THESIS

DOES MODALITY MAKE A DIFFERENCE? A COMPARATIVE STUDY OF MOBILE AUGMENTED REALITY FOR EDUCATION AND TRAINING

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ABSTRACT

DOES MODALITY MAKE A DIFFERENCE? A COMPARATIVE STUDY OF MOBILE AUGMENTED REALITY FOR EDUCATION AND TRAINING

As augmented reality (AR) technologies progress they have begun to impact the field of education and training. Many prior studies have explored the potential benefits and challenges to integrating emerging technologies into educational practices. Both internal and external factors may impact the overall adoption of the technology, however there are key benefits identified for the schema building process, which is important for knowledge acquisition. This study aims to elaborate and expand upon prior studies to explore the question *does mobile augmented reality provide for stronger knowledge retention compared to other training and education modalities?* To address this question this study takes a comparative experimental approach by exposing participants to one of three training modalities (AR, paper manual, or online video) and evaluating their knowledge retention and other educational outcomes.

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CHAPTER 1. INTRODUCTION

As technologies such as mixed reality, and more specifically augmented reality (AR), continue to advance they provide new opportunities and affordances that may provide benefits to the education and training practice. Of particular interest is the effect these technologies have on an individual's schema. These cognitive structures are used to store, process, and access information and are constructed through experience. Due to the potential new experiences provided by AR it should come as no surprise that it is a prime candidate for study in relation to education and schema.

In fact many researchers have begun to explore the use of AR, and related mixed reality technologies, for education and knowledge building. Several potential benefits, as well as challenges, have already been identified by these prior studies. Furthermore these studies span a wide range of educational practices from K-12 education to professional vocational training. This variety in approaches has revealed several different potential avenues for integration including task training and specialist training.

While the technology used is important, the learning process is rooted in schema. This is especially true when considering prior experiences. Both prior experience with the educational content and the educational modality provide benefits and barriers to further schema building and engagement. AR provides new tools and opportunities to improve knowledge building due to the spatial embodied nature of the technology. This allows for greater consideration of the end user and their experience which in turn may improve educational outcomes.

Based on each of these aspects this study uses a comparative experimental approach to address the question *does mobile augmented reality provide for stronger knowledge retention compared to other training and education modalities?* By comparing knowledge building from different established training modalities, primarily paper manuals and online videos, to a proprietary AR application developed for mobile devices (i.e. Android and iOS) this study seeks to understand if the affordances present in an AR modality are able to better support knowledge building and retention for task based training.

This document begins with an overview of background concepts relevant to the study's purpose. These include the current challenges and trends in technological integration with education practices, the current state of mixed reality technologies (especially AR), different approaches to capitalizing on AR for education and training, how these new and emergent media experiences relate to the knowledge building process as described by schema theory, and strategies and considerations for effective technology integration to support the educational process. After elaborating on these background topics this study presents several hypothesis that can be inferred from prior research, then discusses the method used for addressing these hypothesis and the overarching research question. Finally it presents the results of this study as well as considerations for further research.

CHAPTER 2. LITERATURE REVIEW

2.1 Emerging Technologies Impact on Education

A variety of factors can impact 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 (Skulmowski & Rey, 2020), as well as technological advancement. New opportunities afforded by emergent technologies, such as mixed reality, or more specifically for this study AR, also help to enable these changes in education practices. While integration of emerging technologies has proven to be beneficial there are still many elements of AR that merit further exploration when applied to educational practices including the tangible affordances of different AR forms, the challenges with integration, and how the technology relates to the schema building process.

This literature review aims to address each of these elements. It begins by discussing emergent technologies integration into education on a broad scale. Then a slight detour is taken to discuss schema theory, which is essential for understanding the knowledge building process. From here a discussion on the specifics of mixed reality and AR is introduced, which leads to specifics on AR's integration with education and training. These topics are then related back to schema with a more focused discussion on the elements of AR that may prove useful for knowledge building. Finally this chapter concludes with an overview of the research question (*Does mobile augmented reality provide for stronger knowledge retention compared to other training and education modalities?*) that guides this study and the hypothesis inferred from prior scholarship.

2.1.1 Emerging Technology Integration

The shift to interactive mediums such as Web2.0, gaming, and AR has lead to a variety of integration of technology into education practices. These shifts accompanied a shift in overall teaching structure and practices creating a "participant teacher" experience (Kurt et al., 2019). Rather than transmitting information to the students participant teachers act as guides helping to build student knowledge. Several key benefits of Web2.0 technologies have been shown to assist with this guiding experience, such as the ability to create and share content, continual interaction through social media, and remote cooperative work (Kurt et al., 2019). These benefits can be achieved from a variety of Web2.0 enabled technologies such as Google Forms, Quizzizz, Metaverse Studio, etc., many of which have seen actual adoption into classroom settings by educators (Kurt et al., 2019).

Another technology that has seen successful integration is that of gaming, with many new publications focused on education and educational research (Martí-Parreño, Méndez-Ibáñez, & Alonso-Arroyo, 2016). The trend toward gamification, the application of games and game design principles to experiences not solely concerned with entertainment purposes, is due to the potential benefits as well as an attempt to appeal to younger generations who are often considered as "digital natives" (Beavis, 2013). Gaming is often considered a "fun" experience which in turn may increase engagement with content. For instance a research study using an iPad game developed for a science center found that designing around different styles of "fun" allowed for the educational gaming experience to appeal to a wide audience of users and provide deeper engagement (Atwood-Blaine & Huffman, 2017). With gaming and education the "ultimate goal is to use gaming to facilitate the most meaningful and effective connections between formal and informal science education in a way to help all students achieve in science" (Atwood-Blaine & Huffman, 2017, p 64). AR, discussed in more depth later, is capable of providing similar benefits to the education process.

Leveraging the technology and the affordances they provide is essential to proper integration of emerging technologies. However this process is not without it's difficulties. Many of these technologies are quite complex making it difficult to identify all attributes that may provide a benefit (Beavis, 2013). Additionally this makes adoption for educators exceptionally difficult as it often requires extensive training and knowledge of the technology on top of educational content (Kurt et al., 2019). The potential for erroneous integration is ever present requiring proper understanding of the opportunities and affordances provided by emerging technology.

2.1.2 Emerging Technology Opportunities and Affordances

In order to understand the opportunities, challenges, and affordances provided by technologies such as AR the concept of affordances must first be clarified. Affordances are often discussed in conjunction with new and emergent mediums. The classical definition of affordances was in relation to ecology describing affordances as "what if offers the animal, what it provides or furnishes, either for good or ill" (Gibson, 2011). They are interactions between a creature and it's environment that are either explicitly or implicitly presented. While the concept of affordances traditionally describes ecological interactions it's definition has been adapted to other non ecological fields such as communication; with an environment being reconceptualized as including virtual spaces (i.e. social media or virtual environments).

This is a driving assumption behind a variety of interactive communication research. In these cases researchers are "platform oriented" taking into consideration the platform opportunities and affordances (Rathnayake & Winter, 2018). This is especially important with new and emerging technology as they may provide affordances that were previously nonexistent. Increased actual or perceived interactions can dramatically impact user experience (Sundar, Xu, Bellur, Oh, & Jia, 2011). These interactions are enabled and shaped by the affordances presented by a platform which in turn affect the overall user experience. This experience in turn can shape effects, attitudes, and outcomes such as subsequent user actions or behavior intentions (Sundar et al., 2011).

2.2 Experience and Schema

As with the concept of affordances the initial theoretical proposal of schema was developed outside of the field of communication and was later adapted. In this case schema theory finds its roots in cognitive psychology. It is initially described as the process of "active organization of past reactions, or of past experiences" (Bartlett, 1932, p. 105). It suggests that every experience an individual is exposed to is processed and stored into cognitive structures referred to as schema. These structures are adapting and changing as new experiences and information are processed and integrated. Further experience may then recall previously established schema bringing forth a mass of connected information (Bartlett, 1932). Schema are then important for memory recall, or in the case of education and training knowledge recall. It also stands to reason that since affordances shape user experience and experience is used to build and shape schema, which are then used to process new information and recall prior knowledge the technological platform used to communicate information for education and training may very well affect a user's memory and knowledge. The relation between schema, experience, and AR will be further explicated later in this chapter, however this initial summary is important to consider as the discussion regarding mixed reality, and it's relationship to experience, progresses.

2.3 Mixed Reality

While many mixed reality technologies are not new they have garnered recent attention due to increased commercial offerings from a variety of companies such as Oculus (owned by Facebook/Meta), Apple, Google, Valve, etc. Affordable, fast, and graphically adept hardware has become affordable and accessible to a greater audience. Mobile devices such as iOS and Android powered phones are capable of true mixed reality and augmented reality experiences. A variety of new tethered (connected to a computing device) and untethered (standalone) virtual reality systems have exploded onto the scene since the introduction of the first Oculus Rift and HTC Vive HMDs. As with any other emerging technology these advances provide potential avenues for education and training, however it is first important to consider what the nature, affordances, and outcomes of these individual technologies are.

2.3.1 Collection of Technologies

Mixed reality is a blanket term that refers to a collection of technologies. Virtual reality (VR), augmented virtuality (AV), and augmented reality (AR) all fall under the mixed reality umbrella with each one describing a different interaction between virtual and physical objects. While this study is primarily concerned with AR technologies it is important to understand the interplay between these technologies and to define inclusionary and exclusionary requirements as they are often related, but provide different experiences and affordances. These distinctions also help to establish the specific opportunities and affordances that drive the selection of AR for this study.

These technologies are often described as part of a spectrum or continuum (Milgram & Kishino, 1994). With the "real" or physical environment on one end and the virtual environment on the other (see 2.1). Each of these technologies is then placed along the divide in reference to their proximity to the two extremes (physical or virtual). VR falls on the virtual end of the spectrum as it’s primary goal is to completely suppress all physical stimuli (i.e. the physical room a person resides in) and present a virtual world through completely simulated stimuli (i.e. sound from the earphones of an HMD and visuals from the screen of an HMD) (Jerald, 2016). AV falls near VR, but is slightly removed as AV works to merge physical elements *into* virtual environments (Milgram & Kishino, 1994). For example a user may don a VR HMD, then while in the simulated virtual environment (that is currently suppressing the psychical reality) they receive a direct video feed from a colleague for a hybrid meeting (ala zoom or skype). This video feed is seen within the HMD and serves as a window into and reminder of the physical world just outside of the virtual.

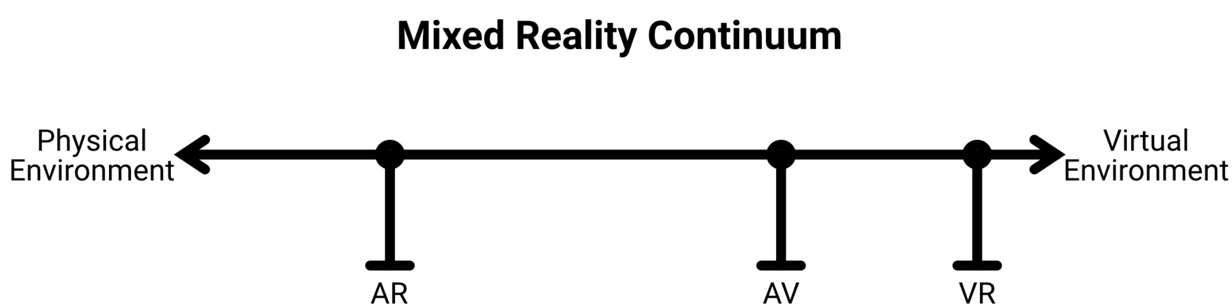

Figure 2.1

Note: The Mixed Reality Continuum based on the first description from Milgram & Kishino, 1994

While AR and MR are technically different technologies, with AR being "any case in which an otherwise real environment is ’augmented’ by means of virtual (computer graphic) objects" (Milgram & Kishino, 1994, p. 4) and MR being an environment where "real world and virtual world objects are presented together within a single display" (Milgram & Kishino, 1994, p. 3), they have more recently been used synonymously. MR is a broader term than AR and can encompass both AR and AV whereas AR is specifically the overlay of virtual objects into a physical environment (as opposed to AV where physical objects are integrated into a virtual environment). In order for an experience to truly be consider AR it must meet three criteria: 1) combine physical and virtual, 2) be interactive in real time, and 3) allow for 3D registration (Azuma, 1997).

