Mixed Reality Equipment Training

A Pilot Study Exploring the Potential Use of Mixed Reality to Train Users on Technical Equipment

Andrew, J, Miller
Department of Electrical and Computer Engineering, Texas A&M University

Stavros, Kalafatis
Department of Electrical and Computer Engineering, Texas A&M University

ABSTRACT

The increasing availability and capability of Extended Reality (XR) systems has led to swift augmentation of many daily tasks. Research in Mixed Reality (MR), an XR branch allowing simultaneous interaction with virtual and real objects, has shown great potential for enhancing training such as learning how to use technical equipment. In this work, a pilot study was conducted to evaluate how users perceived instruction details given in a traditional written format or MR application. Participants were asked to set up a complex resin-type 3D printer following one of the instruction formats, having no prior experience with any equipment used. Performance was evaluated in regard to efficiency, precision, perceived difficulty, task comprehension, and experience preferences. This work resulted in clear analysis of how details in written and MR instructions are perceived, which can be used to more effectively leverage MR visuals to convey information in training applications.

CCS CONCEPTS

• Human-centered computing; **• Visualization**; **• Visualization application domains**; **• Information visualization**; **• Human computer interaction (HCI)**; **• HCI design and evaluation methods**; **• User studies**; **• Applied computing**; **• Education**; **• Computer-assisted instruction**; **• Scientific visualization**;

KEYWORDS

Mixed Reality, Human Computer Interaction, Training

ACM Reference Format:

Andrew, J, Miller and Stavros, Kalafatis. 2023. Mixed Reality Equipment Training: A Pilot Study Exploring the Potential Use of Mixed Reality to Train Users on Technical Equipment. In *2023 the 7th International Conference on Virtual and Augmented Reality Simulations (ICVARS) (ICVARS 2023), March 03–05, 2023, Sydney, Australia.* ACM, New York, NY, USA, 9 pages. https://doi.org/10.1145/3603421.3603436

1 INTRODUCTION

The rapid development of Extended Reality (XR) systems, namely Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), has led to XR being quickly adapted for human-computer collaboration in many everyday tasks. While prior research has shown that XR offers many potential benefits for augmenting human performance, it has also highlighted the need for thorough evaluation and accurate measurements.

To that end, this research aims to evaluate how well MR can be used to train a user on technical, as compared to following traditional written instructions. This MR study was evaluated using traits identified in prior research that were found necessary for effective XR implementation: it must show conclusive benefits, performance must be similar or better than traditional tools, user perception and satisfaction must be considered, required setup must be minimal, visual immersion must be a key instruction component, goals must be clear, it should not impede a user's self-efficacy or self-confidence, and it must ensure effects on human performance in regard to efficiency, comprehension, and precision are clearly measured. Following these conditions ensured the results gave insight into how MR visuals convey instructional information.

2 RELATED WORK

A number of prior studies have explored using XR to enhance human performance. In the healthcare space, authors in [14] reviewed research that used XR to assist with remote collaboration, planning of procedures, managing perioperative tasks, and even full procedure training. They noted great opportunity for XR training on cardiothoracic procedures, but also the lack of definitive measurements on which aspects of XR benefited users compared to traditional training. Similarly, authors in [18] reviewed XR work designed to enhance a doctor's orthopedic surgery skills, finding it could enhance data visualization, procedure planning, and improved task comprehension. Researchers in [1] evaluated using MR for caregiver training, finding that MR improved user engagement, reduced testing times, and increased user confidence.

XR research has explored augmenting modern industrial work. Authors in [6] implemented a framework to assist users in understanding a robot's perception state along with offering a Natural Language Processing (NLP) verbal interaction, providing an intuitive human and robot means of communication that yielded improved customer service. Authors in [4] explored using MR to train workers on dangerous equipment, finding both MR and face-to-face training gave similar performance in both time and information retention, supporting the notion that MR training can be as effective as traditional methods. Authors in [2] reviewed XR research on vehicle servicing and found that most studies only look at effectiveness in terms of time and error, but often overlook the interplay of factors such as people skills, previous experience, disorientation, presence, usability, and satisfaction. In [17] the authors describe shaping MR application requirements using the context of the operating environment and its user's needs, specifically regarding oil refining. These authors noted that MR training minimize training

ICVARS 2023, March 03–05, 2023, Sydney, Australia

ACM ISBN 978-1-4503-9746-9/23/03.
https://doi.org/10.1145/3603421.3603436

on the tool itself, ideally needing a 15 minute or less introduction on how to use the application. Researchers in [12] reviewed VR and MR studies on construction training and found that most studies tracked effectiveness via interaction with simpler computer monitors and keyboards but had not extensively compared it to the effectiveness of using a 3D visual.

