BRIDGING THE LEARNING GAP AUGMENTED REALITY'S IMPACT ON ASSOCIATIVE INFORMATION PROCESSING, COGNITIVE LOAD, AND WORKING MEMORY: A MIXED-METHODS RESEARCH STUDY

By

DAVID R. SQUIRES

Assistant Professor, Instructional Design and Educational Technology Program, College of Education and Human Development, Texas A&M University-Corpus Christi, Texas, USA.

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ABSTRACT

A mixed methodology study measuring the use of Augmented Reality (AR) information overlay mapping in online instructional design courses, and the impact on participant's working memory is presented. Novel AR technological expansions, and the rapid proliferation of powerful computing tools embodied by emerging mobile and wearable computing devices, illustrate a significant shift in 21st century learning strategies. This study may help to increase the body of knowledge on effective AR integration plans, adapted working memory utilization in technology-enhanced classrooms, and the viability of AR assistive devices in online learning domain studies. This study investigated whether AR systems provided a uniquely beneficial learning context due to AR's native function to overlay information onto manifold electronic and physical domain settings. While the quantitative data collected in this study was limited due to a minor sample size (n=27), the qualitative results indicated that AR users were exceedingly engaged, and recalled content readily; indicating greater student engagement. The results of the study indicated several data points that posit affirmative correlation in regard to recall and memory with the AR only group. However, the general combination of qualitative and quantitative data to triangulate a discernible relationship between AR and working memory gains remained inconclusive overall, with marginal statistical distinctions. Future studies with mobile AR implementations are recommended with larger statistically significant participant sample sizes to measure potential impact on working memory and associative information processing.

Keywords: Augmented Reality, Online Learning, Mobile Learning Analytics, Working Memory, e-Corsi, Task Load Index (TLX) Cognitive Load Assessment, Mixed-Methods Research.

INTRODUCTION

While AR technology may seem relatively novel, it has in fact been around for decades in various iterations: "It has been used in fields such as: military; medicine; engineering design; robotic; telerobotic; manufacturing, maintenance and repair applications; consumer design; psychological treatments" (Mehmet and Yasin, 2012). That being said, AR is also constantly evolving and is now at the forefront as an innovative tool that can enhance educational content and can create new types of automated applications to enhance the effectiveness and attractiveness of teaching and learning for students in multiple pedagogical situations. While educational studies on AR are indeed comparatively limited in the field of education, the technology has finally reached a scalable possibility that its propagation can be used and acquired by educators and learners with relative ease. Similar studies have been conducted with "Quick Response Codes". These QR codes studies have illustrated that the "strength of mobile learning is to link e-learning content with specific locations in which that information will be applied” (Macdonald and Chiu, 2011).

Augmented Reality takes 'tagging' and interactions to a new level according to behavior science studies conducted with AR: Augmented Reality augments virtual information onto the real world with continuous and implicit user control of the point of view and interactivity (Mehmet and Yasin, 2012). As Mehmet and Yasin (2012) point out, AR provides a composite view for the user with a combination of the real scene with overlaid computer generated virtual scenes. This augmentation of the real world occupies an ordinary place, space, thing, or event in a way that is partly unmediated, creating a new approach that enhances the effectiveness and attractiveness of teaching and learning. The ability to overlay computer generated virtual artifacts onto the real world changes the way students interact with content, and training becomes real, that can be seen in real time rather than a static experience (Mehmet and Yasin, 2012). In other words, AR brings virtual content through a smartphone (most smartphones now have this capability) or any relevant device and can host virtual content onto a physical space (See Figures 1 and 2).

