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Comparing learning outcomes in physical and simulated learning environments

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ABSTRACT

The use of 2D and 3D simulated learning environments in education and training has increased significantly in the past decade. Simulated learning environments provide several advantages over physical learning environments including increased safety and accessibility. Simulated learning environments can also be utilized in an online setting, increasing the efficiency of delivery, access, and supporting greater personalization of the learning process. Despite a long history of use in workforce education, researchers have questioned whether simulations provide learners with the same quality of education as physical learning environments. This research investigated how learning to construct electrical circuits using a 2D simulation, a 3D simulation or a physical breadboard impacted learning outcomes. Additionally, this study examined the influence of learner characteristics, cognitive ability and goal orientation, on the relationship between the simulated learning environments and learning outcomes. The study utilized a pretest-posttest between subjects design and included 48 participants. Results suggest that learning to construct a circuit with physical components results in higher self-efficacy, faster construction times, and higher odds of correct construction than learning in a 2D or 3D simulation. Participants in the three conditions achieved comparable results in terms of cognitive outcomes; the differences identified were based on cognitive ability and goal orientation. There were no significant differences in outcomes achieved between participants in the 2D and 3D simulations. Implications for the design of simulated learning environments and potential impact for online technical curriculum are discussed.

Relevance to industry: This study supports the evaluation of using online educational technology to learn technical skills. This is relevant to workforce education, especially with a diverse and distributed workforce that requires technical training.

1. Introduction

Technical education has been slower than other disciplines in adopting online delivery for course and laboratory instruction (Bernard et al., 2004). This is, in part, due to the belief that laboratory education for technical skills requires hands-on, classroom-based instruction that simulated environments cannot provide (Bourne et al., 2005; Zacharia and Olympiou, 2011). This perspective is supported by concerns that the adoption of simulations has occurred more rapidly than empirical evidence supporting its effectiveness (Goode et al., 2013) and recognition that offering technical courses, specifically those requiring a lab component, in an online setting requires the development of pedagogies that support course adaptation and effective evaluation (Bernard et al., 2004). However, simulated learning environments provide several advantages over physical learning environments including a safer learner environment that allows learners to practice at their own pace, on their own schedule, and until the point of proficiency (Krueger, 1991; Zacharia, 2007). Simulations can also be delivered in an online setting, allowing increased accessed and efficiency of delivery, and greater personalization of the learning process (Henderson et al., 2015; Kim et al., 2013). Developing effective simulations for technical courses, including simulated learning environments to support laboratory-based instruction, is instrumental for increasing educational access and opportunities for students and fully exploiting the benefits of online education. This research sought to evaluate the influence of simulated learning environments, both 2D and 3D, on learning outcomes for a technical course with a corresponding laboratory-based activity.

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2. Background

2.1. Physical and simulated laboratory instruction

Laboratory instruction is a key educational feature for technical disciplines as well as science, engineering, and math. These learning environments were developed with the belief that understanding how to apply science to solve real world problems required both theory and practice (Auer et al., 2003). In laboratories, students may study proper laboratory technique, develop analytical thinking, connect theory to practice, and gain hands-on experience (Woodfield et al., 2005). Students also engage in active learning, conduct experiments, and employ problem-solving skills that facilitate the application of theory in practical situations (Feisel and Rosa, 2005). Laboratory instruction has typically occurred in a classroom environment where students work individually or in team and are guided by an instructor or teaching assistant. Using physical equipment and materials during laboratory instruction represents the highest level of fidelity. Physical learning environments allow students to experience the sensory characteristics of the equipment and experiments and gain familiarity with the environment within which they will be used (Zacharia, 2007; Zacharia and Olympiou, 2011).

Simulations are designed to model the core principles of a particular system (Jaakkola et al., 2011). Simulated learning environments include 2D, desktop 3D, and immersive virtual environments. In addition to providing increased accessibility these environments can foster the attention and engagement of students more readily than traditional methods (Adams et al., 2008; Stone, 2001). Simulations have the ability to "make the invisible visible" (e.g., showing the current flow of an electric circuit), which can help students learn complex relationships (Finkelstein et al., 2005; Jaakkola et al., 2011). Simulations also have the added benefit of helping students to learn in an ideal environment where they can focus on exploring concepts without the complications associated with equipment and device reliability (Finkelstein et al., 2005). However, simulations limit students from experiencing hands-on manipulation of real materials, may lack the necessary detail and realism to effective teach scientific techniques, and can distort reality (Scheckler, 2003; Woodfield et al., 2005). Simulations also lack physicality, which is "the actual and active touch of concrete material," which is believed to be important for learning (Zacharia and Olympiou, 2011, p. 318). Other researchers have suggested that it is the active manipulation, rather than the physicality, that is the most important element of laboratory instruction (Resnick, 1998) and physicality may only be necessary for perceptual-motor skills (Triona and Klahr, 2003).