Other MR work has aimed to immerse users in more effective learning environments. Authors in [20] compared typical video-based instructions against an MR experience for teaching martial art students. They found immersive visuals were easier for users to understand and copy motions, which led to faster learning. In [7], authors compared traditional music lessons to lessons given in an MR environment. They found that while MR lessons only indicated small performance improvements, users still found the experience more engaging and memorable which led to greater information retention.

MR has also been used in education for immersive academic learning. In [15] the authors explored using MR to teach students product design through stronger visualization and conceptualization. The authors noted that while some results indicated faster task completion times, greater creativity, and clearer understanding of their designs, it was still difficult to compare performance considering task and overall goal comprehension. Researchers in [9] developed an MR application to simulate teaching in a university. They found MR shows promise for deeper immersion and sense of presence, but was difficult to determine the performance value of using MR over traditional methods. In [16] the authors compared teaching design course content using traditional and MR formats. They found that using MR instructions improved learning efficiency and comprehension of complex structures and models. In [28], the authors outline effective characteristics for virtual classroom designs. In [5], recent MR studies were reviewed to understand the pedagogical elements used for effective teaching. The authors emphasized the need to enable and not impede a user's self-efficacy and self-confidence with minimal to no learning of the new MR technology.

Prior research has also found somewhat mixed response in effectiveness of these tools, primarily driven by application use. Researchers in [25] found that more complex visualizations offered in newer interaction technologies like Cave Automatic Virtual Environments (CAVEs) and 3D desktop environments are generally as easily adopted as simpler technology alternatives like smartphones, despite offering a greater degree of immersion. Authors in [21, 23] found that using an AR head-mounted display (HMD) allowed for intuitive and satisfying information retrieval during maintenance applications, along with task completion enhancements such as localizing objectives more quickly and reducing overall movement. Similarly, authors in [27] found that AR using AR instructions improved user execution time and error rates especially regarding localization and selection of parts. Whereas authors in [22] reviewed a variety of industrial maintenance-oriented AR studies and found overall that AR did not yet meet the robustness and reliability need, and that HMDs need to become more comfortable and powerful. Authors such as those in [24] recognize both the benefits of new intuitive, accurate, and natural interaction methods as well as what their current limitations are, offering insight into which aspects should be addressed and tested as XR technology evolves.

Still other work aims offers considerations that should be made when designing effective MR-based training. Authors in [8] conducted a widespread survey of XR studies focused on training enhancements. While the authors noted some conclusive trends in improved immersion and task comprehension, they note gaps in existing work regarding how XR is affected by people groups, quality of hardware, and especially as to what makes XR tasks consistently efficacious for training. In [29], authors identified individual differences, prior experiences, task design, and VR design as key influencing factors of cognitive load VR. In [26], the authors noted evidence that the difficulty of an assembly step may not affect user performance when comparing written to AR instructions, but that AR instilled greater confidence and transfer learning to other tasks. Researchers in [10] outlined potential ethical implications of using AR, VR, and MR. Though not directly focused on performance analysis, this overview outlines the need for a clear understanding of how these technologies influence human performance in regard to efficiency, comprehension, and precision so that clear ethical safeguards are put in place. Researchers in [3] showed that assuming the potential benefits is sufficient to build functioning simulation and training, but not for determining exact value additions. In [10], the authors tested the effects of visual cue designs on usefulness. They found that while visual communication cues aided task times and usability, the cues themselves did not necessarily lead to a higher sense of presence or reduction in mental effort. Similarly, authors in [13] showed effective use of MR aided visualization of complex interactions, although the extent of the benefit was unclear. Authors in [11] aimed to reduce application deployment differences by proposing an MR design model for consistency in MR applications. Similarly, authors in [19] defined a way to standardize a taxonomy of terminology and evaluation parameters to more clearly.

3 EXPERIMENT PROCEDURE

In this work, an MR application was built to guide a user through setting up a piece of equipment that required a variety of object manipulations. The MR application was designed to only represent the same information provided in the original written instructions for a fair comparison. The technical piece of equipment needed to be sufficiently complex so that an uninformed user could not complete a flawless setup by guessing, but also one that did not require extensive training. The MR application conveyed information without extensive physical interactions in order to isolate the benefits and limitations of visually-represented details while avoiding bias from the addition of physical interaction benefits of XR.