Figure 2 is an example of an AR overlay hosting that illustrates and conjoins electronic online learning with mobile learning. Namely, by hosting content online via a personal computer, then accessing the content via a mobile device, this interaction arguably enriches the user experience fulfilling a completely novel level of user interactivity. Thus, the possibilities for AR technology combined with education and learning are potentially

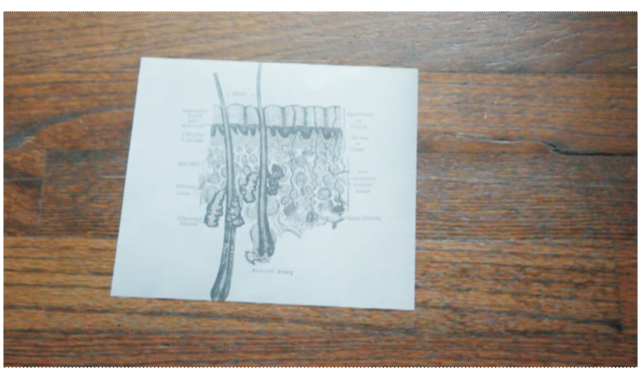

Figure 1. Example of a Skin Cell Print

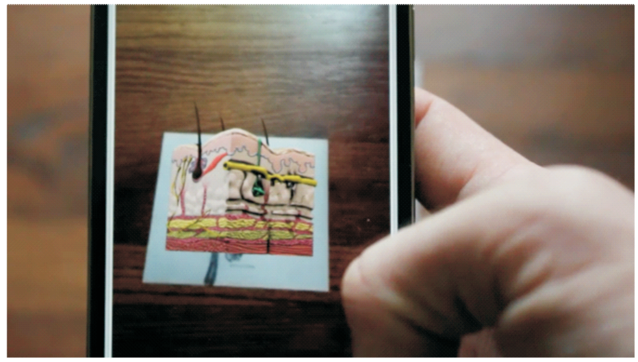

Figure 2. Example of an Augmented Reality Mobile Application being Pointed at the Static Image and a 3D Model being Superimposed (iTunes App Store AR education)

limitless, tagging static content with audio, video, web links, 3D graphics, and more recently, to enter the collective consciousness: Pokémon. While the novelty factor and gaming components of AR are well documented, burgeoning research conducted with handheld displays and mobile technology illustrate how AR can potentially revolutionize the way humans interact and absorb learning content in day to day life, and in learning environments (Mehmet and Yasin, 2012). While researchers must be careful not to over evangelize innovative technology. That being said, there are strong indicators that AR can be applied, and in many cases, is being applied to learning and edutainment by enhancing a user's perception and interaction with the physical world. Learners interact with three-dimensional virtual images and view it from any vantage point, just like a real object: “The information conveyed by the virtual objects helps users perform real-world tasks” (Mehmet and Yasin, 2012). That is, the notion of a 'Tangible Interface Metaphor' is one of the important ways to potentially improve learning and make what may have been seemingly impossible possible, such as viewing a skin cell up close without a microscope.

Tang, Owen, Biocca, and Mou (2003) employed a cognitive workload measurement adapted from NASA TLX, whereby they utilized the TLX instrument to specifically measure an Augmented Reality object assembly task. By adapting the TLX instrument to object assembly and having students' rate categories to measure working memory and overall cognitive load, Tang, Owen, Biocca, and Mou (2003) were able to gather data on Augmented Reality's impact on cognitive load and its impact on working memory. According to Tang, Owen, Biocca, and Mou (2003), working memory and cognitive load measuring instruments can be adapted and applied to AR tools, in the NASA TLX example, allowing users to self-report on their cognitive load by detailing their use with the AR enabled device, and their overall interactions in the enabled contexts. The TLX instrument measures cognitive load and the impact on effective working memory utilization (Hart and Staveland, 1988).

1. Research Question

Does the quantitative data and qualitative data converge support a conclusion that Augmented Reality can positively impact associative information processing and working memory?

2. Methods

The AR education study sought to identify the effects of Augmented Reality information overlays applied within an online learning environment and the potential results of efficient information access on human associative information processing and working memory. The purpose of the study was to measure the outcome of assistive information and content overlays on information processing and working memory capacity. Due to the unique ability of Augmented reality to decipher and overlay digital content onto physical and virtual spaces, it is reasonable to hypothesize AR which can potentially prompt a learner's transition from novice to unaided expert by reducing potentials for error via efficient information access. This study followed previous studies conducted with Augmented Reality tools to specifically measure working and spatial memory (Tang et al., 2003; Juan et al., 2014). Previous research has posited that AR enabled environments may have a positive impact on working memory and learners recall ability (Tang et al., 2003; Juan et al., 2014).

