Mixed Reality Multimedia Learning to Facilitate Learning Outcomes from Project Based Learning

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ABSTRACT

Effective construction engineering and management education requires hands-on experiences that have not traditionally been offered in classroom settings. Physical building competitions like Solar Decathlon are valuable for providing experiential learning opportunities that may support tacit and explicit knowledge development among students, but they are often not available to all students due to funding and resource limitations. Less resource intensive teaching strategies, such as project based learning, can mimic the benefit of physical experiences by providing context to learning content. This paper reviews project based learning literature to identify trends in reported learning gains from the adoption of this strategy. Additionally, emerging technologies offer the ability to create low cost, immersive multimedia environments that may be able to support the types of learning targeted by physical design and construction experiences. Literature on multimedia learning theory is explored to identify opportunities for multimedia applications to facilitate learnings derived by physical educational contexts, but with the use of increasingly affordable multimedia strategies. This paper resulted in identifying six learning gains that have a theoretical potential to be facilitated using augmented reality and virtual reality technologies. The theoretical potential was deduced based on prior research on teaching strategies that provide real-world context to learning content. The authors of this paper propose using the identified learning gains as targets to specifically design implementation studies to verify this potential. The learning gains identified in the results section can be targeted and measured in future research when empirically validating the use of immersive technologies for construction education. The contribution of this work is in synthesizing the learning gains that future researchers should target based on evidence from prior research in related learning contexts.

KEYWORDS: Augmented Reality, Virtual Reality, Construction education, Experiential learning, Project/Problem based learning, multimedia learning

INTRODUCTION

Due to the complex and diverse nature of project scopes within the Architecture, Engineering, and Construction (AEC) industry, a demand for team members with tacit knowledge, in addition to the more traditional 'explicit' knowledge, has emerged (Hizar Md Khuzaimah & Hassan, 2012; Woo et al., 2004). Explicit knowledge is typically conveyed through textbooks, manuals and detailed in-class examples (Collins, 2010; Hizar Md Khuzaimah & Hassan, 2012). Unlike explicit knowledge, tacit knowledge leverages individual experiences and is defined by the understandings and capabilities of individuals (Pathirage et al., 2008). This type of knowledge is usually expressed as points of view that the individuals develop during their career experiences (Collins, 2010; Nonaka & Takeuchi, 1995; Pathirage et al., 2008). Thus, it can be challenging for students, who have not yet had extensive engineering and construction careers, to develop this critically important form of knowledge.

Educational researchers have begun exploring novel pedagogical strategies to enable their students to develop tacit knowledge. Physical construction and design competitions have been used to provide an in-depth context to learning content. Providing such context stimulates original thinking and develops a wide range of thinking strategies and perceptual skills, which may not always be elicited by books or lectures (Williams, 1986). However, due to the high resource requirement in creating such physically engaging learning environments, physical learning environments remain uncommon. Project (also known as "Problem") Based Learning (PBL) has gained momentum as a teaching strategy due to its ability to provide real world context to students. PBL theorists suggest that these types of problems capture students' interest and provoke serious thinking to enable them to acquire and apply new knowledge (David, 2008). PBL also encourages students to develop solutions to ill-defined, and realistic, problems without single right answers (Thomas, 2000). These problems give students the opportunity to work relatively autonomously over extended periods of time and culminate in products or presentations based on realistic understanding of the content matter (Jones, Rasmussen, & Moffitt, 1997; Thomas, Mergendoller, & Michaelson, 1999). Because PBL directly connects problems in the classroom to those in the real world (Efstratia, 2014), this paper analyzes PBL research that indicates specific learning gains afforded from projects involving practical design and construction experiences that help generate comprehensive tacit and explicit knowledge.

While PBL strategies situate learning content in a realistic context, conceptually, they do not necessarily require a physical context to further re-create the real-world learning experience. Therefore, the authors explore Multimedia learning theory, which uses media-based experiences that enable students to build mental representations from words and pictures in order to add context to learning content. Multimedia learning can include simple book-based environments consisting of text and illustrations to more sophisticated computer based and virtual gaming environments with interactive speech and animated immersive microworlds (Mayer, 2002). Media such as Augmented and Virtual Reality (AR/VR) that are capable of immersively simulating physical experiences in a virtual environment are of particular interest in this work. In the interest of simplicity, the authors use "MR" (Mixed Reality) in this paper as an umbrella term to consider all applications that fall within the Mixed Reality spectrum. This attribute of immersion may enable these media to simulate and replace physical experiences in a classroom setting at a relatively low cost.