3.1 Technical Equipment

A Formlabs Form3 resin 3D printer, shown in Figure 1, was chosen as the piece of equipment due to its setup requiring tasks ranging in difficulty and complexity. Setup of the printer requires the manipulation of a resin tray, a build plate, and a resin cartridge.

While this printer is not overly complex, without careful instruction a user might touch the thin film on the bottom of the resin tray, the nozzle of the resin cartridge, or the internal laser mechanism

Figure 1: The Formlabs Form3 resin 3D printer and components. (https://formlabs.com/3d-printers/form-3)

and permanently damage the printer. A successful setup of the Form3 printer requires careful completion of six steps:

- Step 1 - Open the printer hood by lifting from the hand slot on the front.
- Step 2 - Open the resin tray container, carefully lift the tray out of the container by the side hand slots, insert the tray into the printer by aligning the sides with the printer rails, and push the tray down and into the rails until it clips into place. The touchscreen gives a notification when it is correctly installed.
- Step 3 - Flip up the build plate latch, grab the build plate, flip it over, insert the build plate onto the holder pushing it firmly into place, and flip the latch back down.
- Step 4 - Close the printer hood by pulling down from the hand slot on the front.
- Step 5 - Pick up the resin cartridge by the hand slot on the top, insert the cartridge into the back of the printer, and click the cartridge tab on the top open.
- Step 6 - Follow the touchscreen instructions to ready the printer for a new printing job.

Each step required different amounts of careful attention and number of movements for completion. Opening and closing the hood, steps 1 and 4, were the simplest to complete if the user moved the hood by the hand slot on the front as each only required one motion. Step 2 was the most complex, requiring special care when handling the tray to not damage the film and a very specific motion to insert and push the tray into place. Step 3 required the user to notice the orientation of the keyed slot that the build plate was installed in, as well as not push down on the build plate to avoid damaging the printer's motors. Step 5 required noting the keyed slot the cartridge was installed in, avoiding touching the resin nozzle on the underside, and remembering to click the cartridge tab open. Step 6 required the user to click a series of buttons on the printer touchscreen and read its prompts until it showed it was ready to print.

The typical setup of this printer involved following written instructions which described these six steps primarily in text with a few corresponding figures, such as Step 3 show in Figure 3. A custom MR application was built for the Microsoft Hololens 2 MR headset using the Unity game engine which allowed users to see the real world Form3 printer alongside animated holograms depicting the same information as the written instructions. For example, Figure 4 shows how the user would see animated holographic hands moving a virtual duplicate of the printer and parts showing how to complete Step 3. The holograms also contained a simple text statement clarifying the goal of that step, but not how to complete. As seen in Figure 4, the text prompt says, "Step 3) Flip the build plate latch up, insert the build plate, and flip the build plate latch down." The side-by-side layout of the MR application and real printer as viewed by a participant can been seen in Figure 5.

3.2 Participant Selection

A group of 26 participants were randomly split into two groups of 13 and asked to set up the Form3 printer twice. One group experienced the written instruction format first and MR instructions second, while the other group received MR instructions first and written instructions second. Although participant's second setup is naturally biased due to having setup the printer once before, the second setup provided insight into how the participants compared instruction mediums, comprehended tasks, and retained knowledge. The 26 included participants from a wide range of backgrounds, ages, and experience which provided a reasonably unbiased evaluation of the instruction methodologies. Each participant verified they had normal or corrected-to-normal vision, were a healthy adult without any psychiatric/neurological disorders or physical/cognitive disabilities, were at least 18 years of age, were able to read and speak fluent English, were able to move/interact with equipment in a typical lab environment, had no prior experience using an MR headset of any kind, and had no prior experience using a 3D printer of any kind.

3.3 Methods of Evaluation

In these experiments the instruction type operated at the independent variable, and the participants performance and experience as the dependent variable. During each setup, participants were monitored to observe how they interacted with printer and its components. After each setup was completed, the participants answered a questionnaire asking them multiple questions about their perception of that instruction type and its usefulness regarding various attributes. Based on criteria mentioned in [2], these metrics and questions were designed to compare information given in a written format against an MR format in the following 5 criteria:

- Efficiency - How quickly participants completed tasks and how few steps they completed them in.
- Precision - How few mistakes the participants, damaging or not.
- Complexity - How difficult participants perceived steps based on the given instruction medium.
- Comprehension - How well participants understood the goal of the instructions provided.