The AR education study followed previous research-based Augmented Reality methodological studies by integrating a mixed methods approach to Augmented Reality data collection in order to triangulate survey data, application analytics, descriptive statistics and direct participant feedback (Bressler and Bodzin, 2013). Due to the novel nature of AR applications in learning applications, the novelty effect often requires more detailed participant continuation than quantitative data alone can often elucidate (Bressler and Boszin, 2013). Therefore, the primary methodology for this study was based on Creswell's (2010) convergent mixed-method design to integrate descriptive quantitative and qualitative results to generate a larger picture for a phenomenon by comparing multiple methodological intensities within a single research study (Creswell, 2010). Furthermore, the convergent mixed-method design was employed in order to provide an inclusive degree of triangulation: quantitative and qualitative results are combined into a more complete understanding of a phenomenon and assist in comparing multiple levels of a phenomena within a longitudinal study (Creswell and Plano, 2011).

3. Research Site

Participants were recruited from two domain-specific Master's level instructional technology courses. The site's characteristics are based on users who would potentially implement novel technology in an educational technology enriched learning environment. Access to the research site for this study was long and followed collections for semester long sessions and three selected interviews with participants. Sampling included each course of the entire registered students. The selection of participants and the criterion for interviews were based on survey feedback response questions and embedded Google Analytics Software Development Kit (SDK) data showing user feedback timing and task completion rates. Participation in this case was voluntary and the courses selected for data collection were domain-specific technology courses, targeted towards working professionals and Master's students in Instructional Technology and Design who were also learning about technology integration strategies, with potential access to a mobile iOS device. Participants first answered an initial survey to determine qualifying and disqualifying traits to participate in each group. Participants were placed in Group 1 if they did not have an iOS device, and participants were selected for Group 2 based on their self-reported ability to obtain a mobile iOS device, along with participant's capacity to point their AR enabled device at learning content and answer knowledge transfer feedback questions in a succession. The survey instruments were designed with the mentioned discriminating factors in mind to limit participation in the AR group to only those who had a mobile device and could download an iOS application from iTunes.

While the participants completed the initial surveys, embedded software analytics recorded user's responses, timing, unique device identification, and time spent on each question. Group 2 had access to a visual companion AR course online (piazza.com), which contained AR visualization tasks involving the AR reader application's custom course content. This content was Instructional Design domain specific and after consent was granted, listed how to download the AR app and aim at the enabled course content. The AR course employed a variety of visual and cognitive variables, such as superimposed or "floating" 3D and auditory stimuli, that could only be accessed within the AR education application framework, when the handheld Augmented Reality reader's device camera was pointed in the vicinity of the external content trigger image.

4. Data Collection

The data collected by mixed method inquiry utilized pretest e-corsi baseline measurements, surveys and the unique ability of the Augmented Reality (AR) application-programming interface to collect data via embedded application programing interface, Google analytics, and time on task-based selection for in-depth interviews. Data was also gathered via open-ended surveys. Two intact groups of students from two courses were measured: one group that downloads the AR education application and the other that do not. The group that did not download the application was asked to participate in an e-corsi baseline working memory test and a survey, based on their learning tasks and content transfer without the app. The other group completed the pretest, then utilized the AR education app downloaded from the Apple iTunes store. The application graphical user interface displayed AR learning overlays, and embedded software development kit began collection with the AR education group as soon as the participants downloaded the AR education app. Both groups answered TLX cognitive load questions after using the app and after completing the LMS course modules. The TLX working memory procedures involved have been effectively adapted to an AR environment, as Tang (2003) have illustrated. Initial survey data was collected by Qualtrics.