The purpose of this paper is to review literature on learning benefits related to PBL and multimedia learning environments. By synthesizing the findings from these two research domains, the findings help to identify potential for emerging visualization technologies, with relevant problem contexts, to target learning gains similar to those reported using resource-intensive physical design and construction learning experiences. These findings contribute to the body of educational research in the AEC realm by providing specific directions for future researchers that are grounded in relevant educational research findings.

BACKGROUND

In this section, the authors examine the existing literature on the learnings that have been attributed to the use of physical learning experiences and PBL teaching strategies. Furthermore, prior research that validates the ability of MR in simulating physical environments and learnings reported from those studies are explored. Multimedia theory is reviewed and referenced to theorize the ability for these immersive environments to offer learning gains like those offered by physical experiences but at a lower resource requirement.

Physical Experiences and Project Based Learning

Considering the goal of providing context to learning content, physical experiences have been shown to be effective through competitions that have a physical building component to them. Solar Decathlon is a one such competition that includes a physical building component to the project. During such building processes, students gain experience building their design at full scale, which is a rare opportunity outside the competition (Matulka, 2013). Prior literature has lauded such competitions for their real world experience and reported the inability to be replicated in classrooms (Grose, 2009). Douglas (2011) reports there is a direct correlation between the level of active learning and knowledge gained from those activities. These works illustrate the potential for physical experiences in education to support various learning gains, but remain inaccessible to most students because of their intensive resource requirements.

PBL is a teaching strategy that leverages real world projects to conceptually structure the learning process, but without the need to invest in projects where students physically design and construct building elements. The PBL handbook for teachers provides definitions and characteristics for what constitutes an ideal learning environment (Mayer, 2002). Some of these characteristics are that the project is authentic in content and assessment, it uses teacher facilitation without direction, and the goals are explicit in their definition (Moursund, 1999). This model encourages cooperative learning, reflection, and incorporation of adult skills (Diehl et al., 1999). According to two Expeditionary Learning Outward Bound (ELOB) publications, 90% schools demonstrated significant improvement in students' test scores on standardized tests of academic achievement when PBL was used (ELOB 1997; 1999a). Shepherd (1998) reports that PBL can have a positive effect on students' acquisition of critical thinking skills. It has also been shown to enable students to improve design proficiency, understand traditional geometric concepts, and submit designs that can actually built (Barron et al., 1998). In another study, PBL was observed to impact students' problem-solving skills, metacognitive strategies, and attitudes towards learning (Cognition and Technology Group at Vanderbilt, 1992). These works collectively illustrate how PBL can successfully provide context to learning content in order to support learning gains that can be targeted by less resource-intensive means than projects requiring physical design and construction activities.

Multimedia Learning and Mixed Reality

Mayer (2002) defines multimedia learning as the learning that happens from creation of mental models based on the pictures and text presented to the learner. Multimedia learning can be achieved using various media which could be book-based, computer-based, or even game-based (Moreno & Mayer, 1999a). The messages delivered using these different media could be in the form of animations (pictures/videos), narration (words/sounds), or a collaboration of both animations and narration. These prior works highlighting the value of imagery and multimedia for learning suggest similar or greater potential for emerging AR and VR technologies to provide immersive, high fidelity, virtual representations of physical environments (Le, Pedro, & Park, 2015).

Using the qualifications suggested by the multimedia learning theory, it is possible to design AR and VR experiences to deliver multimedia messages. Prior research reports on the ability for such immersive technologies to successfully simulate physical environments (Dunleavy, Dede, & Mitchell, 2009). AR allows users to move in a physical space, while interacting with a virtual model. VR allows users to be totally immersed in a virtual model. This approximation of physical experience has been theorized to facilitate tacit knowledge generation (Hartless et al., 2018). AR and VR, both, have shown results to support better decision making which were abilities previously exclusive to physical mock-up experiences (Alsafouri et. al., 2017). Immersive virtual environments have a potential benefit over real, physical competitions due to their cost-effective nature and the ease of repurposing them for other projects. Despite the potential for AR and VR to provide cost-effective simulations of physical design and construction learning experiences, the research community has not generally defined MR learning experiences to directly target the learning gains reported with more resource-intensive learning environments. Therefore, this paper aims to identify what learning gains are indicated by prior works that justify the need for subsequent MR implementation studies.