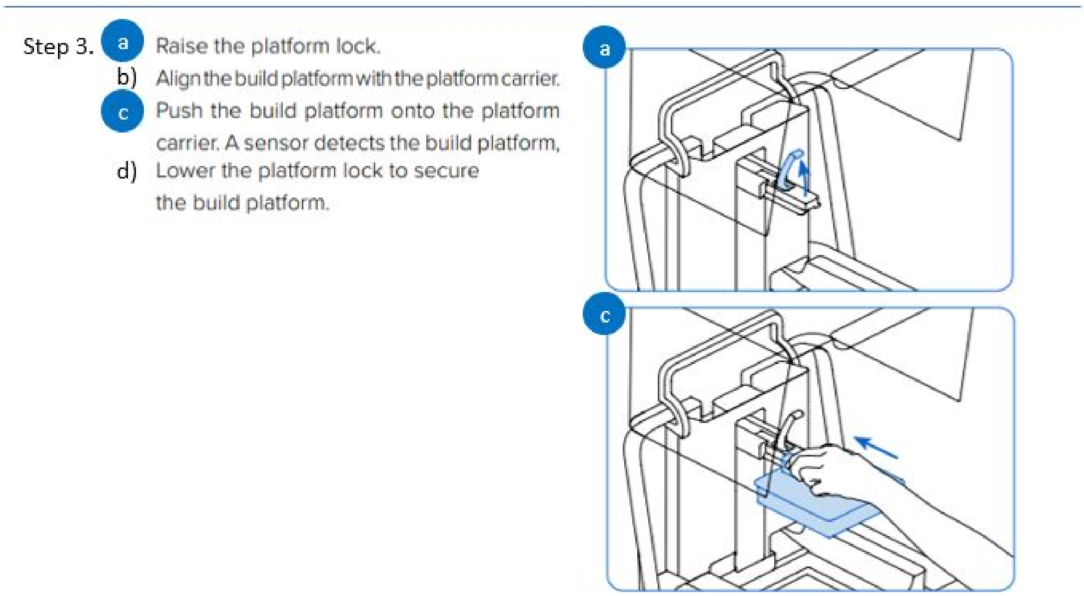

Figure 2: The written instructions provided for Step 3.

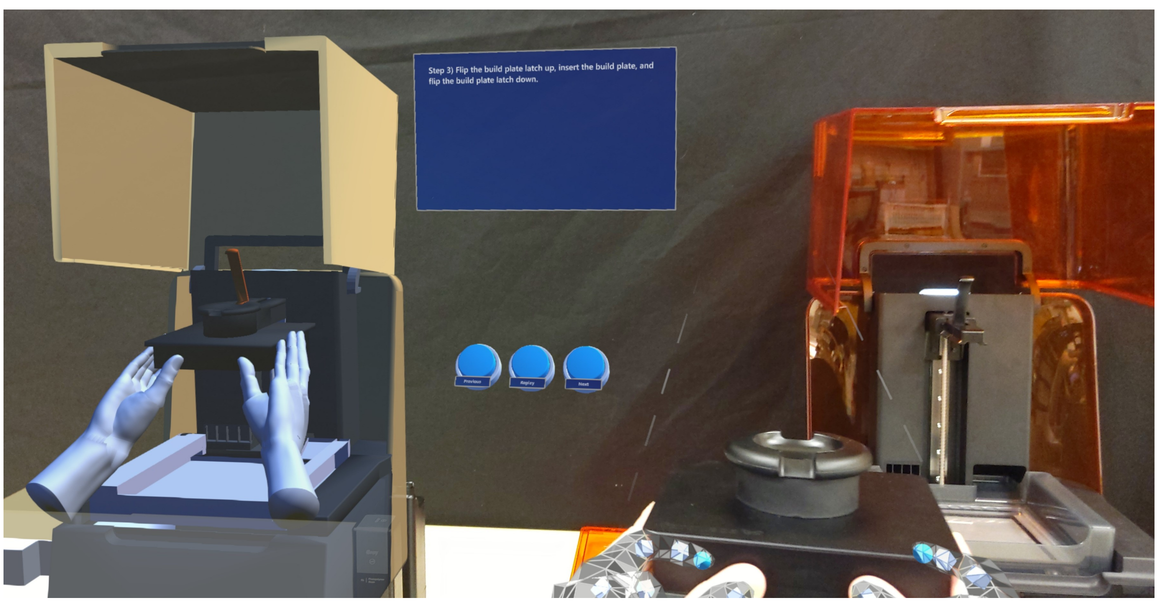

Figure 3: The MR instructions provided for Step 3.

