Emergent Individual Factors for AR Education and Training

Brendan Kelley[1(✉)], Anil Ufuk Batmaz[2], Michael Humphrey[1], Cyane Tornatzky[1], Rosa Martey[1], and Francisco Ortega[1]

[1] Colorado State University, Fort Collins CO, USA
brendan.kelley@colostate.edu
[2] Concordia University, Quebec H3G 1M8, Canada

Abstract. As augmented reality (AR) has continued to expand the technology has seen integration into education and training practices. This study uses a comparative approach to address the question *does prior experience provide for stronger knowledge retention on mobile augmented reality compared to other training and education modalities?* A total of 33 participants were assigned to one of three training modalities (AR, paper manual, or online video). Once the training task was completed, they were tested on their knowledge retention from the experience via a 10-question quiz. While results from this study do not indicate AR provides for a better learning experience than other modalities several results point to the importance of individual characteristics.

Keywords: Augmented reality · mobile AR · training · education · user preference

1 Introduction

A variety of factors can impact the successful integration of emergent technologies into educational practices. Changing political, social, or environmental factors may affect the adoption and uptake of these technologies, such as the COVID-19 pandemic accelerating the hybridization of education on university education [20], as well as technological advancement. New opportunities afforded by emergent technologies, such as mixed reality, or more specifically for this study, Augmented Reality (AR), also help to enable these changes in education practices. While the integration of emerging technologies has proven beneficial, many elements of AR merit further exploration when applied to educational practices, including the tangible affordances of different AR forms, the challenges with integration, and how the technology supports the education process. To this end, this study sought to address the question *does prior experience provide for stronger knowledge retention on mobile augmented reality compared to other training and education modalities?* The results of this work suggest that a "one size fits all" or a generalized approach to education modalities may not be

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an ideal approach. Instead, it may be beneficial and necessary to explore individual characteristics (such as learning style, prior experiences, etc.), preferences, and differences that impact education experiences presented through variable modalities.

1.1 AR Training and Education

The expansion of commercially available mixed reality technologies has already led to integration attempts with education and training practices at a variety of different levels, such as children's education, professional assembly tasks, and electronic device repair. For instance, Jung et al. used an Xbox Kinect v2 to educate youth on proper responses to crisis situations (i.e. flooding, fires, earthquakes, etc.) [10]. In this system, a Kinect sensor detected the user's position and posture (limb placement and orientation) and then rendered crisis-related graphics onto a live video feed of the user. Afterwards, users were given prompts on how to react properly to the current situation. This allowed for a more responsive and interactive experience [10].

Professional training has also seen the adoption of mixed reality technologies, such as a recent study exploring the use of AR for engine assembly tasks [22]. For instance, in Werrlich et al.'s study [22], two different HMD-based AR systems were tested (one with four levels of training complexity and another with the same levels of complexity and an additional post-training quiz). Participants were asked to follow along with their assigned training to complete the assembly task. While the study did not produce any AR to non-AR comparative results, it does provide insights into best practices for designing mixed reality training as participants who took more time to complete the training were able to immediately recall more information, and the post-training quiz did not create a higher perceived workload among participants [22]. The application of AR technologies into professional assembly tasks is becoming increasingly common [2,5,14].

Other hands-on trainings have seen the adoption of mixed reality technologies, such as vocational education [5] or electronics repair [11]. In Dayadag et al.'s study, students used an AR HMD that utilized a mobile phone for computation to learn about basic information technology tasks such as crimping ethernet cables [5]. The latter study [11] used AR to present the disassembly instructions of a Playstation 3 console; an often required step in repairing hardware defects and failures. It then compared the results and experience of the AR mode to users utilizing a paper document. Participants using the AR modality exhibited greater knowledge improvement than the paper group [11], which would be expected as increased interactivity has been demonstrated to improve overall engagement with content [21].

Several studies discussed here include completion time as a metric along with performance metrics (i.e. quiz performace) [14,22]. In both academic and professional settings it is important to consider time commitments from both the individual and the institution. An individual user will only have so much time to devote to training before they will need to begin working and institutions have expectations for how long an individual will take to train. If there are little to no tangible benefits to using a particular modality but it requires a larger time commitment to complete it may not be beneficial to adopt and integrate that modality. However there may be other factors such as cost of training, external support, personalization, etc. that can offset time commitment costs.