METHODOLOGY

The authors of this paper reviewed prior literature reporting the learning gains that are achieved in PBL and multimedia learning environments. In order to do this, they first defined papers through searches in Computers and Education Journal and other scholarly database. After papers were identified they carefully analyzed each to extract specific information that would support analysis.

Identification of Publications

The wide variety of projects under the PBL banner make it difficult to assess what is and what is not PBL due to the lack of a universally accepted model or theory (Tretten and Zachariou, 1997). There is also a possibility of looking over studies reporting on projects that do have a hands-on learning aspect, but do not use the term PBL. Therefore, to find literature on PBL, in addition to “Project/Problem Based Learning”, “Hands-on Learning” and “Discovery-Learning” were added to the search terms used in finding studies in the database. This exposed the search to old studies and teaching strategies that used projects as a part of the curriculum but was not an integral part of this which is a requirement for the type of PBL studies that were sought (Thomas, 2000). To balance the additional search terms and unwanted traditional studies that came with it, a time frame for 20 years was set as a filter.

To find prior literature on learning gains from immersive technologies, the Computers and Education Journal was used as the primary source. As a secondary source, learning gains were identified using the following search phrases in Google Scholar without a constraint to the publication year: “Immersive learning”, “AR in construction/education”, “VR for construction/education, and Mixed Reality in construction education”.

Project characteristics were used as criteria to filter them further. These defining characteristics are adopted from Thomas (2000) in his review of PBL. The criteria are centrality, autonomy, and realism. First, the project must be central to curriculum and not peripheral to the coursework which is not uncommon in traditional teaching strategies. Thus, only studies in which the project was the primary tool in teaching the subject matter were selected. The second criteria, autonomy, ensured the selected projects were student driven rather than teacher-led. This eliminated studies with projects like laboratory exercises which have a predetermined path or outcome chosen by the teacher and offered no autonomy to students. In the selected projects, students have autonomy over their decisions and conduct a significant amount of unsupervised work. The third criteria, realism, helps to identify projects that provide real work context to learning content. There are distinctions between real-life challenges and academic challenges (Gordon, 1998). This criterion helps select real-life challenges where the focus is on problems that have the potential to be implemented. Using these guidelines, the PBL cases selected had projects that provided real-world context to learning content to replace the experience of working on a real project.

Analysis of Publications

The PBL studies resulting from the filtration method were reviewed to identify specific learning gains that have been achieved by providing real world context to learning content using PBL. Similarly, from the studies reporting on using immersive technologies for education, learning gains were identified that had potential to be facilitated using MR. Finally, the findings that were reported by both PBL and technology-based learning were organized in order to define learning outcomes that have a theoretical basis for future researchers to target with MR and other emerging visualization technologies.

RESULTS AND DISCUSSION

Table 1 lists learning gains, which have been reported with both, PBL and Multimedia learning environments that implement MR. In some cases, the reports are largely intuitive. For example, researchers have found that having students physically construct building elements can support their ability to sequence construction activities (Matulka, 2013). This is intuitive because the process of physically building intrinsically requires individuals to determine ordering of pieces to construct. However, it is noteworthy to see that MR has also been reported to enable this form of learning (Ku & Mahabaleshwarkar, 2011), even though MR does not necessarily involve the physical construction. These reports of similar learning gains through different learning environments are especially encouraging when considering the comparatively low cost of emerging MR devices. Furthermore, because MR does not involve physical construction and demolition, it may offer a longer lifespan to support learning than physical building materials may enable. The findings reported from prior literature will enable future researchers who study emerging visualization media to strategically target similar learning gains through these increasingly affordable technologies.