- Preference - Which aspects participants preferred about each instruction medium.

4 RESULTS

In the figures, "Written 1st" and "Written 2nd" refer to participants who performed their printer setup following the written instruction on their first and second setups respectively, while "Hololens 1st" and "Hololens 2nd" refer to those that followed the Hololens MR instructions on their first and second setups respectively. Thus the "Written 1st" and "Hololens 2nd" groups are the same participants, as wells as the "Hololens 1st" and "Written 2nd" groups.

4.1 Efficiency

The first evaluation criterion was to compare the efficiency of participant performance, measured in both time and how few actions it took to complete steps.

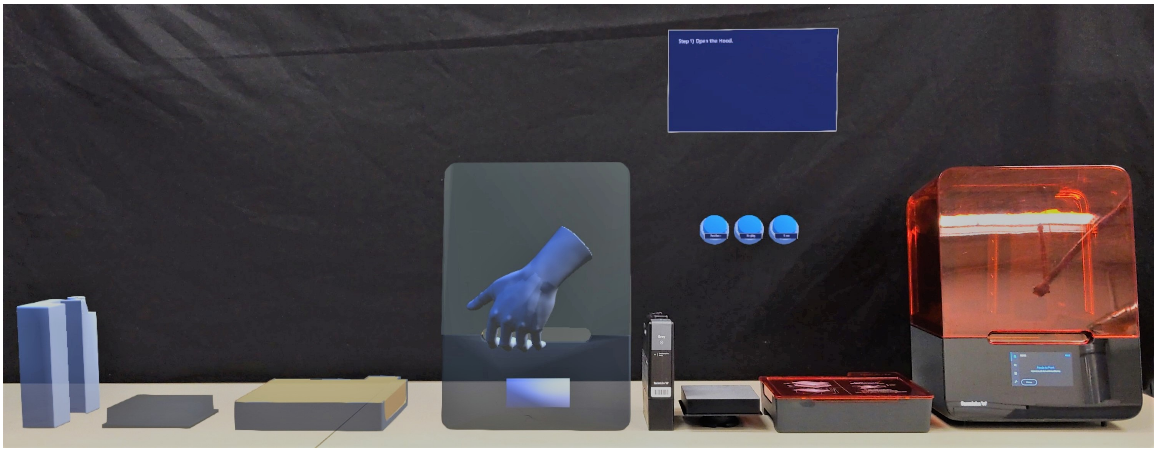

Figure 4: The Form3 3D printer with Mixed Reality instructions displayed side-by-side.

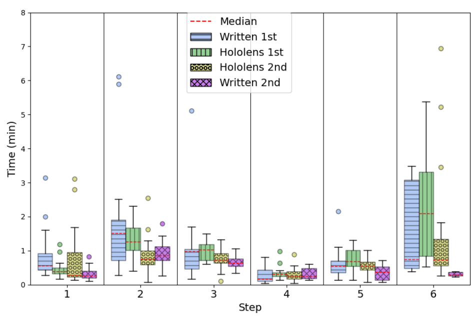

Figure 5: Completion Times for 1st and 2nd Setups.

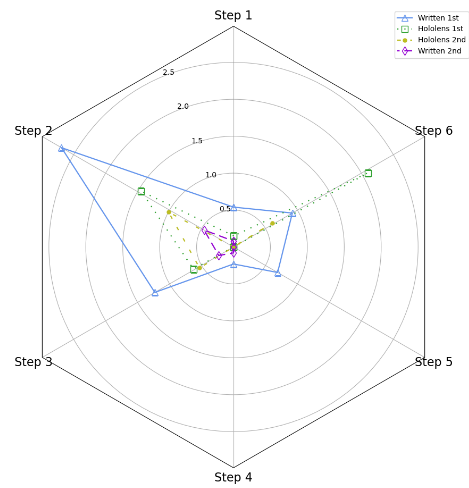

Figure 6: Number of actions taken for 1st and 2nd setups.