As the definition of AR suggests (Milgram & Kishino, 1994) it is a technology that depends on the merging of virtual objects into a physical environment. As such any experience that does not merge, overlay, or otherwise combine virtual and physical cannot be considered AR. This merging may be done via any method, however the two most common are video pass through (where a live video feed is processed and then rendered with virtual objects spliced into the feed) or optical see-through (where holograms or projections are transposed onto clear lenses that allow both the projections and the physical reality to be viewed simultaneously) (Azuma, 1997). The interactivity requirement is primarily used to differentiate AR from other technologies. For instance Adobe Photoshop can be used to embed simulated elements into a photograph of the physical world, but this would not be considered AR, instead it would be considered art. Similarly a movie using computer generated images for special effects (i.e. the Hulk from *The Avengers* does also combine virtual and physical, however the lack of real time interactivity denotes these as cinematography and film rather than AR. 3D registration is responsible for creating the illusion that the physical and virtual worlds coexist (Azuma, 1997). Virtual objects must be aware of the physical environment and respond accordingly. This is especially important for high precision applications such as medical training (McKnight et al., 2020) or precision mechanical work (Werrlich, Nguyen, & Notni, 2018; Büttner, Prilla, & Röcker, 2020).

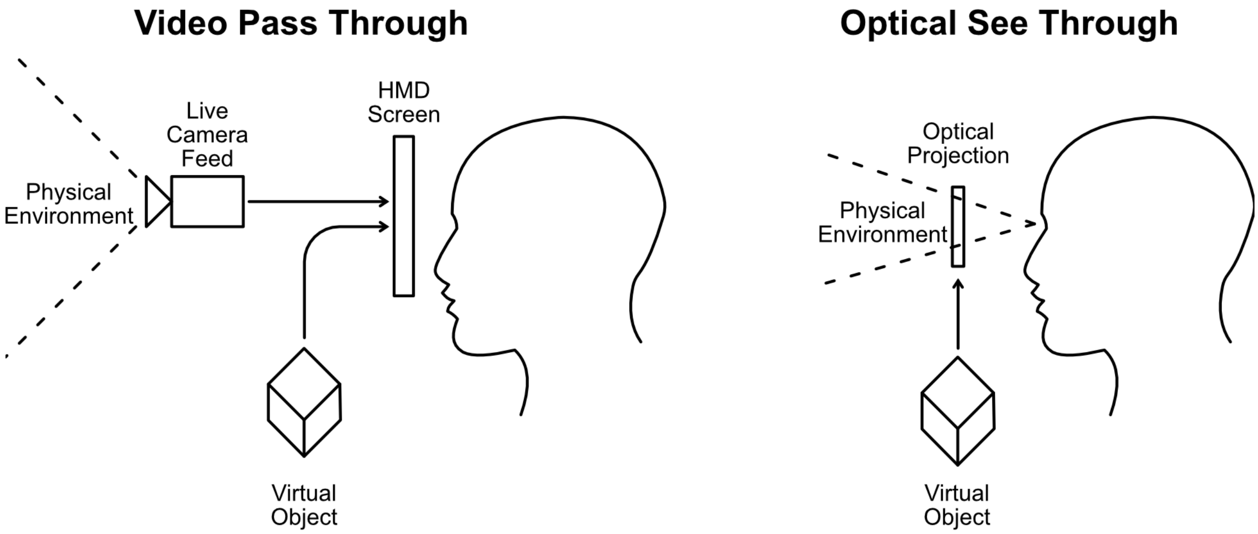

Figure 2.2

Note: Differences between Video Passthrough and Optical Seethrough approaches to AR.

2.3.2 Mixed Reality Have Already Begun Impacting Education and Training

The expansion of commercially available mixed reality technologies has already lead to integration attempts with education and training practices at a variety of different levels. This includes children's education, professional assembly tasks, and electronic device repair. In one study used an Xbox Kinect v2 to educate youth on proper responses to crisis situations (i.e. flooding, fires, earthquakes, etc.) (Jung, Cho, & Jee, 2016). In this system the Kinect sensor detects the user's position and posture (limb placement and orientation) then render's crisis related graphics onto a live video feed of the user. They are then given prompts on how to properly react to the current situation. The system was cited as having several benefits over other non AR options including more accurate response detection (which in turn allows for more useful and accurate response feedback) and a lack of cybersickness (motion sickness unique to VR or similar technologies (Jerald, 2016)) (Jung et al., 2016). These types of systems also provide a more responsive and interactive experience which, as discussed in 2.2, may affect the schema building process.

Professional training has also seen adoption of mixed reality technologies, such as a recent study exploring the use of AR for engine assembly tasks (Werrlich et al., 2018). In the study 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 trainings 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 (Werrlich et al., 2018). The application of AR technologies into professional assembly tasks is becoming increasingly common (Büttner et al., 2020; Dayagdag, Catanghal, & Palaoag, 2019; Nguyen & Meixner, 2019).

Other hands on training have seen adoption of and benefits from mixed reality technology. Such as vocational education (Dayagdag et al., 2019) or electronics repair (Lam, Sadik, & Elias, 2020). The latter study (Lam et al., 2020) 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 (Lam et al., 2020) which would be expected as increased interactivity has been demonstrated to improve overall engagement with content (Sundar et al., 2011).

2.3.3 Difficulties with Emerging Media Integration

While there is strong evidence to suggest that proper integration of emerging technologies, such as mixed reality, 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" (Cloete, 2017). 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, or shifts in social developments (Cloete, 2017; Kelley, 2020). This can be seen with the recent adoption of digital technologies in academic spaces as a response to the Covid-19 pandemic (Skulmowski & Rey, 2020).

In addition to external factors there are several factors within education and training practices that provide challenges to successful integration. A recent study of 117 education professionals sheds light on some of the biggest challenges to emerging technology adoption (Atabek, 2019). Knowledge, information, and processes behind the integration of technologies were found to be the most significant barriers, with trainings on proper integration being one of the greatest challenges (Atabek, 2019). Additionally there exists a lack of time to learn about or develop content for technologies as well as a lack of proper incentives to pursue integration (Atabek, 2019). Importantly it is not the devices and technologies themselves that present the barriers (Atabek, 2019), but instead a lack of content for and educator awareness of the technologies.

Both the external and internal factors related to emerging technology integration within education and training affect mixed reality, however there also exist aspects unique to mixed reality that may present further barriers. The two biggest examples of further challenges unique to AR are the continued evolution of the technology and the shifting social sentiment regarding the technology. AR, as with most emerging technologies, "exist in a state of flux as a mixture of blueprint and hardware, plan and practice, the soon to arrive and the almost obsolete, surrounded by speculation and speculators, who make often-contested claims about their promises, perils, and possibilities" (Liao & Iliadis, 2021, p. 280). AR is a still developing technology, even more so than VR (McKnight et al., 2020), meaning that as the technology is being adapted it is also being restructured, redesigned, and reintroduced. With each advancement comes new possibilities, but also new obsolescence. This, in turn, may compound the already complicated issues regarding integration into education and training and highlights the necessity of continued investigation of the technology.

In addition to the continued development there are also social factors that affect AR. An ever evolving technology produces ever evolving discourse and social sentiment. Initially in early AR development stages much of this sentiment was driven by theoretical ideation and media portrayals, particularly in the science fiction genre (Liao & Iliadis, 2021). As the technology progressed and became a functional reality corporate influences, such as sponsorships and marketing began to influence the discourse, research, and drive regarding AR (Liao & Iliadis, 2021). However these influences from corporate and academic spaces have not yet influenced public audiences. Indeed there are still discrepancies between public understanding of the technologies capabilities and offerings and the reality of those offerings (Thompson & Potter, 2020). This divide between expectation and reality further compounds the difficulties of education integration in regards to educator awareness and resources. However as with any challenges proper consideration and investigation of the problems and potential solutions through academic research or otherwise can help to identify solutions and provide insight on successful integration.

2.4 Approaches to Extended Reality Education and Training

Throughout this discussion of mixed reality within the realm of education and Training there have been a variety of different approaches to integration. A variety of technologies have been used such as an Xbox Kinect sensor (Jung et al., 2016), AR HMDs (Werrlich et al., 2018; Dayagdag et al., 2019), and mobile AR (Lam et al., 2020). Each of these serve as examples of possible benefits and approaches to implementing mixed reality technologies. These approaches may be driven by the affordances provided by the technology, the potential benefits of the technology, or changing social factors. In general these, and other similar studies fall into one of two categories: task training, or specialist education. However it is worth noting that some examples may fall into unique use case categories and while this study is primarily concerned with task training it is important to distinguish the two.

2.4.0.1 Task Training

Task education and training centers around a single task with specific and repeated steps with little to no prior knowledge required to complete the task. These trainings may instruct on a variety of different tasks from a variety of fields, such as engine assembly (Werrlich et al., 2018), pneumatic assembly (Büttner et al., 2020), information technology development (Dayagdag et al., 2019), or robotics (Nguyen & Meixner, 2019). In these cases digital objects are integrated into a physical task and serve to inform users on how to progress through the steps. Each step is typically sequential requiring that a previous step be completed prior. In many cases little to no prior knowledge regarding the task is required.

2.4.0.2 Specialist Education

Specialist education experiences, in contrast to task training, typically require prior knowledge of a subject for proper engagement with the education and training content. In these experiences individuals are provided with a space and experience to continually develop and hone skills. This type of training is often used in medical fields as it provides opportunities for "skill mastery outside the operating room" (McKnight et al., 2020, p. 670). Individuals with prior knowledge of related medical practices are then able to practice complex and adaptive procedures that help to reinforce their knowledge and skills.

2.5 Schema Are Used to Process New Knowledge

As previously elaborated on in 2.2 schema serve as cognitive structures for the storage, maintenance, and recall of information derived from experience (Bartlett, 1932). This process may be achieved through accretion (the gradual process of adding new concepts to existing schema without disrupting the established structure through daily experience), tuning (when an established schema is modified to align with new experiences and information), or restructuring (when a new schema is established to accommodate new experiences) (Neumann & Kopcha, 2018). With every new experience an individual's mind must decide how to process and store that information. If the experience aligns with a currently established schema that information may simply be incorporated into the established structure. If the experience challenges a currently established schema that information may be used to restructure the existing schema. If the individual lacks a schema that relates to an experience they may then use the experience to construct an entirely new schema thus expanding acquiring new knowledge.

Specialist education is primarily concerned with accretion or in some cases tuning. In these cases an individual has already established schema related to the trained content, such as a veterinary student who constructed schema during their undergraduate courses. They are then exposed to an AR training that allows them to practice a procedure they learned about in a course. This AR experience would provide them with stimuli and experiences that access those existing schema. From there the individual would either incorporate the new experiences into the schema if the experience aligns with their established schema or use the knowledge to restructure the existing schema (perhaps due to mislearning the content in their courses). Task training on the other hand is primarily concerned with restructuring (although in some cases may also be involved with tuning), since these types of trainings are not reliant on previously established schema. The lack of prior experience and established schema lead to the individual using the new experience to establish a new schema.

Regardless of the training type it is important to consider the role that schema play in the processing and acquisition of new knowledge. Different approaches and strategies have been employed to aid in these processes such as concept mapping (a form of knowledge reflection and physical organization) and inclusion of imagery (a form of expanded stimuli) (Neumann & Kopcha, 2018). These strategies, when combined with assessing an individuals prior experiences can lead to improved educational outcomes (Torney-Purta, 1991; Crawford, Roger, & Candlin, 2018). Prior experience is especially important as it can be a key factor in how an experience is processed and incorporated into an individuals schema. What becomes complicated with AR and other emerging technologies is that both previous experience with the content and previous experience with the technology may play a role in these processes.

2.6 Familiarity on Content and Modality

The processes of accretion, tuning, and restructuring are each dependent on an individuals prior experience (or lack thereof). This applies for not only the content being communicated, but also to the modality used for communication. The expert-novice gap refers to the performance and outcome differences among individuals depending on their familiarity with a process, software, task, or technology (Barfield, 1986), with experienced experts (who have developed schema related to the experience) outperforming individuals with little to no prior experiences (and thus underdeveloped or nonexistent schema). Solutions to resolve this gap are similar to strategies used for the support of schema construction in education practices, such as the use of concept maps (Ifenthaler, 2010) or reflective metaphors (Hsu, 2006). In relation to training and education, prior content and prior modality experience may be significant confounding factors when individuals are exposed to education materials.