1.2 External Factors on Training and Education

While there is strong evidence to suggest that proper integration of emerging technologies, e.g., mixed reality [5,11,14,22], can provide various benefits to the education and training process, there exist several challenges with the integration process. First and foremost, it is important to consider "technology as embedded in other social developments"[4]. Any technological advancement and subsequent adoption (or rejection) of that technology can be deeply affected by factors outside of educational practices. These may include economic constraints, cultural expectations, individual characteristics, or shifts in social developments [4]. Essentially there may not be a viable one size fits all approach.

The prior knowledge of the users also affects the training performance. A recent study compared the use of an AR application and a paper manual for both familiar and unfamiliar tasks for car mechanics [9]. Each participant was tasked with completing both wiper change (unfamiliar) and bumper replacement (familiar) using either the AR application or the paper manual. Results from this study "strongly suggest that routine has much more influence on the way car mechanics conduct a familiar task than the support medium" [9, p. 287]. Similarly, a study on performance during a medical simulation game also found that prior knowledge significantly impacted user performance [12]. However, Richter et al. showed that the cognitive load of the users were reduced for learning processes when individuals had prior knowledge regarding the content [18]. All of which may also impact the overall engagement from individuals [6]. Essentially, the prior knowledge of the users has an impact on their performance in training systems.

The use of emerging technologies for education further suffers from modality familiarity as a mediating factor in addition to content familiarity. In addition to finding that routine is a significant factor in task completion, researchers also found that AR modalities take longer for individuals to complete [9]. This may be due to the novelty of the technology as participants "were curious how [the task] would look like" [9, p. 287]. Other studies have also suggested that the medium used to engage with content can act as a potential barrier to access and engagement [15]. This phenomenon should improve as technologies develop, as further development would not only provide improved experiences [13] but also provide increased exposure and practice [9].

While AR may provide benefits for spatial content, it may not be suited for all content or all learning styles. In passive learners, the technological affordances of mixed reality have been found to potentially harm the education process, whereas active learners were found to benefit from the increased interactivity, presence, and embodied consideration [19]. Different types of knowledge engagement (identification, elaboration, planning, or execution) may also affect the overall engagement of individuals [17]. In essence, differences in the task being taught, the individual, and the modality used may impact the overall education experience.

With emerging technologies such as AR, modality differences may be even more pronounced. This is in part due to a potential lack of familiarity [9], but also due to subtle differences in execution. There exists a wide array of not only AR hardware (i.e. HMD vs. mobile), but also software implementation. The inclusion of different interactive techniques and responses, which are often a product of designer choice, provide different affordances, which in turn affect the education process [1]. This becomes especially challenging with the constant advancement and flux of AR technology. As such, it is important to consider not only potential individual differences but also technical nuances when exploring emerging technology education.

This study aims to address the question *does prior experience provide for stronger knowledge retention on mobile augmented reality compared to other training and education modalities?* by comparing post-training quiz results among three different modalities (AR, paper manual, and online video). A mobile AR (AR using smartphone devices) application was developed for the purposes of this study. This study was also conducted in the Nancy Richardson Design Center (RDC); a non-lab setting. This increases the ecological validity of the study by exposing participants to a setting that more accurately resembles actual training conditions. Many prior studies on AR training and education utilized laboratory settings where every factor can be controlled, however when applying these technologies outside of academic research settings there are numerous uncontrollable factors (i.e. noise level, other individuals, lighting, etc.) that are present in this study. Additionally this study includes both expert and novice participants. Each of these aspects provides novelty over prior studies and takes well documented approaches to AR development and explores them in an applied setting comparable to what a student or worker may experience as AR becomes more commonplace.

2 Methodology

To explore the limitations and benefits of mobile AR training in comparison to other training modalities and address the guiding research question, an experimental approach is used. This experiment used a 3 (modalities: online video, paper, AR) by 2 (task familiarity: prior experience and no prior experience) design with an additional variable for only the AR training (AR familiarity: prior AR experience, and no prior AR experience). Participants began by completing a presurvey to collect demographic information and their prior experience with both the machine being trained (a Roland LEF-300 UV printer) and AR. They were then assigned to one of the three training modalities and used their assigned mode to complete the material loading procedure on the LEF-300 UV printer.