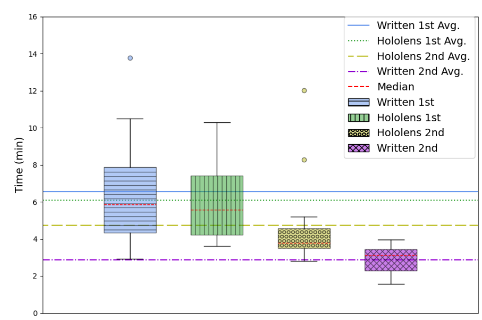

Figure 7: Total setup times.

4.1.1 *Completion Time.*

Participants were timed during each setup to observe how long it took to complete each step and the complete setup, shown in Figure 6. Not all steps were equal in complexity or number of setup actions, so each step expectedly varied in completion time. While participants could proceed even if the current step had not finished, the printer could not be initialized in step 6 unless all previous steps were correctly completed.

4.1.2 *Number of Extra Actions.*

Efficiency was also recorded in terms of how few actions it took a participant to complete tasks. An action included any movement such as picking an item up, opening or closing the hood, flipping the latch up or down, or interacting with the touchscreen. The recorded numbers are additional actions performed on top of the minimum needed to complete the step. The average number of actions participants used on each step in the first and second setups are shown in Figure 7.

4.1.3 *Total Times and Actions.*

Efficiency was also viewed as overall performance for all steps. The distribution of total times spent on each setup are shown in Figure 8, and the total number of actions spent on each setup are shown in Figure 9.

4.2 Precision

Participant actions were carefully monitored to track any errors made, such as lifting the hood by the sides or the resin tank without using the appropriate hand slot, touching the resin tray or cartridge

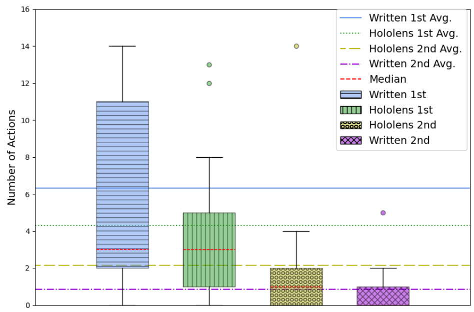

Figure 8: Total setup actions.

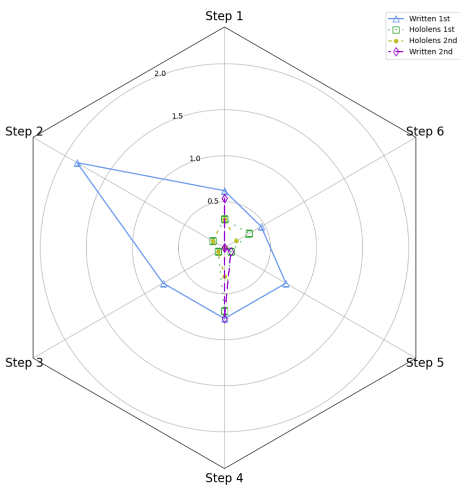

Figure 9: Number of errors committed for 1st and 2nd setups.

nozzle and contaminating the surface, bending or stretching the tray's delicate film, pushing too hard on a motorized mount, and trying to force the wrong object into place. The errors recorded for each step are shown in Figure 10.

4.3 Complexity

Following each setup, participants were asked how difficult actions were on a scale from 1 (not difficult) to 7 (very difficult). The perceived difficulty of completing single-action steps is shown in Figure 11, multi-action steps in Figure 12, and steps requiring extra caution in Figure 13.

4.4 Comprehension

Participants were asked a series of questions about information conveyed in each instruction mediums. The percentage of participants that agreed with each question is shown in Figure 14.

4.5 Preference

Participants were asked a series of questions pertaining to their experience with both instruction mediums. The percentage of participants that agreed with each question is shown in Figure 15. Participants were also asked to compare instruction mediums for

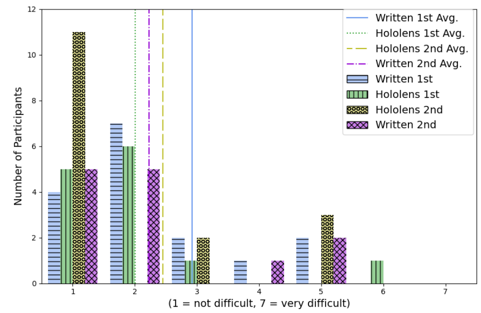

Figure 10: Complexity of single-action steps.