2.6.1 Prior Knowledge with Content

A recent study compared the use of an AR application and a paper manual for both familiar and unfamiliar tasks for car mechanics (Hoffmann, Büttner, Prilla, & Wundram, 2020). 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" (Hoffmann et al., 2020, p. 287). A study on performance during a medical simulation game also found that prior knowledge significantly impacted user performance (Lee, Donkers, Jarodzka, & van Merriënboer, 2019). Cognitive loads were also reduced for learning processes when individuals had prior knowledge regarding the content (Richter, Scheiter, & Eitel, 2018). All of which may also impact the overall engagement from individuals (Dong, Jong, & King, 2020). Essentially, once someone has been educated or trained on some content new information is more easily processed and in some cases new information is entirely unnecessary and ignored, leaving prior knowledge with content to be a significant mediating factor. This is in line with the notions of accretion, tuning, and restructuring as both tuning and restructuring require more cognitive effort (with restructuring requiring more than the former) (Neumann & Kopcha, 2018).

2.6.2 Prior Experience with Modality

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 was a significant factor in task completion, researchers also found that AR modalities took longer for individuals to complete (Hoffmann et al., 2020). This may be due to the novelty of the technology as participants "were curious how [the task] would look like" (Hoffmann et al., 2020, 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 (Okhovati, Sharifpoor, Aazami, Zolala, & Hamzehzadeh, 2017). This phenomenon should improve as technologies develop, as further development would not only provide improved experiences (McKnight et al., 2020), but also provide increased exposure and practice (Hoffmann et al., 2020).

2.7 Effective Knowledge Building

Several strategies have been suggested for improving the schema building process. Some, such as concept mapping (Ifenthaler, 2010), are useful for a wide variety of topics; both tangible and abstract. However AR may provide distinct benefits for effective knowledge building when applied to content with spatial elements. This is due to not only the spatial elements required to define a technology as AR (Azuma, 1997), but also due to the reduced levels of concept abstraction the 3D elements may provide.

2.7.1 Schema Building is Rooted In Embodied Interactions

The schema building process is rooted in interactions. These interactions are more impactful when they take into account that individuals are embodied beings. Embodiment is the notion that experiences, emotions, behaviors, and ideas are rooted in bodily interactions (Meier, Schnall, Schwarz, & Bargh, 2012). Any experience an individual has must be processed using their corporeal form. In any interaction sensory, semantic, and behavioral factors contribute to the overall experience (Sohn, 2011). Each of these factors is in relation to an individuals embodied form with sensory elements pertaining to external stimuli perceived by the body, semantic elements referencing past knowledge processed through the body, and behavioral elements utilizing the body as a mode for action or reaction. The experience processing functions of embodiment are inescapable, as such any successful knowledge building must account for the physical form of the individual.

2.7.2 Spatial Approaches to Education

As we are three dimensional beings who move through and interact with a three dimensional world any explication of content using 2D planar surfaces (such as paper, TVs, or monitors) is abstracted from embodiment. This is not to say that these abstracted forms are ineffective, but rather a 3D spatially aware approach, such as AR, may provide for stronger educational results. Several studies have demonstrated benefits to both short and long term memory. A study where participants were asked to either use an AR or paper manual to memorize and recall the location of virtual objects found that users who interacted with the AR mode performed better in short term memory recall (Munoz-Montoya, Juan, Mendez-Lopez, & Fidalgo, 2019). Similar results were produced in a study comparing paper manuals to AR for the disassembly of a Playstation 3 console (Lam et al., 2020). Benefits were also present for long term memory recall. A longitudinal study with fourth grade students found that while initial (short term) recall of information was similar regardless of modality, students exposed to the AR version of an anatomy lesson were better able to recall information after both two and four weeks (Pérez-López & Contero, 2013). In regards to physical embodied tasks AR seems to provide benefits to the schema building processes allowing for stronger short and long term information recall and retention, whereas more abstracted methods of training or educating, such as paper manuals or other 2D representations of a 3D task, were less effective.

2.7.3 Differences in Education Approaches Impact Knowledge Building and Retention

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, where as active learners were found to benefit from the increased interactivity, presence, and embodied consideration (Sari, Warsono, Ratmono, Zuhrohtun, & Hermawan, 2021). Different types of knowledge engagement (identification, elaboration, planning, or execution) may also affect the overall engagement of individuals (Quinlan, 2019). Essentially 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 potential lack of familiarity (Hoffmann et al., 2020) 2.6, but also due to subtle differences in execution. There exist 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 (Bakkiyaraj, Kavitha, Sai Krishnan, & Kumar, 2021). This becomes especially challenging with the constant advancement and flux of AR technology. As such it is important to not only consider potential individual differences, but also technical nuances when exploring emerging technology education.

2.8 Concluding Summary

The use of mixed reality, and more specifically AR, for training and education draws upon scholarship from education, cognitive psychology, and human computer interaction to create a complex problem with multiple factors. A multitude of challenges exist with integration of these technologies, both external and internal to the education and training practices. However the potential opportunities and affordances presented by the developing technologies can often be beneficial to the overall education process. These new affordances present opportunities for new experiences, which are the foundation for the construction of schema and new knowledge.

Several prior studies have already explored the use of mixed reality in education and training; highlighting not only the benefits, but also the potential difficulties with integration. Both task and specialist education have seen the integration of these technologies. However regardless of the end use case various factors, such as familiarity with content and familiarity with modality, continue to affect the knowledge building process. In order for effective schema building to occur (and thus effective knowledge building) embodiment and the spatial nature of experience must be considered.

As AR continues to evolve the nature, use, and sentiment of the technology will continue to change. In turn the constant flux of the technology requires consistent upkeep and vigilance in research. It is precisely this that drives this study to address the question: *does mobile augmented reality provide for stronger knowledge retention compared to other training and education modalities?*

2.8.1 Research Question and Hypothesis

In addition to the research question '*Does mobile augmented reality provide for stronger knowledge retention compared to other training and education modalities?*', several hypothesis can be inferred from the findings of previous work.

Based on prior results exploring the relationship between AR technologies and the schema building process (Munoz-Montoya et al., 2019; Lam et al., 2020; Hoffmann et al., 2020; Pérez-López & Contero, 2013) it can be hypothesized that AR training may provide fro better short and long term knowledge retention. Of particular interest are results from a study with fourth grade where students educated on anatomy using an AR modality displayed better performance on knowledge quizzes both two and four weeks after training (Pérez-López & Contero, 2013). Based on these results and similar results regarding knowledge retention immediately after training two hypothesis (H1 and H2) can be inferred:

- H1: Using augmented reality for training will improve the immediate knowledge retention compared to other modalities (paper manual and online video).
- H2: Using augmented reality for training will improve the long term knowledge retention compared to other modalities (paper manual and online video).

Several studies also suggest that once an individual is properly trained they no longer require further knowledge as they have already developed schema related to the content (Hoffmann et al., 2020; Torney-Purta, 1991; Crawford et al., 2018; Barfield, 1986). Additionally the modality used may also present a barrier for knowledge building due to an individual's lack of experience with the particular technology (Hoffmann et al., 2020; Okhovati et al., 2017). These insights suggest four more hypothesis (H3, H4, H5, and H6):

- H3: Prior experience with the training material will decrease the overall training time.
- H4: Prior experience with the training material increase knowledge retention.
- H5: Prior augmented reality experience will decrease the overall training time.
- H6: Prior augmented reality experience will increase knowledge retention.

As with any task individuals are considered cognitive misers with a limited cognitive capacity. Unfamiliarity with a modality may not only provide a barrier for knowledge retention (Hoffmann et al., 2020), but may also present a point of frustration for a user. However the spatial elements of AR also provide a modality that is less abstracted and more directly related and representative of reality than other training modalities (i.e. paper manual or video) (Sari et al., 2021; Quinlan, 2019; Hoffmann et al., 2020; Bakkiyaraj et al., 2021; Sohn, 2011; Meier et al., 2012). Due to these factors the final two hypothesis (H7 and H8) can be inferred:

- H7: Users will find less abstract training modes less demanding (AR less than both paper manual and online videos).
- H8: Users with no augmented reality experience will find the augmented reality training more demanding.

CHAPTER 3. METHODS

To explore the limitations and benefits of mobile AR training in comparison to other training modalities an experimental approach is used. This experiment uses 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 will begin by completing a presurvey to collect demographic information and their prior experience with both the machine being trained and AR. They will then be assigned to one of the three training modalities and use their assigned mode to complete the material loading procedure on the LEF-300 UV printer. After their training is completed they will take a postsurvey which contains both a knowledge test quiz as well as NASA task load index scales (TLX) (Hart, 2006; Hart & Staveland, 1988).

This leads to another potential benefit to exploring true mobile AR. High end HMDs are often prohibitively expensive for an average user to justify purchase such as the Hololens 2 (MSRP $3500) (*Hololens 2*, n.d.). While mobile HMD systems are often more cost effective most individuals will not have a compatible housing at their disposal throughout their day, due to the relative bulk of the HMD housings. However, as of February 2020 85% of USA citizens reported owning a smartphone, many of which would be capable of running AR experiences (*Mobile Fact Sheet*, 2021). This creates an opportunity for greater accessibility to AR experiences as it can be reasonably assumed that most smartphone owners will have the devices with them throughout their day. The potential for more accessible AR experiences is a driving factor for this studies design choices.

3.1 Theoretical Framework of the Method

This study utilizes a comparative experimental approach. Participants will be assigned to either a paper manual, online video, or mobile AR training. Results from the different training modalities will then be compared. This is in line with previous work that also used a comparative experimental approach for AR and non-AR training modalities (Hoffmann et al., 2020; Büttner et al., 2020;

Chien, Chen, & Jeng, 2010; Pérez-López & Contero, 2013; Werrlich et al., 2018). However, unlike previous studies, this study will be in a non-lab setting. This is due to location necessities and hardware access issues that require participants to be present in the same space as the Roland-LEF 300.

3.2 Instruments and Variables

Several variables have been identified for measurement along with methods and instruments for measurement.

3.2.1 Main Variables

Knowledge retention is defined as a participants ability to recall information. Both *Knowledge Retention (Immediate)* and *Knowledge Retention (Long Term)* are of interest to this study. *Knowledge Retention (Immediate)* has been used in prior studies to measure training and education outcomes (Werrlich et al., 2018; Pérez-López & Contero, 2013; Lam et al., 2020). It is the ability to recall information shortly after (typically within a few hours) the conclusion of a training session. Often this is measured using a follow up quiz. *Knowledge Retention (Long Term)* on the other hand is the ability to recall information after an extended period has elapse (typically seven or more days) (Pérez-López & Contero, 2013) and is often also measured using a quiz. For both *Knowledge Retention (Immediate)* and *Knowledge Retention (Long Term)* this study uses a quiz derived from the certification quiz used by the RDC.

Training Modality is the actual training method used by participants. In most prior studies AR was compared to either a paper manual or personal mediation (Hoffmann et al., 2020; Büttner et al., 2020; Pérez-López & Contero, 2013). This study will also compare AR to non-AR modalities, and like previous studies will use a paper manual as one of the non AR modalities. Additionally this study will use online videos as another non AR modality, in part due to their use in current RDC practices, but to also explore abstraction effects as both the paper manual and the

AR application require direct interaction with the trained machine, whereas the online videos are completely removed from physical interaction.

As discussed in 2.6 both familiarity with both content and the training modality may affect education outcomes. This is due to prior knowledge having a stronger effect than training modality (Hoffmann et al., 2020) and potential issues with engagement with content from inexperience with the delivery mode (Barfield, 1986). As such both *Prior Content Experience* and *Prior Content Experience* are considered as possible confounding variables and accounted for in a presurvey.

3.2.2 Other Variables

In addition to knowledge retention another common measure used for education and training is the total time the training takes to complete (Büttner et al., 2020; Hoffmann et al., 2020). *Training Time* is the total minutes and seconds required for the participant to complete the training content with their assigned modality (i.e. AR, paper manual, or online video). This measure is important as participants will be allotted as much time as needed to complete their training. Additionally significant differences in time for completion among modality may provide insight into best practices for training, although the variable of primary interest is still Knowledge Retention. In order to capture *Training Time* a stop watch is to be used. The start and stop steps for this stop watch will also be standardized to minimize any human error and bias.