After baseline selection, participants were enrolled in a course hosted on the Learning Management System Piazza. The course Learning Management System (LMS) collected user information related to user feedback, posts, completion of coursework, and time spent using the custom AR study website and mobile device in combination to unlock Augmented Reality assigned tasks. Embedded analytics data was collected and sent from within the app itself using the Software Development Kit (SDK) from the iOS AR education app platform. The Augmented Reality communication that was unlocked, and the timing for each interaction, was accessed by the application internally from an enabled database, therefore an Internet connection, or minimal cellphone data, was also required to tether Internet to a working iOS mobile device. All AR interactions were uploaded with the AR education app, and an extensible markup language (XML) compression file via an Apple iTunes Connect developer account. The AR packet contained uniform resource location data, audio, video, flash and three-dimensional object reference content that was tracked and analyzed using the Google analytics software development kit and Application Programming Interface (API) embedded within the AR education app itself. After completion of the AR embedded modules, iOS participants received embedded prompts to complete a TLX cognitive load assessment survey of the AR tasks on their mobile devices.

5. Results

Of the 27 total students in the two Master's level educational technology courses surveyed (n=14, n=13), all (n=27) agreed to participate in the study. In course #1 (female n=7, male n=5) agreed to participate in the study (n=13) and in course #2 (female n=8, male n=6) agreed to participate (n=14). The pre-survey served the purpose of enrolling Course 1 and 2 participants and dividing participants between discriminating factor of access to a mobile Apple iOS device. The Course 1 group contained iOS users, 7 (female n=4, male n=3) and non-iOS users, 5 (female n=3, male n=2). Course 2 was divided between iOS users, 8 (female n=4, male n=4) and non-iOS users, 6 (female n=4, male n=2). The total group of iOS users for each combined course was 15, and 12 non-iOS users. After the pre-survey, each of the two course groups were combined and divided into group 1 - iOS users and group 2 - non-iOS users. Qualitative data is broken into two segments detailing open-ended survey responses, and narrative inquiry excerpts from combined interview data.

As shown in Table 1 (a and b), on average AR users reported definitely (33.33%), or probably remembering (46.67%) which they could remember what they just learned with the AR triggers (mean=1.87). A minority of AR users (n=3) report which they might or might not remember (20%).

As shown in Tables 2 (a and b) the majority of AR user group reported, they strongly agreed (33.333%) or agreed (46.67%) that they could remember what they just learned with the AR content (mean=2). Some users (n=2; 1 being they strongly agree, 7 being they strongly disagree) reported they neither agreed or disagreed (13.33%) that they could remember, only one user (6.67%) reported that they only somewhat agreed that they could remember what they learned.

Do you remember what you just learned with the AR Trigger image?	%	Count
1 - Definitely yes	33.33%	5
2 - Probably yes	46.67%	7
3 - Might or might not	20.00%	3
4 - Probably not	0.00%	0
5 - Definitely not	0.00%	0
Total:	100%	15

(a)

Field	Mean	Std. Deviation	Variance	Count
Do you remember what you just learned with the AR Trigger image?	1.87	0.72	0.52	15

(b)

Table 1 (a&b). TLX Assessment

Can you apply what you just learned?	%	Count
1 - Strongly agree	33.33%	5
2 - Agree	46.67%	7
3 - Somewhat agree	6.67%	1
4 - Neither agree nor disagree	13.33%	2
5 - Somewhat disagree	0.00%	0
6 - Disagree	0.00%	0
7 - Strongly disagree	0.00%	0
Total	100%	15

(a)

Field	Mean	Std. Deviation	Variance	Count
Can you apply what you just learned?	2.00	0.97	0.93	15

(b)

Table 2(a&b). iOS Can you Apply What you Learned

As shown in Table 3, AR users reported that the task of aiming at AR triggers with their mobile devices and completing course content was generally easy (mean=3.42).

As shown in Table 4, AR users reported a low instance of insecurity, discouragement, irritation, stress or annoyance (mean=1.73) while completing the AR only tasks.

The study explored potentials of AR in learning

AR Users	Mean	Std. Deviation	Variance	Count
Extremely Easy	3.42	1.32	1.74	12
0-10 Scale (0 = very easy 10 = extremely hard)				

Table 3. iOS Mental Demand; How hard was the AR Task to Learn?