During this training task students were timed using a stopwatch for consistency. While it is possible to use the proprietary AR software developed for this training to time, there was not a feasible way to use the same timer for the paper or video modality. After their training was completed, participants took a post-survey which contained both a knowledge test quiz consisting of 10 questions derived from the certification test already in place at the RDC as well as NASA task load index scales (TLX) [7,8]. This is in line with previous work that also used a comparative experimental approach for AR and non-AR training modalities [2,3,9,16,22]. The paper manual and online video used for this study were already developed by the RDC. Additionally, the quiz used as part of the post-survey is used for lab user certification in the RDC facilities. This allows for comparison against actually implemented training materials and practices that are comparable to other lab and fabrication center training approaches.

A total of 33 participants were recruited for this study (15 female, 18 male) with an average age of 24.64 (SD=5.8). Of these participants, 5 had prior experience with the LEF-300 UV printer. In total, 16 participants had experience with other specialty printers (any printer that prints on non-paper material or paper larger than 11" by 17"). Unfortunately due to the "in the wild" nature of this experiment it was not possible to find participants with the same level of experience to develop a full factor design. Additionally expertise among participants with prior experience may vary widely (i.e. even among 50 trained surgeons their actual experience will vary) and was self reported potentially leading to greater variability.

2.1 Apparatus

For this study, a software was developed in partnership with the center. It is a mobile AR application that is compatible with both Android and iOS (Apple) operating systems so long as the installed device supports either ARCore or ARKit (Android and Apples' respective AR software development kits (SDK)). The application, titled the Augmented Reality Assistant or ARA, was built using the Unity game engine and the Vuforia AR Plugin, which allows for robust AR functionality without extensive development requirements. While the application can be applied to a variety of training content, this study chose to focus on task training, where users were guided through the loading procedure of a Roland LEF-300 UV printer.

After opening the application, users chose the desired module from a menu screen. For the purposes of this study, only two modules were available: 1) a brief tutorial module that informs the user on how to use this specific application and 2) the LEF-300 training module. Once a module was selected, the user saw a live video feed from the front of their devices facing camera(s). They then scanned an image target with the camera (see Fig. 1), which spawns the AR objects into the environment. These virtual objects were anchored to the image target and the user's relative position.

From now on, we refer to the primary virtual object users interact with as "quest steps." These objects consisted of informative text, spatially aware highlights, and decorative user interface elements. The text reflected the current step the user was on and provided guidance for the completion of that step.

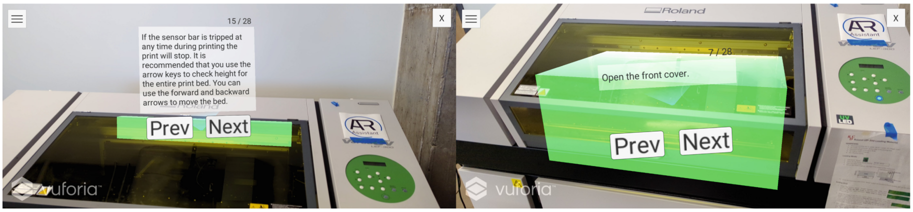

Fig. 1. The Augmented Reality Assistant (ARA)

The semi-transparent highlights encompassed the area or part of the machine that the user would interact with to complete the step. In addition to these elements, there were also two navigation buttons; one labeled "prev" and one labeled "next." As their labels suggest, the "prev" button returned the user to the previous step, and the "next" button advanced to the next step. Once the user was on the last step, the "next" button transitioned into an "exit" button and returned participants to the main menu. Additionally, they can return to the main menu using the "x" button anchored on the screen.

3 Results

3.1 Time Results

Time results were significant for modality ($F(2,32) = 13.803$, $p < .001$) based on ANOVAs run with the Python 3 Scipy package. Examination of QQ plots showed a normal distribution of the data. Further power analysis revealed a large effect size for time results ($d = 1.24$) with an alpha of 0.05. To achieve a power of 0.8 a total of 24 participants with groups of $n = 8$. Participants using the AR modality took the most amount of time to complete the task averaging 789 s for completion (*Standard Deviation (SD)* = 219 s). The paper manual took the second most amount of time with an average of 519 s for completion (*SD*= 144 s). At an average completion time of 312 s (*SD*= 81 s), the video training took the least amount of time. We did not observe a significant difference for prior mobile AR experience impact on the training time; however, prior HMD AR experience did provide a statistically significant impact on the training time ($F(1,31) = 5.41$, $p < 0.05$) .