Other subjective measures are also important to consider, in particular overall training demand. The NASA TLX (Hart, 2006; Hart & Staveland, 1988), while not the only measure of task demand, are often used for training system evaluation to capture *Perceived Demand*. NASA TLX was chosen over other potential options due to the brevity of the questions so as not to overload the participants with questions on the post training survey.

3.3 Training Materials

This study draws on current training practices used the RDC and similar facilities. Both paper training manuals and online videos are consistently used for training users on digital fabrication

Table 3.1

Variables and Measures

Variable	Measure
Knowledge Retention (Immediate)	Knowledge quiz administered immediatly after training
Knowledge Retention (Long Term)	Knowledge quiz administered seven days after training
Training Modality	Random assignment: Paper Manual, Online Video, or Mobile AR
Prior Content Experience	Presurvey Questionaire
Prior AR Experience	Presurvey Questionaire
Training Time	Stopwatch
Perceived Demand	Postsurvey Questionaire NASA TLX: Likert Scales (1-7)

tools and techniques. For this study both the paper manual contents and the video training contents are taken from the current RDC practices and materials. The AR modality is a novel training practice that does not currently have widespread adoption, as such the AR contents were created for this study.

3.3.1 Augmented Reality Application

For this study a piece of proprietary software was developed in partnership with the Nancy Richardson Design Center (RDC). 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 source 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 a task training where users will be guided through the loading procedure of a Roland LEF-300 UV printer.

After opening the application users then select the desired module from a menu screen. For the purposes of this study the only two modules available are a brief tutorial module that informs the user on how to use this specific application and the LEF-300 training module. Once a module is selected the user will see a live video feed from their devices front facing camera(s). They then scan an image target with the camera which spawns the AR objects into the environment. These virtual objects are anchored to the image target and the user's relative position. As the user moves through the physical space the virtual orientation of the virtual objects update accordingly.

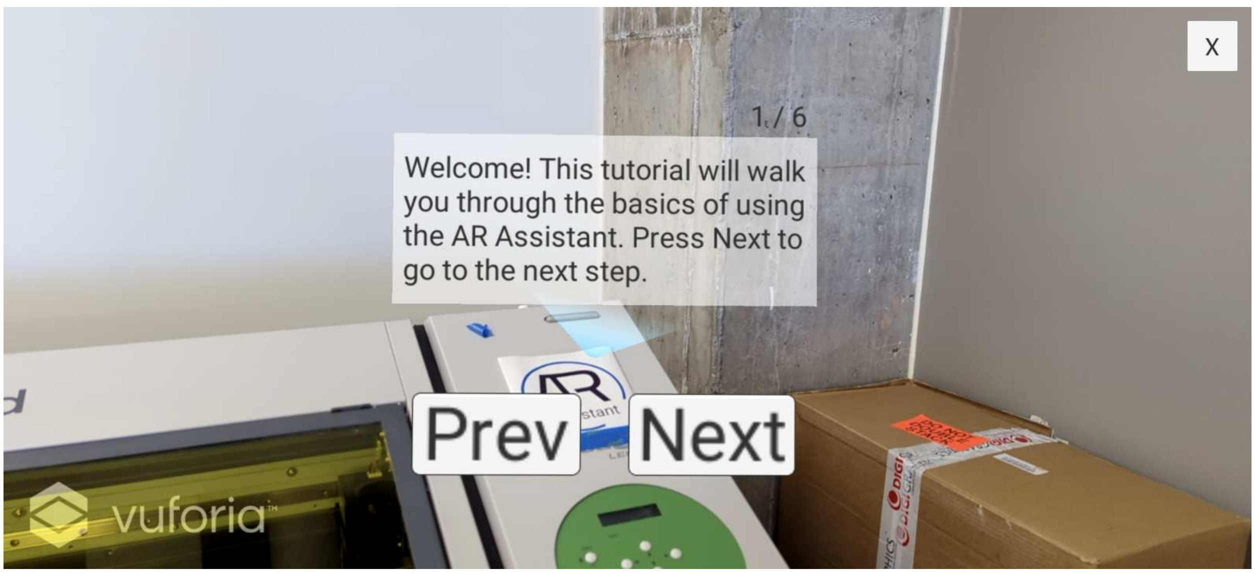

Figure 3.1
Note. When a user scans the AR target a Quest Step appears. Users can than iterate or retreat through the steps.

The primary virtual object users will interact with are referred to as "quest steps" (see 3.1). These objects consist of informative text, spatially aware highlights, and decorative user interface elements.The text reflects the current step the user is on and provides guidance for the completion of that step. The semi-transparent highlights encompass the area or part of the machine that the user will need to interact with in order to complete the step (see 3.2). In addition to these elements there are also two navigation buttons; one labeled "prev" and one labeled "next." As their labels suggest the "prev" button returns the user to the previous step and the "next" button advances to the next step. Once the user is on the last step the "next" button transitions into an "exit" button that returns them to the main menu. Additionally they can return to the main menu using the "x" button anchored on the screen.

Figure 3.2
Note. Semi-transparent spatially aware highlights are overlayed onto points of interest to help guide and inform ARA users.

An additional navigation feature is also present for the LEF-300 module. The "step library" allows users to select a predetermined point in the training steps. This allows them to return to the beginning of a section of related steps or to advance to a section further on in the training as needed.

3.3.1.1 The Nancy Richardson Design Center

The RDC is home to a collection of three different build labs; a wood lab, a metal lab, and a digital prototyping lab. Each one has a collection of different tools and equipment related to the type of work associated with the lab (i.e. the wood lab has wood saws, the metal lab has welding equipment). This study makes use of the RDC prototyping lab which houses a variety of tools for turning digital files into physical objects, such as 3D printers, laser cutters, and the Roland LEF-300.

Figure 3.3
Note. The Nancy Richardson Design Center's Digital Prototyping Lab houses a variety of tools for fabrication and is open to all Colorado State University students and faculty.

While the lab is open to any student on Colorado State University's (CSU) campus these students must complete a machine training before they are able to utilize a particular machine. Currently the RDC uses a combination of in person mediation, online videos, and paper manuals for training. After completing a training a lab user must pass a certification quiz to be allowed access to a machine.

3.3.1.2 Trained Machine: Roland LEF-300 UV Printer

While the ARA can be used to train students on any machine in the RDC labs this study focuses on a module developed for the Roland LEF-300 UV Printer. The LEF-300 is a large format printer that is capable of printing on any non reflective surface that fits within the build volume. It utilizes UV sensitive ink that is cured using a UV lamp after being laid down onto the printing material.

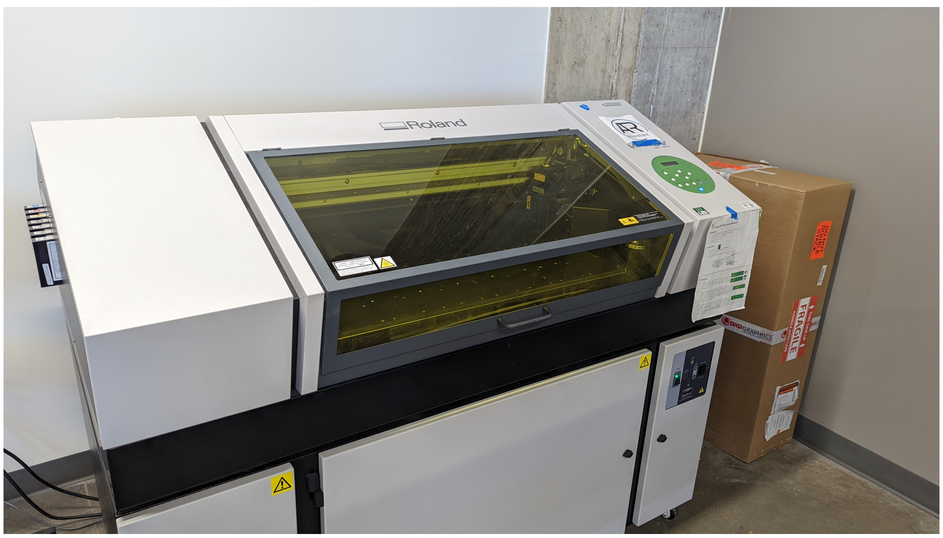

Figure 3.4
Note. The Roland LEF 300 UV printer is the machine to be used for this study's training task.

3.3.1.3 Mobile AR

Mobile AR was selected for the ARA for two key reasons: 1) a lack of literature focused on mobile AR devices, and 2) the increased accessibility from using commonly available hardware. While some studies have incorporated mobile devices into their design they often used either commercially available (Lam et al., 2020) or proprietary (Dayagdag et al., 2019) extraneous devices to provide a stereoscopic HMD experience. This fundamentally changes the overall user experience as the device is now anchored to the users head rather than in their hands. Essentially the mobile device is used as a computer for an HMD rather than as a mobile device. In many ways these mobile HMD systems are more comparable to high end HMDs (such as the microsoft hololens) than to mobile AR experiences (i.e. Pokemon GO).

Figure 3.5
Note. HMD AR (left) and Mobile AR (right) have different form factors and affordances.

3.4 Data Collection

3.4.1 Sample and Recruitment

This study aims to collect data from 30-50 participants. These individuals will be recruited through the current RDC lab user mailing list, a study recruitment system maintained by the Journalism and Media Communication Department at CSU referred to as SONA, and through professors associated with the Computer Science and Journalism and Media Communication Department at CSU. This convenience sample is composed of CSU students who must be 18 years of age or older. Additionally they must either have an active RDC lab membership, or complete a liability waiver before engaging with RDC supplied equipment (i.e. the Roland LEF-300). An recruitment message will be sent to or posted to both the RDC mailing list and the SONA system (see A.4). No compensation is planned for participation, however participants may receive a benefit from extra training time and content not currently provided by the RDC.

3.4.2 Data Collection Procedures

Participants will be sent a recruitment message through either the RDC mailing list, through the SONA system, or through professors in the Computer Science or Journalism and Media Communication Department at CSU. This message will include a sign up link for study time slots. When the participant arrives they will be briefed on the study, its purpose, and informed consent will be gathered. If the participant is not currently an active RDC member they will be asked to complete a waiver to meet RDC liability requirements for use of their resources. This waiver is not part of the study record and is instead kept on record at the RDC.

After informed consent and the waiver have been gathered participants will be asked to complete a presurvey (see A.1). This presurvey consists of demographic information as well as prior experience reporting; with either the Roland LEF-300, similar large format/specialty printers, or AR systems. Once the presurvey is completed a researcher will provide the participant with the training materials (either a paper manual (see A.6), a PC with access to the online video (see A.7), or a mobile device with the AR application loaded (see A.5). At this point a stopwatch will also begin recording the training time.

Once the participant completes the training using their assigned mode the stop watch will be stopped and time will be recorded. The participant will also return all training materials and begin a post survey (see A.2). This post survey consists of a knowledge quiz and SUS measures. Once they have completed the survey they will be asked if they wish to participate in a follow up quiz to assess long term knowledge retention. If they are inclined they will be sent to a separate survey that collects email contact information for the follow up survey link (see A.3). They will also be provided with a reminder note. Seven days from their initial training they will be sent a link via email to complete the follow up quiz via an online survey. If the participant declines they will be dismissed and only the data from the training session will be used.

Overview of Data Collection Procedures:

1. Recruitment materials sent to potential participants via email or message using the RDC mailing list, SONA, or CSU professors.

2. Briefing and informed consent are collected. If a participant is not currently an RDC lab user a waiver is also collected.

3. A presurvey on demographic information and prior content and AR experience is administered.

4. The participant is given training materials and time collection begins.

5. The participant uses the training material to complete the trained task.

6. Training materials are returned upon completion of the task and time collection ends.

7. A post survey containing a knowledge quiz and NASA TLX measures is administered.

8. The participant chooses to either complete their involvement or receive a follow up survey 7 days from their session.

9. If the participant chose to continue participation in the follow up survey they receive and complete the same knowledge quiz via email 7 days later.