Several studies have evaluated using simulated environments in laboratory instruction as a supplement, a substitute, or in some combination with physical instruction. Research has found both positive and negative effects of simulation based instruction on learning outcomes (Lee, 1999; Sitzmann, 2011). Simulations have been found beneficial for helping students prepare for lab (Dalgarno et al., 2009; Martinez-Jimenez et al., 2003) and students learning in simulated environments can outperform students learning in physical environments (Campbell et al., 2002; Finkelstein et al., 2005). A meta-analysis by Lee (1999) also found that simulations had a positive effect on learning but reported negative effect on students' affect for technology-based learning. Combined simulation and physical instruction was found to result in superior learning outcomes than students learning solely in a physical environment (Campbell et al., 2002; Jaakkola et al., 2011; Zacharia, 2007) and simulations were effective for learning both presentation and practice when used with other instructional methods (Lee, 1999).

Simulations, however, can also vary greatly in their level of fidelity. Instruction using 2D simulation might be less effective as 2D representations may be inherently deficient for 3D representations and translating the representation from 2D to 3D may result in additional cognitive load for learners (Regian et al., 1992; Richards and Taylor, 2015). The use of 3D representations provides more flexibility and realism, however, the increased complexity can make it difficult for inexperienced users to navigate and attend to all to all of the information being conveyed resulting in degraded performance (Gillet et al., 2013; Sampaio et al., 2010; Stuerzlinger and Wingrave, 2011). Technical issues like poor resolution and lag in a 3D virtual environment can also lead to performance deficiencies (Kenyon and Afenya, 1995). Prior research has suggested that higher levels of fidelity are not necessary, and sometimes even detrimental, to learning and transfer (Alexander et al., 2005). Additional research is needed to understand what aspects of 2D and 3D virtual representations of tasks are beneficial for learning, as well as tasks, contexts, and domains may be best suited for these types of technologies (Richards and Taylor, 2015).

2.2. Learner characteristics in simulated learning environments

Learner characteristics influence instructional effectiveness and learning outcomes (Anderson, 1982; De Raad and Schouwenburg, 1996; Noe, 1986; Snow, 1989; Shute and Towle, 2003). Personality features are believed to impact affect; overlay features influence domain knowledge; and cognitive features which influence students' information processing (Kim et al., 2013). This study focused on two learner characteristics, goal orientation and cognitive ability, previously found to influence learning outcomes. Goal orientation, commonly conceptualized as performance goal orientation (PGO) and learning (or mastery) goal orientation (LGO), describes the way an individual approaches an achievement task (Button et al., 1996; Elliott and Dweck, 1988). A PGO leads learners to focus on a narrow set of concepts impeding the learning of more involved task relationships that results in good initial performance but poor ability to apply the material in other contexts (Kozlowski et al., 2001). A LGO fosters a desire to explore relationships in greater depth and acquire the knowledge and skills required for competency while building task-specific self-efficacy (Kozlowski et al., 2001). Cognitive ability describes an individual's capacity to perform higher-order mental processes such as critical thinking and problem-solving (Clark and Voogel, 1985). Higher cognitive ability is associated with learning, retention, and application of skills and knowledge (Busato et al., 2000; Clark and Voogel, 1985). Lower cognitive ability individuals may need a more structured learning environment (Snow, 1989) suggesting that the less structured and more autonomous nature of 2D or 3D environments may be detrimental to low cognitive ability learners particularly in online settings. Currently, the authors are unaware of research investigating moderation effects of goal orientation and cognitive ability on fidelity (e.g., 2D simulation, 3D simulation, or physical labs) for learning outcomes.

2.3. Purpose of this study

Although previous research has identified value in using simulations as a supplement or in combination with laboratory education, little research outside of the workforce training has specifically investigated the differences in outcomes between 2D and 3D simulations as well as the influence of learner characteristics (Kim et al., 2013; Richards and Taylor, 2015). The current study aimed to explore the role of the fidelity of the learning environment by comparing learning outcomes associated with learning in a 2D, 3D, or physical environment. This research also aimed to investigate the roles of goal orientation and cognitive ability on learning outcomes for participants learning in those different environments.

3. Methods

3.1. Participants

Participants were recruited using word of mouth, flyers, and email blasts. To be eligible, participants could not have been currently