Table 2 lists learning gains that have been reported using either immersive virtual or physical and applied learning environments. Two such learning gains that were identified, empathy for team members and interdisciplinary negotiation skills do not have evidence to support their generation when MR is used. These two learning gains seem to root in interpersonal communication & collaboration abilities of MR applications. Better collaboration in a shared location with team members and remote collaboration with professionals from other disciplines has been studied which could potentially help MR applications to facilitate more learning gains (S. Nilsson, B. Johansson, & A. Jonsson, 2009). Empathy and effects due to an embodied experience have also been explored in the past (Shin, 2018). These learning gains need further exploration to discover MR’s potential as a teaching tool. The immersive technology is developing every year and thus these learning gains cannot be ruled out from the scope of MR. Thus, Table 2 can help future researchers in identifying learning gains that can be targeted to broaden the range of learning gains that can be facilitated by immersive technologies at an affordable resource requirement.

Table 1. Results Indicating Learnings That Were Reported When Using Both Physical Experiences/PBL and Mixed Reality Applications

Learnings Reported	Physical/PBL	Mixed Reality
Sequencing Construction Activities	(Matulka, 2013) (Glick et al., 2012) (Sampaio & Martins, 2014)	(Ku & Mahabaleshwarkar, 2011)
Autonomous Decision making	(Craft, Click, & Marshall, 2004)	(Alsafouri et al., 2017)
Students reported higher motivation for activities	(Holt, 2012)	(Martín-Gutiérrez, 2017), (Radu, 2014)
Increased communication with team members and other stakeholders	(Thomas, 2000)	(Le et al., 2015),
Ability to solve problems without teacher-instruction	(Thomas, 2000)	(Okamura, 2004)
Increased student engagement during activities	(Thomas, 2000)	(Enyedy, Danish, & DeLiema, 2015)

Table 2. Results indicating learnings that were reported when using either Physical experiences/PBL or Mixed Reality applications

Learnings Reported	Physical/PBL	Mixed Reality
Empathy for team members	(Matulka, 2013)	
Increased Interdisciplinary Negotiation skills	(Holt, 2012)	
Access to multiple visual perspectives		(Teizer, Cheng, & Fang, 2013)
Long-Term Memory retention		(Radu, 2014)
Collaborative Learning		(Martín-Gutiérrez et al., 2015)

These two tables offer a list of learning gains that have been reported through PBL and also immersive multimedia environments by past literature. When considering both tables in conjunction, the findings illustrate how many of the types of learning gains targeted through more resource-intensive physical construction and design learning activities may also be observed through these more-affordable teaching strategies. These findings provide existing evidence to justify the investment in studying increasingly affordable emerging technologies to directly enable the types of learning observed through physical design and construction learning environments.

CONCLUSION

The growing need for an experienced workforce in the construction industry with tacit knowledge has motivated researchers to explore how emerging technologies may enhance engineering and construction education. Traditionally, this type of learning required physical design and build experiences, either through physical design and construction projects, or through career experience. Unfortunately, these approaches can require prohibitively high amounts of resources and time, respectively, which hinder their ability address the industry's current need. Emerging technologies like MR may help in providing experiences that produce similar learning gains, but in a less resource intensive, simulated, environment.

In order to guide researchers exploring the educational affordances of these emerging technologies, this work identified several learning gains for which there is evidence in the research literature that they may be supported through virtual learning environments, physical and applied learning environments, or both. The authors identified six learning gains that have been reported using both MR and also applied, physical, learning environments. Furthermore, the researchers also identified four learning gains that have been reported in either virtual or physical and applied learning environments. For the learning gains that were only reported in physical and applied learning environments, there is not yet research evidence that confirms that these learning gains may also be enabled in virtual contexts, which highlights a potential opportunity for future researchers to study these topics.

The contribution of this paper is in the organization of previously published works in order to identify the types of methodologies that frequently facilitate specific learning gains. The paper also contributes in synthesizing the findings of prior works to identify learning gains that may guide future educational research efforts that explore emerging technologies for enabling experiential learning in a manner that is scalable. By systematically identifying the learning gains that have been reported by educational researchers using similar learning models, this work enables future researchers to strategically target learning gains that have been suggested to be possible by prior research evidence. As researchers empirically prove value to emerging technologies, their works will enable a lower cost, and more scalable, model for addressing the educational needs of the construction and engineering domain.

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