3.4.3 Pilot Studies

Two pilot studies were conducted in the development of this proposal and the AR training tool. The first focused on the development and testing of the application itself. The second was concerned with the study procedures and measures.

3.4.3.1 Initial Usability Study

The initial study served as a technical test of the application and as a usability study for the system. Data concerning training preferences, usability, and general feedback/improvements were collected. This initial pilot study found that overall the use of AR for training was preferred over other potential modalities, however as the study did not contain a direct comparison, instead asking users to rank preferences via a survey, these results are not strong enough to reach any meaningful conclusions. The AR applications was reported as intuitive and easy to use. Additionally technical issues related to application stability arose. This information was then used to adjust and modify the application for a follow up study aimed at improving the experiment procedures.

3.4.3.2 Second Pilot Study

A second pilot study was conducted that used similar procedures as this study, except for the exclusion of a training video and a follow up survey. Its intent was to inform this study. Unfortunately the second study did not favor the AR application as strongly as the first pilot study. The paper manual took almost half as much time for participants to complete (paper = 8.896 minutes, AR = 16.192 minutes). It also produced stronger initial scores (paper = 7.8, AR = 5.6, 0-10 scale). The only factor in which the AR modality performed better was in SUS scores (paper = 44.088, AR = 48.096). This helps to suggest some potential adjustments to the study as well as the AR application. For instance almost all participants reported the iPad pro used for this pilot study as too cumbersome which may have impacted the AR time and scores, additionally these values seem to be in conflict with prior studies (including the previous pilot study). In addition to the time, knowledge retention, and SUS measures several anomalies were present that support the notion of prior impact on training such as one participant with extensive prior LEF 300 training completing the training in less than 6 minutes. While no strong conclusions could be made from this data it does suggest avenues for improvement as well as interesting trends that may reveal more about training and education when studied further.

3.5 Validity and Reliability of the Proposed Study

3.5.1 Reliability

Several steps have been taken to improve the reliability of this study. First, the pre and post survey contents are consistent regardless of training modality. The only variable to be affected by researchers is the training modality. All questions contained within surveys are derived from tested measures. These measures are either currently implemented into RDC and similar training or derived from prior literature. Both the questions and the novel AR application were used in previous pilot studies. Results from these studies were used to inform methods and procedures of this study. Additionally the collection of training time is standardized regardless of training modality.

3.5.2 Internal Validity

Steps have also been taken to improve internal validity of this study. The presurvey accounts for differences in experience with multiple AR technologies, the tested machine (Roland LEF-300) and similar machines. No extra information was given to any participant during the training process; they only had the content of their training modality to reference. While the RDC lab space cannot be removed of other users, the participant was instructed to refer all questions to the researcher present and was discouraged from interacting with other lab users during the study session. Additionally the researcher would not answer any questions that may compromise the integrity of the study. For participants who completed the follow up survey an additional question regarding continued use of or continued training with the Roland LEF-300 was asked to accommodate for potential effects from extra knowledge during the seven day time gap.

3.5.3 External Validity

While the sample used in this study is of convenience, thus limiting external validity, steps have been taken to improve it. Students from every department and college are present in the RDC lab spaces leading to a more diverse sample, however this may skew toward communications related fields due to the use of SONA. Additionally both undergraduate and graduate students are frequent RDC lab users which helps to expand the age demographic. This helps to include a wider range of people with different backgrounds and perspectives and may expand the average age of the participants beyond the typically college age often found in studies such as this.

3.5.4 Ecological Validity

Ecological validity is improved in several ways. Training content and procedures are derived from documents and processes that are already used in the RDC labs. These processes are also similar to spaces other than the RDC, such as maker spaces, public labs, and other fabrication spaces (i.e. woodshops, metalshops, etc.). Additionally the knowledge retention measures used in the post and follow up survey are derived from implemented certification measures used at the RDC. As such the material used for this experiment would be mostly similar to training materials used in other fabrication lab spaces; RDC or otherwise. Mobile devices are also commonly used in daily activities and as AR technologies expand there is a higher chance of individuals encountering the use of AR for training and education on mobile devices. The AR technology used in this study is also similar to current implementation practices, makes use of current commercially available tools, and would most likely not deviate significantly in the future, so the AR application developed for this study would be similar to commercially developed AR applications implemented into similar spaces.

3.6 Concluding summary

This study uses a comparative experiment to evaluate the potential benefits and shortcomings of using mobile AR over other established training methods. A variety of other studies have used a similar approach to explore these differences (Hoffmann et al., 2020; Büttner et al., 2020; Chien et al., 2010; Pérez-López & Contero, 2013; Werrlich et al., 2018). This comparative approach is useful for addressing the question: *does mobile augmented reality provide for stronger knowledge retention compared to other training and education modalities?*

4.1 Results

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 and 16 had experience with other specialty printers (any printer that prints on non paper material or paper larger than 11 by 17). Among the participants who were assigned to the AR experience 5 reported prior AR HMD experience and 7 reported prior mobile AR experience. Eleven participants responded to the followup survey, however these results heavily skewed towards the AR modality (AR=7, Paper=2, Video=2).

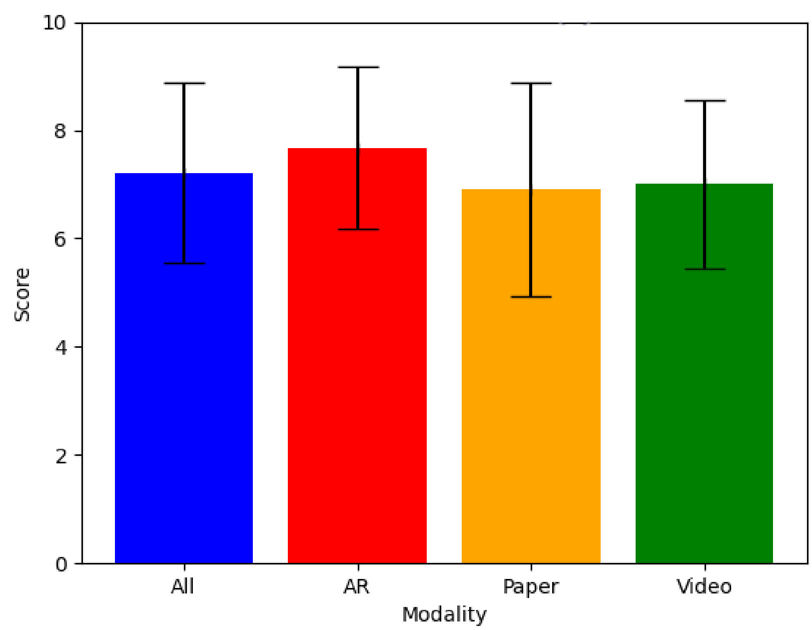

Figure 4.1

Immediate Knowledge Retention
Note. These scores were captured immediately after the training conclusion across modalities.

The average score among all modalities immediately after training was 7.21 (*SD*=1.67). The AR score was the highest at 7.67 (*SD*=1.50). This was followed by the video modality with an average immediate score of 7.0 (*1.56*) which was followed closely by the paper modality with an immediate score of 6.91 (*SD*=1.97). The average followup score among all modalities was 7.55 (*SD*=1.29). The average AR followup score was 7.57 (*SD*=1.13). Both the paper and video modality followup average scores were 7.5, however both of these modalities only had two data points for analysis.

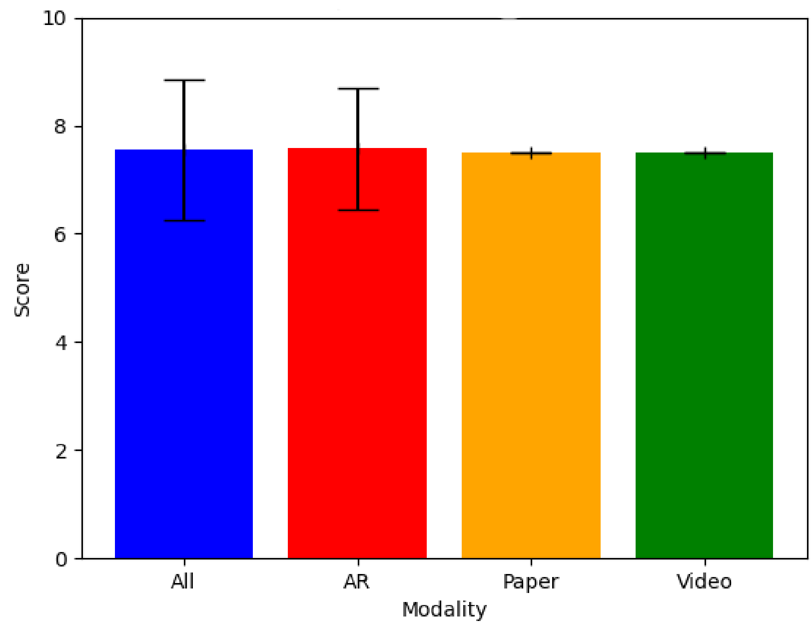

Figure 4.2

Long Term Knowledge Retention
Note. These scores were captured seven days after the training conclusion across modalities.

The average time to complete the training among all modalities was 9:15 (*SD*=4:13). The AR modality took the longest amount of time on average to complete (13:09 *SD*=3:39). This was followed by the paper modality with an average time of 8:39 (*SD*=2:24). The video modality took the least amount of time to complete with an average of 5:13 (*SD*=1:21)

The paper modality was ranked as the least mentally demanding (2.36 *SD*=1.12) on the TLX scales (ranked 1-7 with 1 being the least demanding and 7 being the most). Users in the video modality reported the highest mental demand (3.9 *SD*=1.66) and AR was ranked in between the paper and video modality at 3.33 (*SD*=1.56).

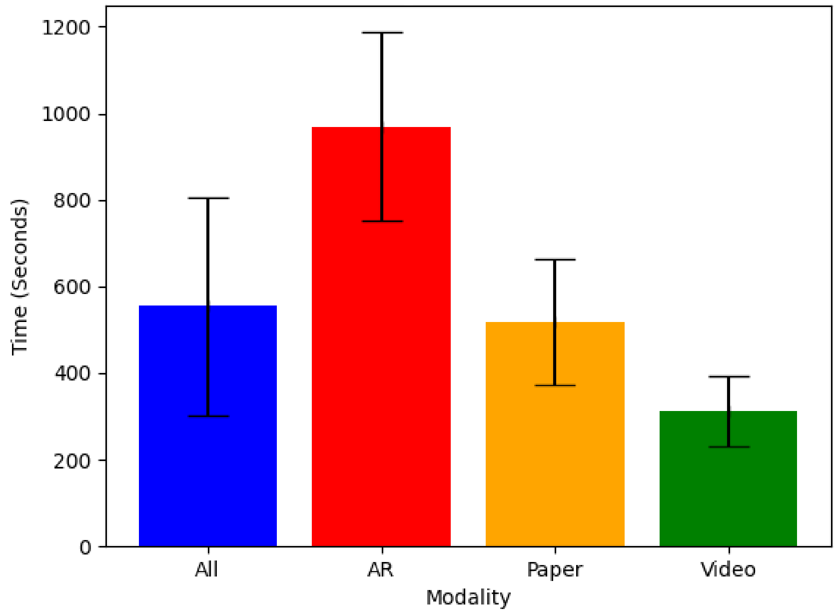

Figure 4.3

Training Time
Note. Time taken to complete the training task across modalities.

The AR modality had the highest reported physical demand (2.0 *SD*=1.21). Both the paper and video modality were similarly ranked, but with paper having a slightly higher reported physical demand (paper: 1.27 *SD*=0.47, video: 1.2 *SD*=0.42).

The video modality was reported as being the most rushed (2.2 *SD*=2.2). The least rushed modality was paper with a reported score of 1.45 (*SD*=1.51). The AR modality fell in between the paper and video in terms of reported pacing at a score of 1.83 (*SD*=0.72).

Individuals who participated in the paper training reported a higher level of confidence (5.45 *SD*=1.29). The next highest confidence average confidence rating was among those who used the AR training modality with a reported score of 5.17 (*SD*=1.64). The video group was the least confident with an average rating of 4.2 (*SD*= 0.92).

Both the video and AR modalities had an average reported workload of 3.0 (*SD*=1.49, 1.13). The paper modality had the lowest reported workload with a reported score of 1.73 (*SD*=0.94).