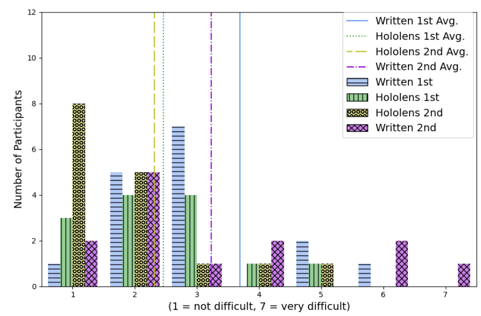

Figure 11: Complexity of multi-action steps.

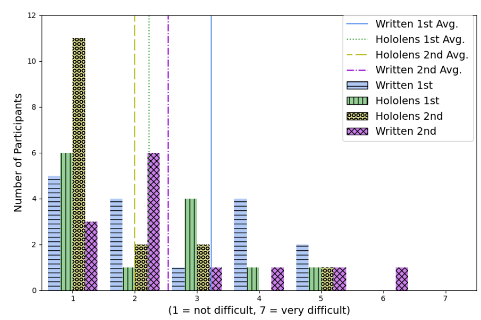

Figure 12: Complexity of steps needing caution.

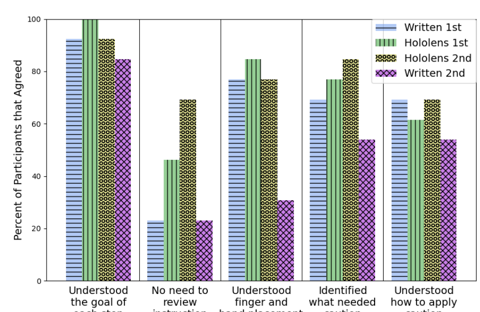

Figure 13: Participant comprehension of provided instruction.

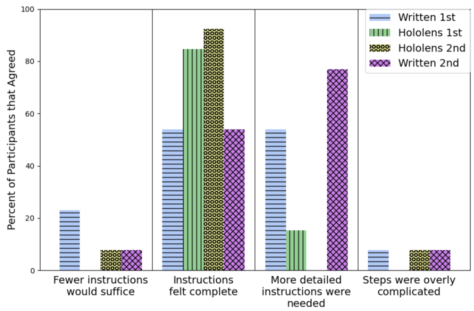

Figure 14: Additional preferences.

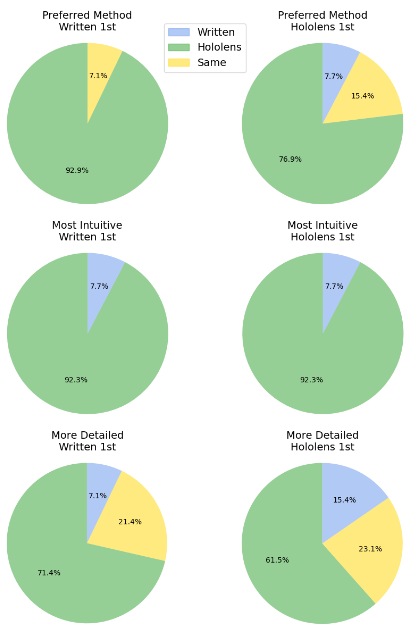

Figure 15: Preferred instruction medium.

which they preferred, which felt the most intuitive, and which provided the clearest information. This can be seen in Figure 15.

5 ANALYSIS

Based on these collected results, a number of important trends were identified by comparing participant groups. Participant feedback was also recorded to reflect noted experience during the setup procedures.

5.1 Efficiency

The first notable trend in Figure 6 is that participants who experienced the Hololens setup first had tighter distributions with fewer outlier times than those which received the Written instructions first. This seems to imply fewer users were confused or became stuck on more difficult actions. Since the MR and written box plots are of similar sizes for first and second setups it is reasonable to conclude setup time efficiency is similar using either instruction method. While users could move to the next step even if the current step was incomplete, step 6 required the user to fix any previous problems before initializing the printer resulting in significantly higher times on first setup procedures. It should also be noted that watching the animated holograms and reading any supplemental text notes was arguably more time consuming than reading the written instructions.

Figure 7 showed participants using the Hololens on their first setup used significantly fewer actions on steps 1, 2, 3, and 5, and had perfect action efficiency on steps 4 and 5. The extra actions on step 6 were due to a couple of participants toggling between touchscreen menus, likely double checking themselves.

Figure 8 showed the average time for following MR instructions was 7.3% faster than written instructions on the first setup, implying MR enabled participants to complete their tasks as fast or faster than when using written instructions. While both groups improved speed in the second setup, those who received MR instructions first completed their second setup 39.7% faster. Since both groups performed similar during their first setup, this improvement seems to imply participants who experienced MR instructions first retained knowledge or had clearer task comprehension than those who experienced written instructions first.