AR Users	Mean	Std. Deviation	Variance	Count
Very Low	1.73	0.96	0.93	11
0-10 Scale (0 = very easy 10 = extremely hard)				

Table 4. How Insecure, Discouraged, Irritated, Stressed, and Annoyed Were You?

environments and for students to become more engaged and active with online learning environments utilizing novel Augmented Reality-based learning. All AR participants (n=15) reported that the AR education systems featured significant potential for learning. As shown in Table 5, the data indicated that during working memory pre and posttest e-corsi block test measurements, working memory blocks remembered increased by 1.06 blocks on average in the Augmented Reality application group posttest group.

AR users had a mean average of 1.06 blocks per participant increase. With comparative baseline testing, participants remembering 7 blocks or more increased by 26.66% from the e-corsi pretest after using the AR education application as shown in Table 5.

This may support previous AR studies which claim that AR can be a poignant catalyst to assist learners with elaborative rehearsal strategies and may aid in increasing working memory (Lin et al., 2013). However, due to the limited sample size and limited response data, running a more in-depth statistical analysis will have to be undertaken in future studies.

The posttest descriptive statistics data suggests an increase in working memory from both AR and non-AR groups (n=27) after utilizing mobile and online learning content during the course of the study. While the non-AR group increased 0.6 blocks on average higher than the AR only group, the AR only group increased users in 7+ or more range at about 10% more overall. While several factors might explain why the AR group increased to

Corsi Blocks	Pre AR Users	Pre AR Users	Post – AR Use	Post – AR Use
1-2	4	26.67%	1	6.67%
3	1	6.67%	1	6.67%
4	2	13.33%	2	13.33%
5	4	26.67%	4	26.67%
6	3	20.00%	2	13.33%
7+	1	6.67%	5	33.33%
	Mean		Mean	
	3.27		4.33	

Table 5. Analysis Working Memory Pre and Posttest Measurements

higher levels of overall memory practicing with the AR visual overlays lead to higher block level memory increases. This may support previous findings that AR systems can be shaped to minimize cognitive load by developing different working memory encodings and maximizing the efficiency of attention allocation (Wang and Dunston, 2006).

The AR only group was also asked to aim a device viewfinder at AR triggers in a succession and report on the tagged content that is overlaid on the optional Piazza.com site. Symbols in working memory procedures are often presented as self-paced, and once a response is recorded the next symbol appears (Lawlor-Savage and Goghari, 2016). The data may suggest that the AR system where participants aim at the tagged content and then move on the next image in a succession, mirrors the working memory model where participants remember blocks and placement.

The embedded Google SDK data revealed users' time on task corresponded with unique users' device identifiers and email. These data were matched with users that opened and accessed the AR education app a lot, a little and a medium amount through the Internet as shown in Figure 3.

Users matched with Unique User Identification (UUID) numbers showed that the AR users (n=15) viewed multiple AR overlays and interacted with the content by engaging with the overlaid matter and pressing on their mobile devices to link exercises that were normally only accessible in the e-Learning Centre (ELC) LMS. The participant path also shows that the same UUID accessed triggers and surveys over 51 times. The AR users were asked to complete qualitative open-ended question to help elucidate and elaborate on the SDK data that tracked their behavior while using the AR education application framework. The UUID shows that users primarily opened the AR education app during the beginning of the semester and did open the application to complete their learning modules. There were no discernable quantitative impacts on AR user's overall course grades versus non-AR user's grades based on the ELC data from all participant groups. Both AR and Non-AR users (n=13