Users reported the highest frustration levels with the video modality (2.6 *SD*=1.84). The AR modality had the next highest frustration level at 2.17 (*SD*=0.93). The modality with the lowest frustration level was the paper manual (1.9 *SD*=1.22).

Table 4.1

Nasa TLX Results (1-7 Scales)

Measure	AR	Paper	Video
Mental Demand	3.33	2.36	3.9
Physical Demand	2.0	1.27	1.2
Pacing	1.83	1.45	2.2
Success	5.17	5.45	4.2
Workload	3.0	1.72	3.0
Frustration	2.16	1.91	2.6

4.2 TLX Correlations

Mental demand was negatively correlated with immediate knowledge retention, but was not statistically significant (r=-0.02, p>.05). Physical demand was similarly negatively correlated with immediate knowledge retention and was also not statistically significant (r=-0.12, p>.05). Increases in how rushed the training felt were negatively correlated with immediate knowledge retention (r=-0.03, p>.05), however this was not statistically significant. Confidence was positively correlated with immediate knowledge retention, and was statistically significant (r=0.44, p<.01). An additional ANOVA indicated that the impact of prior UV experience on confidence levels was not statistically significant (F=0.15, p>.05).Workload and frustration were also negatively correlated with scores, however neither of these were statistically significant (workload: r=-0.14, p>.05; frustration: r=-0.05, p>.05)

Table 4.2

Nasa TLX and Knowledge Retention Pearson's R

Measure	Immediate Knowledge Retention
Mental Demand	-0.02
Physical Demand	-0.12
Pacing	-0.03
Success	0.44*
Workload	-0.14
Frustration	-0.05

Note. * $p < .05$

4.3 Hypothesis Testing

Individuals who used the AR modality for training did show higher levels of immediate knowledge retention (with scores 0.76 points higher than paper and 0.67 points higher than the video training). However an ANOVA suggests that these results were not statistically significant (f=0.69, p>.05). As such there is no support for hypothesis 1 (*Using augmented reality for training will improve the immediate knowledge retention compared to other modalities (paper manual and online video)*). Long term knowledge retention also favored the AR training modality with AR participants scoring 0.07 points higher than both paper and video, however these results are also not statistically significant (f=0.69, p>.05). Thus support for hypothesis 2 (*Using augmented reality for training will improve the long term knowledge retention compared to other modalities (paper manual and online video)*) is also not present.

Prior experience with other specialty printers (i.e. printers that print on material other than paper or on paper larger than 11in by 17in) did not have any statistically significant impact on training time (f=0.002, p>.05) or knowledge retention (f=0.91, p>.05). Similarly the impact of prior UV printer experience was not statistically significant on training time (f=0.4, p>.05).

However prior UV experience was statistically significant on immediate knowledge retention (f=4.68, p<.05). Based on these analyses no support can be drawn for hypothesis 3 (*Prior experience with the training material will decrease the overall training time*), but there is support for hypothesis 4(*Prior experience with the training material increase knowledge retention*).

Prior mobile AR experience's effect on both immediate knowledge retention and training time was not statistically significant (knowledge retention f=0.06, p>.05; training time$f$=0.001, p>.05). The impact of prior HMD experience on immediate knowledge retention was also not statistically significant (f=0.4, p>.05), however the effect of prior HMD experience on training time was statistically significant (f=5.41, p<.05). Partial support can be seen for hypothesis 5 (*Prior augmented reality experience will decrease the overall training time*), but no support can be drawn for hypothesis 6 (*Prior augmented reality experience will increase knowledge retention*) based on these results.

While the AR modality was ranked lower on mental demand than the video modality it was more demanding than the paper modality by 0.97 points. AR was also rated as the most physical demanding with 0.73 points over paper and 0.8 points over video. This provides partial support for hypothesis 7 (*Users will find less abstract training modes less demanding (AR less than both paper manual and online videos)*), but only when comparing the mental demand of AR to video. In regards to physical demand and when comparing the mental demand of paper to AR there is not support for hypothesis 7.

Previous mobile AR experience's effect on mental demand displayed weak statistical significance (f=5.41, p<.1). This was not the case with previous HMD experience and mental demand (f=0.24, p>.05). Both prior experience with mobile AR and HMD AR showed statistically insignificant effects on physical demand (mobile: f=0.21, p>.05; HMD: f=0.001, p>.05). This provides weak partial support for hypothesis 8 (*Users with no augmented reality experience will find the augmented reality training more demanding*), but only when considering mental demand and mobile AR.

4.4 Discussion

Due to the limited amount of statistically significant interactions and trends captured by this study much of this discussion is speculative. As the study results do not allow for many conclusions to be drawn this section considers what other factors may be influencing the measures and how the limitations of this study may suggest further areas of inquiry. This includes adjustments to the current study, elements that did display statistically significant support, surprising results, how individual factors and learning styles may be playing a role, and other potentially confounding factors.

While the AR modality did appear to provide for better knowledge retention the lack of statistical significance prevents any strong conclusions from being drawn. However as this study sample size was inherently limited these relationships may prove to be validated with a larger and more diverse sample population. Additionally as the technology expands and becomes more prevalent this may further sway these results as supported by the weak significance of prior mobile AR experience on mental demand. This is in line with prior research on the expert-novice gap which suggests that as an individuals experience and skill with a software, tool, or technology increases their overall performance and satisfaction increases (Barfield, 1986; Okhovati et al., 2017). It may well be that as AR technology becomes more pervasive the mental demand of training and using unknown AR applications is further reduced due to increased levels of technological skill allowing cognitive resources to be dedicated to the establishment and maintenance of schema related to the content without having to dedicate resources to the modality.

This notion that once a schema has been established this prior information becomes a more impactful element of training (Hoffmann et al., 2020; Neumann & Kopcha, 2018; Barfield, 1986; Lee et al., 2019) is also supported by the statistically significant effect of prior UV experience on knowledge retention. Essentially if an individual has extensive experience with the machine already (thus having established schema for using that machine) information presented regardless of the training modality will not be as strong of an influence on knowledge retention than their existing knowledge. In these cases they are cognitively engaged in recall, accretion, or tuning rather than restructuring. So when exposing one of these individuals to training content the only information that may influence or change the existing schema would be novel information; which would most likely not include step by step instructions on how to load material into the machine.

By far the most surprising result was the effect of prior HMD experience on training time. While the college and major of participants was not explicitly collected there is a possibility that this effect may be due to the technical expertise of users from computer science and related fields. With the exception of prior HMD experience no other prior experience appears to have impacted training time. This suggests that, except in cases of exceptional expertise, the differences in modality are a stronger predictor of training time. So it can be expected that a specific interaction in AR (or another modality) will take on average the same amount of time regardless of the participant.

The difference in mental demand between AR, paper, and video (with video being the most mentally demanding) suggests that direct interaction with the trained material may reduce cognitive resource requirements. This may be due to direct interaction offloading mental demands required to build schema. Physical demand was not affected by prior AR experience. Essentially the physical demands to perform the training tasks do appear to change regardless of established schema. The weak significance of prior mobile AR experience on mental demand supports the notion that as the technology advances and becomes more prevalent individuals may become more accustom to it. Similarly as the mental demand decreases their is a possibility that knowledge retention may increase (further supported by the negative correlation between mental demand and knowledge retention). This may be due to a reduction in the level of cognitive resources required to establish schema on using the novel technology allowing the user to focus more resources on processing content.

There may be another phenomenon manifesting itself that was not explicitly tested for in this study. Often when approaching education there is a discussion of different learning styles and the individual characteristics associated with those styles (Pashler, McDaniel, Rohrer, & Bjork, 2008; Cimermanová, 2018). However this mentality does not always translate to modality studies such as this one. The negative correlation between knowledge retention and self reported measures of mental demand, physical demand, pacing, workload, and frustration, though not statistically significant, may indicate that individual differences in preferred learning style and information processing may be more impact than what was taken into account during this study. Similarly the statistically significant positive correlation between success and knowledge retention further supports this notion. Essentially as individuals are more comfortable and confident with their modality it may be that they are better able to understand the content, however the exact modality that any given individual feels comfortable with would depend on their specific education needs defined by their individual characteristics.

In addition to these individual factors the adoption of AR technologies will continue to create barriers for education both within the academic setting and externally. A lack of resources for educator support and utilization can prevent adoption within the classroom (Beavis, 2013; Kurt et al., 2019) and the continued evolution of the technology (including the failures of 1990s VR and AR ventures (Jerald, 2016)) all impact the uptake of this technology. This in turn limits the prior experience and schema building an individual learner can engage with. There is also potential for any form of AR to be usurped by a different form within a limited timespan potentially creating situations where a user must significantly alter established schema to continue to see benefits from the new AR form.

4.5 Observations During Training

Due to the nature of this study's design the researcher was observing and available during any given training session (although they were barred from providing any additional information to participants). Additionally one of the post survey questions provided an opportunity for participants to provide open ended responses regarding the study, training modality, or any other aspect that arose during their time participating. These observations and insights may provide additional qualitative information to help contextualize some of the findings of this study; including affective responses, information flow, semantic processing, and user goals.

Affect is an inseparable part of experience. As we process new experiences and use those experiences to build and refine schema affective components are invariable incorporated into those schema (Leahy, 2016; Marshall, 1989). While this study did not directly measure affective responses to any given modality observational aspects and open feedback suggest that affect was involved in some of the participant's experience. In particular multiple participants indicated excitement at the prospect of using the AR modality. This excitement may increase engagement with the training or may hinder objective processing of the presented information. Conversely some who were assigned to the paper or video modality expressed disappointment with the "boring" modality they were assigned to. This in turn may have affected their motivation. Other affective responses may have emerged as well without the participants expressly disclosing them, such as anxiety from the test like format used for knowledge retention or frustration due to unforseen barriers to completing the training.

One participant expressed frustration with the phrasing of step 4; specifically the line "Tape *may* be necessary to prevent edge curling." In this case the particular participant determined that the use of the term "may" indicated that using tape to secure the edges was not necessary this then lead to the print material being knocked off the print bed. Other participants, however, did not hesitate to use tape when prompted even with the "may" wording. This not only led to some frustration among the participant, but also points to the potential for differences in semantic processing. Essentially even if two participants read the same word, view the same stimuli, or are prompted in the exact same way their prior experiences and established schema may lead them to process and interpret the information differently resulting in different outcomes (Rueschemeyer, Pfeiffer, & Bekkering, 2010; He, Zhang, Zhang, Xiao, & Wang, 2015).

Along with differences in processing there are also differences in information flow between the modalities that may inadvertently affect the experiences among participants. For instance in the AR modality only one step is presented at any given time, whereas with the paper modality each of the steps is visible at any stage of the process. With both the paper and AR modality the information is presented in a clearly segmented and compartmentalized way (i.e. step 1, step 2, step 3, etc.) whereas the video format lends itself to a more fluid presentation of information. These nuanced differences may then affect the schema building process. These differences also appeared to emerge when individuals ran into significant barriers for completion. Multiple participants at one point or another became stuck, confused, or lost during the training session. When these incidents occurred they were instructed to use the materials they were assigned to attempt to continue or they could move on. In many cases the AR participants appeared to have the most difficulty resuming the process (when compared to the paper modality), potentially due to these information flow differences, where as the video participants did not encounter these issues (most likely due to the lack of direct interaction with the machine).

These differences (both in modality and individual processing) may also lead to variations in individual goals among participants. While this study was intended to measure educational outcomes some participants may have had different outcome intentions and goals. Given that many of the participants most likely had little intention to interact with and use the LEF 300 machine upon the conclusion of their participation (due to a variety of potential factors) their motivations during the training session may have been to have their assigned modality guide them through the steps rather then to commit the process to memory. Due to this knowledge building and education outcomes may not actually be what is measured. This also brings into question when a modality should be implemented. Learning is a process with multiple stages. This particular study was concerned with the initial training stage, however some of the modalities, especially if they are more likely to be utilized for guiding completion rather than learning, may be better suited for recall of information or secondary training.

Each of these observations and insights points to potential other individual factors that may have emerged during this study. Many of these were not explicitly tested for and may have confounded some of the results, however many of these also point to potential future areas of exploration and considerations for future studies examining differences in training modalities. Additionally they may explain some of the unexpected results that emerged during this study.