3.2 Quiz Results

While the AR modality did produce slightly higher average quiz scores (AR: 7.67 out of 10 *SD*=1.50) than either the paper manual (paper: 6.91 out of 10 *SD*=1.97) or the video (video: 7.0 out of 10 *SD*=1.29) an ANOVA demonstrated that these differences were not statistically significant ($F(2,32) = 0.69$, $p > 0.05$). Power analysis of the quiz data showed a small effect size ($d = .2$) requiring groups of $n = 156$ with a power of .7 for statistically significant results

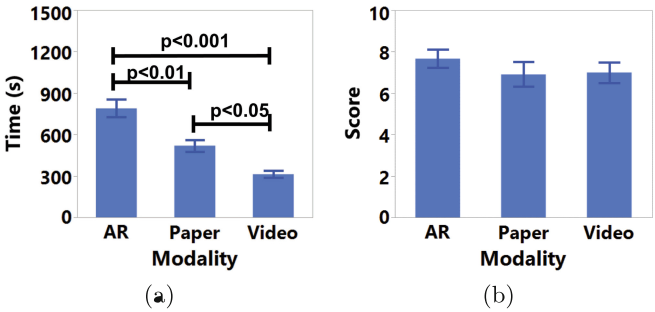

Fig. 2. Training Time (Left) and Quiz Scores (Right)

to emerge. Prior experience with other forms of specialty printers (i.e. any printer that prints on material other than paper or larger than 11in by 17in) did not have a statistically significant impact on the training experience; however, prior experience with the Roland LEF-300 UV printer, which was used for the training task, did have a statistically significant impact on quiz scores ($F(1,31)=4.68$, $p<0.05$) (Fig. 2).

3.3 NASA-TLX

The results of the NASA-TLX scores were given in Table 1. The video modality was rated as the most mentally demanding followed by the AR then paper modality. However the video modality was rated as the least physically demanding with AR being the most. Additionally the video modality was rated as the most rushed with followed by the AR modality and then the paper manual. Participants felt the most successful with the AR and paper manual with AR reported as 5.17 and paper slightly higher with a value of 5.45 for feeling of success. The video was rated as 4.2 for feelings of success. Both the AR and video trainings were ranked as having a 3.0 for workload compared to the lower score of 1.72 for the paper manual. Both the paper and AR manual had a lower rating for frustration than the video.

Table 1. Nasa TLX Results (1–7 Scales)

Measure	AR	Paper	Video
Mental Demand	3.33 (*SD*= 1.56)	2.36 (*SD*= 1.12)	3.9 (*SD*= 1.66)
Physical Demand	2.0 (*SD*= 1.21)	1.27 (*SD*= 0.47)	1.2 (*SD*= 0.42)
Pacing	1.83 (*SD*= 0.72)	1.45 (*SD*= 1.51)	2.2 (*SD*= 0.92)
Success	5.17 (*SD*= 1.64)	5.45 (*SD*= 1.29)	4.2 (*SD*= 0.92)
Workload	3.0 (*SD*= 1.13)	1.72 (*SD*= 0.94)	3.0 (*SD*= 1.49)
Frustration	2.16 (*SD*= 0.94)	1.91 (*SD*= 1.22)	2.6 (*SD*= 1.84)

An additional Pearson's R test was conducted on the NASA-TLX measures and quiz scores (see Table 2). All values except for success ratings were negatively correlated with quiz scores. Thus the higher the reported mental demand, physical demand, pacing, workload, or frustration the lower the quiz score, however these were not significantly significant. The only statistically significant correlation was between reported perceptions of success and knowledge scores but in a positive direction. So as users reporting of success increases their score would also increase.

Table 2. Nasa TLX and Quiz Scores

Measure	Quiz Score Correlation
Mental Demand	−0.02
Physical Demand	−0.12
Pacing	−0.03
Success	0.44*
Workload	−0.14
Frustration	−0.05

Note. * $p < .05$

4 Discussion

In this paper, we investigated if the prior knowledge of the training has an effect across different modalities. While this study did not produce results to exhibit an AR superiority over other modalities for education and training, the results point to a greater area of exploration for human-computer interaction studies. The impact of individual characteristics can be seen in the influence of prior experience with the trained machine on quiz scores. In our study, once an individual possesses knowledge of how to use the device, further information, regardless of the presentation of that information, becomes insignificant. This notion is in line with previous studies that found a routine and prior experience to be a mediating factor [9]. Another example of individual differences affecting the training is the impact of prior AR HMD experience on the training time. This effect, however, was not measured or present in prior studies, such as [2,3,9,16, 22]. Additionally, the effect of AR HMD experience is not intuitively predicted, as this study and training task utilize *mobile* AR, which has several differences in, such as form factor (hand-held device vs head-mounted) and interaction techniques (touch screen vs controller/hand tracking). This was an intentional choice due to the greater accessibility of mobile AR compared to HMD AR as more individuals have access to AR ready mobile devices than expensive AR HMDs.