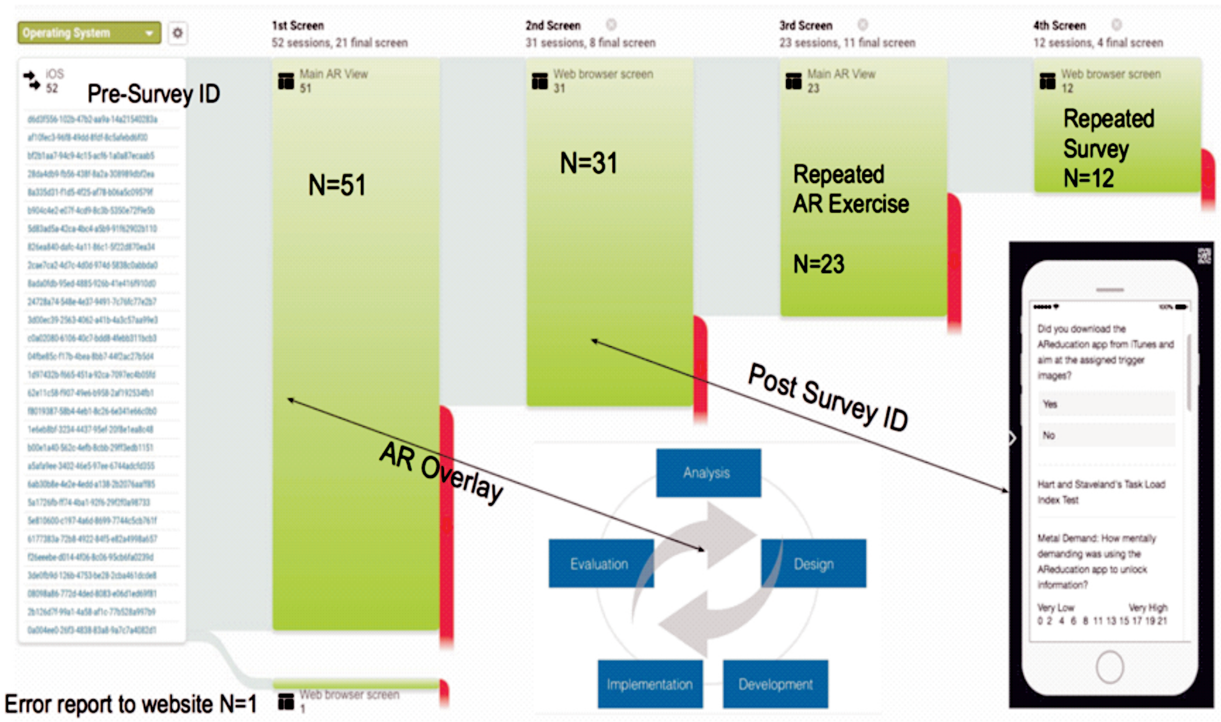

Figure 3. Time-On-Task, Sessions, and AR education Tracking

and n=14) recorded achieved 100% in both respective course modules for graded content.

As shown in Table 6, the qualitative open-ended surveys reported the AR content to be "Useful to help create interactive course material." A majority of AR users found the AR overlay interactions that contained videos more valuable than accessing course content within the online course. They also reported that, in general, having content overlaid on real world images and objects helped them learn and did not overly distract them.

Conclusions

The qualitative data suggested that the AR only users were more engaged, and remembered content more positively due to the novel nature of AR devices in their online classroom. Based on user's verbal feedback, and the simple human information processing model implemented, there was a positive and engaging effect documented with using AR. The effects on the AR only group versus the ELC group illustrate that these differences were also statistically marginal. In general, the descriptive data from the TLX instrument may indicate

Open-ended Survey Question Responses
Ex. AR can bring still images to life and for many applications offer the possibility of simulating real-life situations without the need to fear consequences of a mistake. I especially see the benefits in medicine, technology and vocational education.
Ex. It would be useful to have glasses that respond to AR, that way you can walk into a place and automatically learn its history, or other information needed. Then in the classroom you can have an interactive get out of your seat test and have students walk around and use the AR glasses to fulfill respond to overlays in the classroom.
Ex. I think that having detailed and accurate AR overlays can enable people to be more successful at some job tasks.
Ex. interactivity, endless possibilities
AR users reported that in general the AR education framework helped them to learn and engaged them perhaps helping them remember more content, or in so far as they self-reported that they remembered more content overall:
Ex.1 It definitely would be useful for real time use.
Ex. 2 Repetition with low risk and low cost.
Ex.3 It definitely would be a great alternative if using hands on the real thing isn't an option.
Ex.4 A student could see the inner workings of a car engine or whatever they are working on.
Ex.5 Absolutely or even studying the brain, cells, etc. I think this is extremely beneficial to science classes.
Ex.6 This would be great in learning environments that have layers to look at (i.e. Biology, Fashion Studies, Medical fields,Visual Art, Music, etc.)!