CHAPTER 5. CONCLUSION

As AR expands there may be more significant differences in results, however this may be more closely tied to individual learning differences than the specific modality, especially as AR continues to advance and change. This may also introduce technology adoption challenges that further influence the efficacy of AR for education. It also appears that once a schema has been established the addition of new knowledge is less impactful than the existing knowledge therefor focusing on the initial training experience is a priority. Prior knowledge also does not seem to affect training time which suggests that each modality will inherently require different time commitments to complete. Additionally there are a multitude of different individual factors that may be more predictive of educational outcomes. These different individuals may then prefer one modality over another and may receive greater benefits from their preferred modality.

5.1 Critical Analysis of Project

While every attempt to ensure that this study is as sound as possible there are some limitations that exist due to a variety of factors. Limitations exist with the instruments used, the data sampling and analysis techniques, and the inferences that can be drawn from tested hypotheses. However, while these limitations do exist they may point to promising future work.

5.1.1 Data Sampling and Analysis Limitations

The use of a stopwatch for timing may introduce a human error bias into results. This is true even with the routine and standardized points where the researcher is intended to stop the timer. Additionally, while every attempt has been made to mitigate extraneous variables in the RDC lab spaces there is no way to completely remove other lab users or factors from this setting. This may introduce unforeseen confounding variables. It is also due to this that this study cannot be completely anonymous as other lab users not involved in the study may be present at any given moment, however participants were not asked to divulge any sensitive information (i.e. sexual activity, drug use, etc.). The subject pool for this study was also limited in scale which may have limited the significance of some trends.

5.1.2 Inferences Limitations

The RDC lab setting is not representative of all education and training facilities and the study demographics are also not representative of all learners. This limits some of the transferability of the results as a K-12 classroom may require different design accommodations that were not present in this study. Additionally this study focuses on only one form of AR which is only one form of mixed reality technology. There are potential other affordances present in HMD AR, VR, AV, etc. that may provide different benefits and limitations to educational integration.

5.1.3 Instrument Limitations

It would also be possible for a participant to guess on every single knowledge test question and receive a strong score, which would affect the corresponding data set. There are a also multitude of ways to develop AR technologies and the implemented AR application is only one approach. Even different choices in user interface design may affect the end results. While this study made every effort to develop training modalities as one to one translations this is not an advisable design practice as it inherently constrains the affordances available to deliver content as there are functions that AR is capable of that cannot be replicated on paper or through video. Conversely there are best practices for writing training documents that do not apply in the same manner to AR or to video.

5.2 Future Projects

The limitations presented by the design of the AR application suggest further areas of exploration. This may include expanding to other related technologies (i.e. VR) or incorporating different design techniques or AR forms (i.e. HMD AR, 3D scans, etc.). However direct comparison studies such as the one presented here may be inherently limiting themselves. For instance this study attempted to create an AR application that was a one to one translation (or as close as possible) to the paper manual, however this inherently restricted the design as many of the features afforded by AR are not capable of being reproduced using printed paper. For instance it is not feasible to use 3D animation with printed paper manual, as such using printed words to describe how to do something (such as open the LEF 300 cover) may be the best option. This is not the case with the AR modality however, instead of displaying the same printed phrase in AR it may be better to have an animation play of the cover opening. While moving away from direct translations across modalities would limit reliability it would increase ecological validity, especially as designers typically attempt to capitalize on all affordances presented by a particular modality even when address cross platform content. As such one potential change to future comparative studies such as the one presented here would be to better utilize affordances presented by each modality.

While allowing for more variance across modalities may help to expand what is possible when conducting comparative studies this does not address some of the other challenges and limitations experienced by this study. Instead of evaluating what modality, approach, or technology works for a general audience it may be just as valuable to explore what individual characteristics (be they learning styles, personality traits, experience, etc.) lead to improved performance with a given technology. For instance a study may only use one modality, but administer various measures to identify specific individual traits an individual possesses, or a study may allow the participant to choose which modality they would prefer to use for a task followed not only by performance measures, but also measures of individual traits and how they determined their modality preference. By addressing these factors directly in future studies it may be possible to understand not only what predicts success, satisfaction, or capabilities with a certain technology, but also to understand more about our engagements with technology and the complex constructs and choices that lead one individual to seek out one modality over another. These avenues for future research are predicated on the well founded notion that people are complex, messy, and difficult subjects to observe and measure, but by refactoring how comparative studies are conducted and designed this may lead to the generation of more specific and beneficial knowledge to improve the education space.

5.3 Conclusion

This study presents a comparative experimental approach to address the question *does mobile augmented reality provide for stronger knowledge retention compared to other training and education modalities?* By addressing this question and drawing on many facets of study including emerging technologies, educational challenges, schema theory, and mixed reality it aims to strengthen each of these areas of study and provide possible avenues for cross collaboration. While many of the hypothesis presented do not have strong statistical support this study does point to multiple avenues for continued exploration including how to best utilize and design for emerging technologies or exploration of how individual differences impact the efficacy of any given modality. Additionally this study provides information that can be used to improve currently educational practices as well as stepping stones for continued improvement of the educational experience.

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APPENDICES

Appendix A: Pre Survey Questions

1. What is your age? (Years)

2. What is your gender? (Male/Female/Non-binary/Prefer not to say)

3. Have you used a Roland LEF 300 UV printer before? (Yes/No)

4. Have you used a large format or specialty printer before? (Any machine that prints on paper larger than 11x17 or on a material other than paper) (Yes/No)

5. Have you used an augmented reality headset before? (Hololens, Magic Leap, etc.) (Yes/No)

6. Have you used mobile augmented reality before? (App on iPhone or Android phone) (Yes/No)

Appendix B: Post Survey and Quiz Questions

Knowledge Test Quiz

1. What is the maximum print area of the Roland LEF-300 UV Printer? (30.32 by 13 by 3.94, 24 by 12 by 2, 20 by 12.5 by 3.94, or None of the above)

2. What color will the power button light up when the machine is on? (Blue, Red, Green, or It Does Not Light Up)

3. What two points are used to define the print area? (Lower Left and Upper Right, Lower Right and Upper Left, Top Middle and Bottom Middle, or Lower Left and Lower Right)

4. What does material need to have for successful printing? (Be free of kinks and folds, Have a shiny surface, Be coated with a special priming chemical, or Be porus)

5. What is the maximum weight of printing material? (10 LBS, 20 LBS, 18 LBS, or There is no maximum weight for printing material)

6. What methods can be used to set the bed height? (An auto detection process, the table up and the table down buttons, Both auto detection and the table buttons, The table height does not need to be set)

7. How do you clear previous print media setup data? (Turn the machine off and on, Use the "Clear Data" function in the menu, Press and hold the "Setup" button, or Data never needs to be cleared before setup)

8. Can the Roland LEF 300 UV printer print on reflective surfaces? (No, Yes, Yes, but only if special ink is used, or Yes, but only if lab staff say it is ok)

9. When setting the first point the LCD screen should read: (Scan and Feed, Width and Height, First Point Set Up, or Define First Point

10. How far should the print material be away from the sensor bar? (1 inch, 1/4 an inch, 1/2 an inch, or 1/8 an inch)
11. Which training did you complete? (Paper Manual/Augmented Reality)
12. Were you able to successfully follow the training to load material into the Roland LEF-300 UV Printer? (Yes/No)

NASA TLX Scales (1-7)

1. How mentally demanding was the training?
2. How physically demanding was the training?
3. How hurried or rushed was the training?
4. How successful were you in accomplish the training?
5. How hard did you have to work to complete the training?
6. How insecure, discouraged, irritated, stressed, and annoyed were you during the training?

Additional Feedback

1. Do you have any other feedback for this training? (Yes/No)
2. If yes: What other feedback would you like to share? (Open Response)

Appendix C: Follow Up Quiz Questions

1. What is the maximum print area of the Roland LEF-300 UV Printer? (30.32 by 13 by 3.94, 24 by 12 by 2, 20 by 12.5 by 3.94, or None of the above)

2. What color will the power button light up when the machine is on? (Blue, Red, Green, or It Does Not Light Up)

3. What two points are used to define the print area? (Lower Left and Upper Right, Lower Right and Upper Left, Top Middle and Bottom Middle, or Lower Left and Lower Right)

4. What does material need to have for successful printing? (Be free of kinks and folds, Have a shiny surface, Be coated with a special priming chemical, or Be porus)

5. What is the maximum weight of printing material? (10 LBS, 20 LBS, 18 LBS, or There is no maximum weight for printing material)

6. What methods can be used to set the bed height? (An auto detection process, the table up and the table down buttons, Both auto detection and the table buttons, The table height does not need to be set)

7. How do you clear previous print media setup data? (Turn the machine off and on, Use the "Clear Data" function in the menu, Press and hold the "Setup" button, or Data never needs to be cleared before setup)

8. Can the Roland LEF 300 UV printer print on reflective surfaces? (No, Yes, Yes, but only if special ink is used, or Yes, but only if lab staff say it is ok)

9. When setting the first point the LCD screen should read: (Scan and Feed, Width and Height, First Point Set Up, or Define First Point

10. How far should the print material be away from the sensor bar? (1 inch, 1/4 an inch, 1/2 an inch, or 1/8 an inch)

11. Which training did you complete? (Paper Manual/Augmented Reality)

12. Have you completed any other training materials for or used the Roland LEF 300 machine since you completed the training for this study? (Yes/No)

Appendix D: Recruitment Materials - Email Message

Hello,

My name is Brendan Kelley.

Researchers from the Journalism and Media Communication department at Colorado State University are conducting a research study on different training methods used in the Nancy Richardson Design Center (RDC) build labs and augmented reality (AR) training. The study, Augmented Reality Training Comparison, is the collaborative effort of Dr. Michael Humphrey (Principal Investigator) and Brendan Kelley (Co-Investigator).

Any current CSU student is invited to participate in a 30 minute study in the digital fabrication lab at the RDC. Each participant will be randomly assigned to either a paper manual, AR, or online video training then asked to complete a short quiz and survey following the training session.

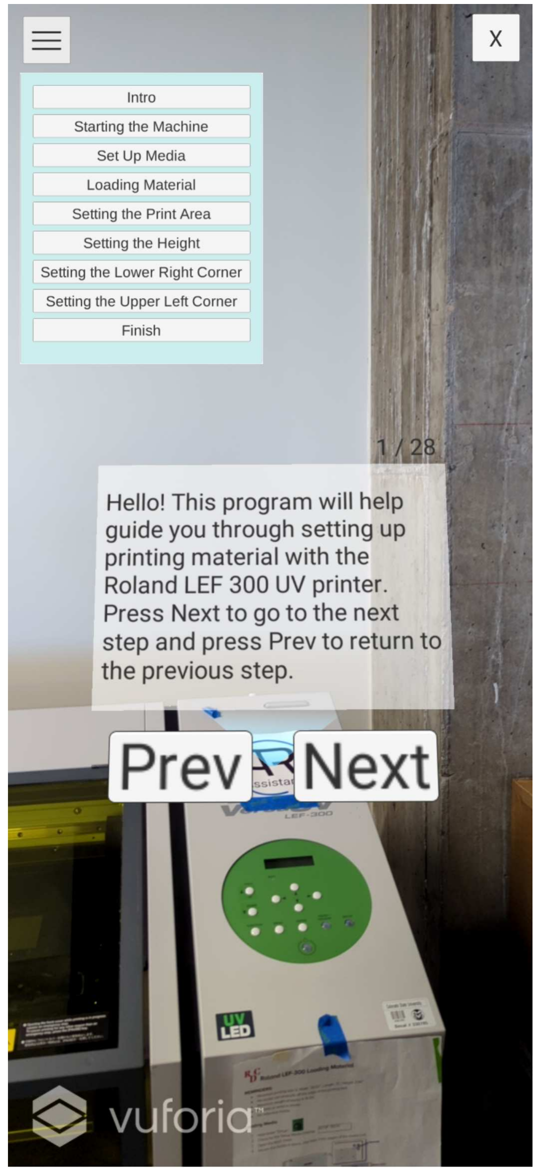
This study will be used to improve the training procedures at the RDC and determine the potential benefits and limitations of different training methods. Additionally participants will receive extra training on the Roland LEF 300 UV printer apart from the training currently available through the RDC.

