also relevant when evaluating the efficacy of learning in simulated environments. Fidelity is the level of realism that a virtual manipulation presents to the learner (Zacharia and Olympiou, 2011). This research focused on physical fidelity, which describes the extent to which the simulation corresponds to the real-world (Goode et al., 2013). While some researchers have called for a more sophisticated taxonomy to describe simulations, “low,” “mid,” and “high” have been the de facto characterization for the fidelity of simulated environments (Goode et al., 2013). With some variation among industries, “high” typically represents immersive 3D environments and “low” represents desktop VR and 2D environments with “mid” incorporating some high and low fidelity elements (Kaptein et al., 1996).

Early research conducted by Regian et al. (1992) found that instruction using 2D simulation might be less effective as translating the representation from 2D to 3D results in additional cognitive load for learners. Conversely, lower levels of fidelity may support learning because of its abstraction of irrelevant and potentially overstimulating details that increase extraneous cognitive load (Sweller, 2010; Zacharia and Olympiou, 2011). Although these findings concerning the efficacy of 2D simulations appear conflicting, they suggest that lower levels of fidelity may support learning but hinder transfer. Alfred et al. (2016) found that while learners enjoyed the simplicity of working in a 2D simulated environment, some of them believed that learning in that environment hindered their real-world performance.

For engineering and hands-on skills, the use of 3D representations may lead to better learning outcomes as 2D representations may be inherently deficient (Richards and Taylor, 2015; Sampaio et al., 2010). The 3D environment can lead to the development of a 3D conceptual model of the physical concepts and may also facilitate recognition in the real world (Dalgarno and Lee, 2010). However, 3D representations can lead to poor performance because their increased complexity can make it difficult for students, particularly novices, to work in that environment (Gillet et al., 2013; Stuerzlinger and Wingrave, 2011). Technical issues like poor resolution and computational lags in 3D environments can also lead to performance deficiencies (Kenyon and Afenya, 1995).

2.2. Transfer of learning from simulated environments

The application of learning in the real-world is called transfer (Yamnill and McLean, 2001). Some researchers suggest that lower levels of fidelity support transfer as they help reduce cognitive load by omitting potentially over-simulating details (Zacharia and Olympiou, 2011; Paas and Sweller, 2014). This idea is supported by Cognitive Load Theory (CLT) which argues that environments or instructional techniques that impose an additional cognitive burden on learners are detrimental to learning (Paas and Sweller, 2014). Environments which can increase the resources devoted to learning, can facilitate skill acquisition and transfer (van Merriënboera et al., 2002). Proponents of high fidelity, however, suggest that the correspondence between the 3D simulation and the real world supports recognition; helping to activate the requisite schemas developed using the simulation (Zacharia and Olympiou, 2011). The 3D environment can also improve transfer of knowledge and skills to real situations through contextualization of learning (Dalgarno and Lee, 2010). This viewpoint is supported by Thorndike's Identical Elements Theory (IET), which posits that there will be a high positive transfer when identical stimulus and response elements are used in the learning and transfer environments because learners are essentially practicing the task which they will have to execute (Goldstein and Ford, 2002; Yamnill and McLean, 2001). Alfred et al. (2015) found evidence that participants who learned a circuit construction task in the physical environment outperformed participants who learned the same task in a 2D or 3D simulated environment. However, participants in the 2D and 3D environments did not significantly differ in performance.

2.3. Retention of learning in simulated environments

Arthur et al. (1998) stated that in order to truly understand the effects of an instructional program, both transfer and retention has to be evaluated along with learning. A major opportunity in the research related to simulated learning environments is examining skill decay and the ability of individuals to retain skills over time. Skill decay describes the loss of knowledge or a skill following a period of nonuse (Arthur et al., 1998). The typical decay curve has found that most loss occurs immediately after learning then decays at a slower pace until it approaches its pre-instruction levels (O'Hara, 1990). There is little extant literature that specifically compares the effects of varying levels of fidelity on learning and retention outcomes outside of the workforce education (Richards and Taylor, 2015). However, Ricci et al. (1996) offered insight on retention in computer-based environments. They suggested there are six attributes of computer-based games that support retention - active participation, immediate feedback, dynamic interaction, competition, novelty, and goal direction. Of the six attributes of computer-based gaming, three of these attributes - dynamic interaction,