The Nasa TLX results indicate a higher reported mental demand with the video modality. This is most likely due to the lack of direct interaction with the trained machine requiring more cognitive resources. The AR application was rated as having the highest physical demand, which is unsurprising given the physical demands of interacting with a mobile phone. The higher reported feeling of success with both the AR and paper modality over the video training may indicate a benefit for directly interacting with the training device. While both AR and video had the same reported workload these may be due to different interaction requirements, with AR requiring more physical resources and video requiring more cognitive.

These results may point to deeper individual considerations. While this study did not explicitly inquire about the education or occupational experience of its participants, one of the main recruitment channels primarily targeted computer science students. As such, those with prior AR head-mounted display (HMD) experience may have other pertinent computing experience that influenced the training experience. This potential deeper connection may also be exemplified by the positive correlation between perceived success and quiz scores. The more confident an individual felt with their training session, the better they typically performed regardless of modality. This also poses our new research question: **what makes an individual feel more or less confident during the training experience?** Since these results are independent of the modality used, there may be other identifiable characteristics at play. It may also be the case that different characteristics support success with different modalities.

This work was limited in several ways. First the use of an "in the wild" setting for the experiment introduces factors outside of our control. Included in this is the prior experience and expertise of the participants due to the method used to collect participant data (presurvey and postsurvey separate with no indicators to link these two surveys together). Additionally the sample size of 33 (with 11 for each modality) may be too small to fully capture trends.

5 Future Work

To clearly understand the complex interplay between an individual and different training modalities, further study is necessary with a larger research program. As with any design-related study, such as the one presented here, there are various adjustments and changes to the AR interface, interactions, and content that can be implemented. Additionally, other related technologies, such as virtual reality, can also be of interest to the education and training field. This study was also particularly interested in mobile AR usage due to accessibility considerations (namely cost), but there may be benefits to using an AR HMD that warrants further exploration. However, these changes would still take a generalized or "one size fits all" approach to the topic. Instead, more consideration must be put on the end user in conjunction with the technology.

To this end, future work may consider including questionnaire items related to learning characteristics, personality traits, or other related psychological concepts. However, this may not be feasible for all studies, especially if other measures are already being administered that pertain to the topics of interest. Instead, it may be prudent to develop studies that specifically engage with individual characteristics in relation to technological considerations. For instance, a study may use only a single modality (i.e. AR, VR, video, paper, etc.) but administer measures to identify traits, characteristics, or experiences that make an individual more likely to succeed using that modality. Or a study may use multiple modalities but then allow a participant to choose which training modality to use for the trained task. Subsequent measures would then be taken on not only performance (i.e. quiz score, accuracy, time, etc.) but also on their choice, traits, characteristics, and experiences to determine how their choice aligns with their experience and them as an individual. Most important, measuring metacognition. All these topics reveal new research questions for our future studies. It is often the case with comparative training or education studies, such as the one presented here, that the end goal is to determine which modality works best for a general population. While this is a useful pursue, it does not take into account that different individuals learn differently [17,19].

By exploring these individual factors in conjunction with technological components, a greater understanding of how we interact with computers, how we learn with computers, and how computers affect us can be achieved. Often there is a focus on determining which modality, solution, or technology works best for a wide audience (which is an important and useful exploration to undertake), but this focus can often overlook important aspects pertaining to the human side of human-computer interaction. Additionally, careful attention to the end user in such a manner may open up possibilities for accessible computing via a greater understanding of marginalized groups and their unique attributes and needs.

6 Conclusion

We analyzed how different prior knowledge of the individuals affects training performance in AR training systems in an applied non-lab setting. A comparative study with 33 participants who were randomly assigned to either an AR, paper manual or online video training was conducted. While the modality did not affect the follow-up quiz scores based on available data several unexpected results indicate the importance of considering individual characteristics, experiences, and traits in addition to the computing technology used, such as their prior experience with the training content and perceived performance.

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