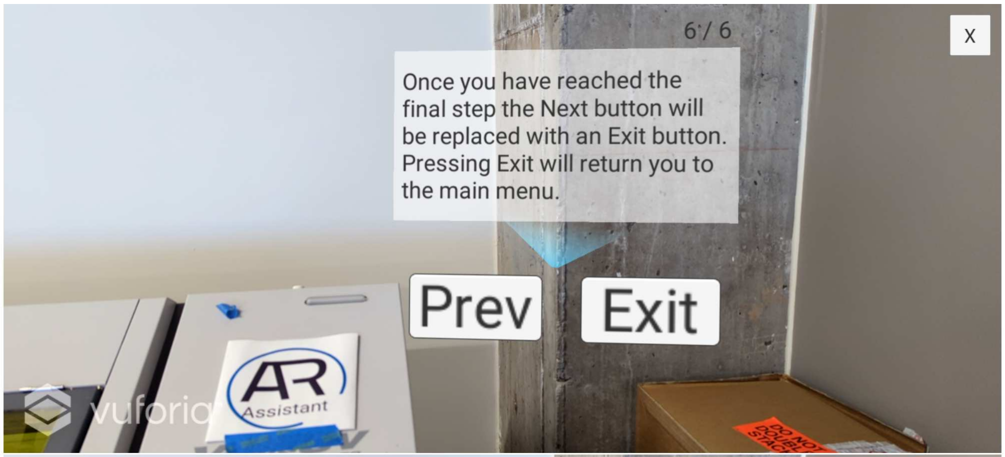
If you are interested in participating in this study please use this link to sign up: <SIGNUP GENIUS LINK HERE>

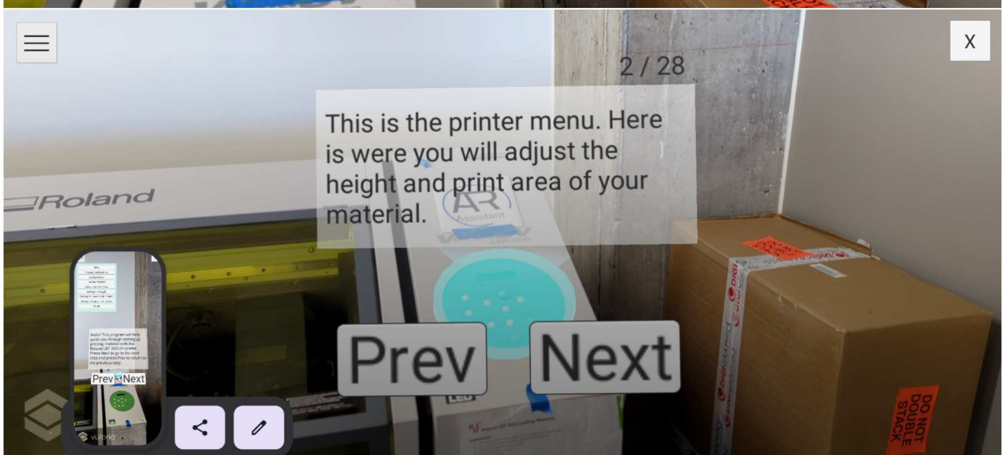
If you have any concerns or questions regarding this study email brendan.kelley@colostate.edu

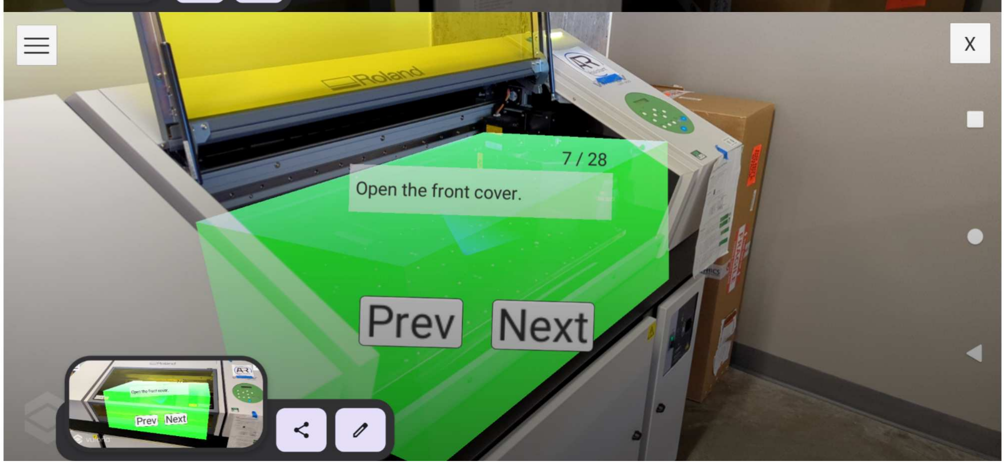
For questions regarding the rights of research subjects, any complaints or comments regarding the manner in which the study is being conducted, contact the CSU Institutional Review Board at: RICRO_IRB@mail.colostate.edu; 970-491-1553.

Appendix E: Augmented Reality Assistant




6 / 6
Once you have reached the final step the Next button will be replaced with an Exit button. Pressing Exit will return you to the main menu.
Prev
Exit
X
vuforia
AR Assistant


2 / 28
This is the printer menu. Here is were you will adjust the height and print area of your material.
Prev
Next
X
Roland


7 / 28
Open the front cover.
Prev
Next
X
Roland

Appendix F: Paper Training Manual

Roland LEF 300 Paper Training Manual

This manual will walk you through the steps of loading material into the Roland LEF 300 UV printer.

The Roland LEF 300 is capable of printing on any non reflective material. This includes slight curves and textured material.

The maximum printing size is 30.32 inches by 13 inches with a depth of 3.94 inches.

Any material exceeding these bounds cannot be printed on.

Any material exceeding a weight of 18 lbs cannot be used.

1. To load media begin by pressing and holding the “Setup” button. This clears any previous setup data.

2. Check the LCD screen to ensure that “Setup Media” is displayed.

3. Open the front cover and place your media on the bed.

4. Ensure that the media is secured in place. Tape may be necessary to prevent edge curling. Media should also be free of any folds or kinks.

5. Close the front cover and press “Setup” to finish loading and set the print area.

6. When the LCD displays “Height” press any arrow on the machine. The LCD should then display “Auto Detection.” Press enter to begin the height auto detection sequence.

7. Alternatively users can use the table up and table down buttons to manually adjust the table. If a manual adjustment is performed ensure that the table sensor bar is approximately 1/8th of an inch away from the media.

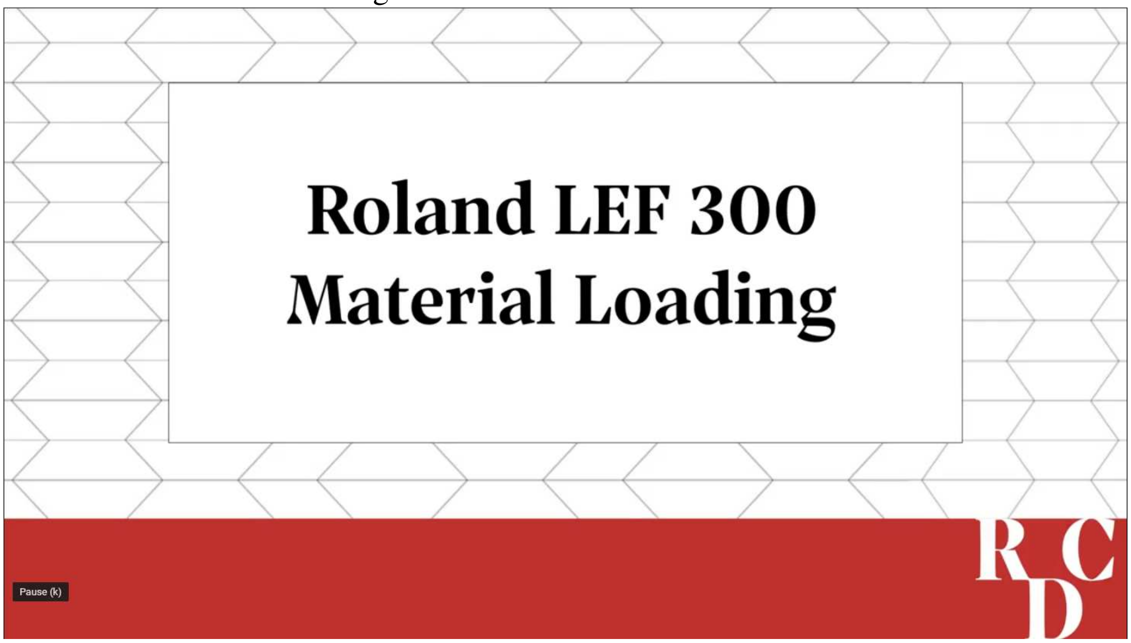
8. When the height is set the next screen should show “Scan” and “Feed”. Press any arrow to begin setting the bottom right corner of your print area.

9. The print head will move over the print bed and shine a laser pointer to help set the point.
10. Use the directional arrows to move the laser pointer. Press enter to set the point at the bottom right corner of your media.
11. The LCD should now display “Width” and “Length.” If the screen still reads “Scan” and “Feed” the first point was not set correctly and needs to be reset.
12. Press any arrow key to begin setting the upper left corner of the media.
13. The print head will once again move over the print bed and shine a laser pointer to assist with setting the point.
14. Use directional arrows to move the last pointer. Press enter to set the point at the upper left corner of your media.
15. After the second point is set the media is ready for printing.
16. To check the accuracy of the print area press “Function”
17. Press the down arrow to find the “Print Area” option
18. Press the right arrow to access the “Print Area Preview” option then press enter.
19. The print head will trace the printable area with the laser pointer.

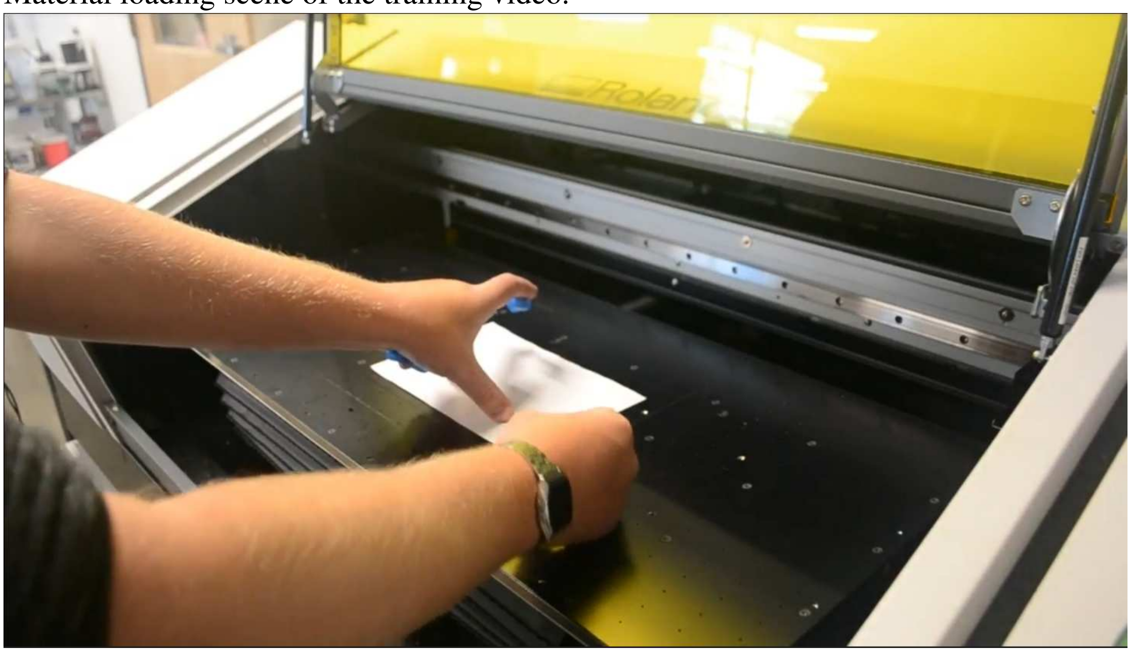
This concludes the training process. Please see the researcher conducting this study for the post training survey.

Appendix G: Online Training Video

The title screen of the training video.



Material loading scene of the training video.



Menu interaction scene of the training video.