Table 6. Open-ended Survey Question Responses

that AR users were slightly less frustrated when completing assignments only with the mobile AR education framework. AR may have been more novel and engaged learners in a variety of interactive ways. While the AR only group reported that they were less insecure, discouraged, irritated, stressed and annoyed when using the AR education framework compared to the non-AR groups average responses. The data suggests that the AR only group, experienced a very marginal .05% average increase of self-reported remembered content versus the non-AR group. When asked if participants could apply what they learned from the AR only group versus the ELC only group, participants had a 0.08% difference favoring the AR only group, strongly agreeing that the AR only group could apply what they had learned to a higher degree. While the non-AR group increased 0.6 blocks on average higher than the AR only group, the AR only group increased users in 7+ or more range at about 10% more overall gains. While several factors might explain why the averages of the AR group increased to higher levels on the TLX narrow sample indicate that the overall statistical reliability is not significant, and it may be more likely that users increased their working memory through repeating the tests rather than the elaborative rehearsal of aiming at AR trigger images and then completing course content.

Limitations

A major limitation of this study was the small number of participants and limited overall sample size. Participants were selected for convenience and their enrollment in a Master's level Instructional Design and Development course, where most participants already had some level of familiarity with mobile learning devices and Augmented Reality.

Discussion

More research is needed to elucidate AR's potential role within intentional online learning spaces. Arguably, effective Augmented Reality technology adoption for classroom instruction shares the common theme that it is learner centered, systematic, sustainable, accounts for instructor preparation, and considers the environment of adoption along with the practicality of implementing the technology (Knowles, 1997). There is no one size fits all solution for new technology, and an effective technology implementation is contingent on learners' pre-existing knowledge, along with the instructional goals of the appropriate stakeholders. While the results of this study may reflect an affirmative relationship with Augmented Reality and online learning, this does not broadly represent a population that is unfamiliar with the tool itself and may require another step in the design process to bridge the content and knowledge gaps. Mobile devices are connecting humans around the world that might not be able to afford traditional computers to access a compendium of world knowledge. AR technology is not a new technology in various iterations, and yet the affordances AR can produce within an instructional setting are continuously evolving. As Mehmet & Yasin (2012) noted, AR has been around for a long time, and is used in fields such as the military, medicine, engineering design, robotic engineering, manufacturing, and consumer design. Future research sites that are already being considered such as factory floors, medical and cognitive rehabilitation centers, and historical museums each offer unique and unexpected challenges and rewards for future implementation and conveying content to a new generation of learners. Future studies planned will ideally take into account theoretical frameworks that seek to measure AR's impact on increasing quality, working memory as it is related more directly to the content being superimposed in a 3-D based dimensional reality, and the potential memory advantages that can be achieved while reducing time and errors with assistive overlays and heads up AR displays.

Recommendation for Future Studies

Future studies necessitate larger sample sizes to demonstrate concrete statistical significance; gather qualitative and quantitative data from both AR and non-AR groups equally; develop more robust survey instrumentation; and take into consideration domain specific research sites. While the results of this study reflect an affirmative relationship with Augmented Reality and online learning, this does not broadly represent a population that is unfamiliar with the tool itself and requires further steps within the research design process to bridge the content and knowledge gaps for uninitiated Augmented Reality learners.

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ABOUT THE AUTHOR

David Squires is an Assistant Professor of Instructional Design and Educational Technology at Texas A&M University-Corpus Christi, USA. David's current research is on Augmented Reality information overlay mapping technology and the potential impact AR may have on student's working memory and engagement in online learning environments. David is currently conducting data collections on Augmented Reality integration within informal learning spaces and the potential impact AR may have in regard to user engagement with static content that has been overlaid with mobile AR visualizations.