Figure 9 showed participants following MR instructions first used 31.7% fewer actions than those following written instructions first. It seems likely those participants were more efficient due to understanding the exact movements needed for each action. Those same participants who then followed written instructions second used 60.7% fewer steps than those using MR on their second setup. Since each group reduced total actions by 3 or 4 between setups, both instruction mediums seem comparable for improving accuracy across multiple setup experiences, although MR instructions may be able to accelerate initial training.

5.2 Precision

Correctly interpreting detailed information is not only critical for precise actions, but also for reducing errors whether damaging to the equipment or not. Figure 10 showed that participants following MR instructions first committed an average of 1.6 errors, a 68.8% reduction over the 5.2 average errors committed by those following written instructions first. This supports the notion that training with MR visuals improves precision when interacting with complex equipment. During the second printer setup participants following written instructions averaged 1.4 errors, while those following MR instructions averaged 1.0 errors. This and the reduction in total setup time seen in Figure 8 may imply that users transitioning from written to MR instructions can improve precision by coupling learned knowledge from written instructions with visual comprehension of how an action should be performed. This may also imply that while users following MR instructions first committed fewer mistakes, effectively accelerating their training, they may not have comprehended instructions as deeply due to not improving precision when transitioning to written instructions as much as the group transitioning from written to MR instructions did. Although the tradeoff is not large, it should be considered if replacing traditional written instructions with an MR equivalent.

Participants following the Hololens instructions did not commit potentially damaging errors to the 3D printer, although they did commit non-damaging errors including lifting the hood by the sides instead of the hand slot, lifting the resin tray by something other than the hand slots, and attempting to insert parts in the incorrect orientations. In contrast, participants following the written instructions committed damaging errors like forcing the wrong part into place due to unclear descriptions or image, not removing the resin tray from its container due to the similar shape of the container and tray, inserting parts with incorrect motions, pushing parts in too hard, forcing motorized rails to move, and disassembling parts when the written action confused them.

5.3 Complexity

Figures 11, 12, and 13 showed that most participants found MR instructions to be less difficult to follow, particularly those who first experienced written instructions. Most participants found multi-action steps to be reasonably harder, particularly inserting the resin tray in step 2 where several participants noted the written instructions did not clearly describe the installation motion which resulted in partial installations. In contrast, participants following MR instructions more clearly understood how to lock the tray in place, commenting that the MR visuals helped them understand interactions with complex printer components more clearly.

5.4 Comprehension

Figure 14 shows that most participants found either instruction medium sufficient to understand the task goal, but that they did not need to review MR instructions nearly as much as written, regardless of which medium they received first. Similarly, participants felt that the Hololens instructions provided greater clarity for where fingers and hands needed to be placed. While participants felt the Hololens provided a little more clarity on when caution was needed, in general they felt both methods were sufficient with a slight reduction in confidence when using written instructions second. Participants also felt they understood when to be cautious, again with reduced confidence when using written instructions second. This improved confidence from using MR instructions supports the notion that MR can effectively be used for training requiring attention to detail, especially when precise motions are involved such when working with complex or delicate equipment.

5.5 Preferences

Human preference can largely influence the perceived usefulness of a technology. As shown in Figure 15 most participants found both instructions sufficient. While several participants that received written instructions first again noted they wanted clearer written instructions for complicated actions such as step 2, all participants felt the MR instructions felt more complete than the written instructions. Further, some participants felt that written instructions were missing information whereas MR visuals seemed to clarify confusing details making them feel more complete. Figure 15 compared both setup experiences for all participants and found MR instructions were preferred, felt more intuitive, and felt more informative.

5.6 Needed Improvements and Future Work

It was anticipated that participants would feel limited in their MR experience due to the minimal virtual physical interactions used. While some participants did comment that they would like a more virtually interactive version, because the application was centered around setting up the 3D printer most still found the animated holograms and limited virtual physical interactions to be sufficient. Interestingly, many participants noted that when instructions were confusing or challenging, they wanted a means to ask for clarity which would have resolved most issues. This need highlights a critical challenge in XR applications such as this, that XR needs means of communication beyond physical interaction for effective human-computer collaboration. In continuing work, we plan to address this need by incorporating a NLP communication layer on top of virtual physical interactions so that users can communicate with their computer counterpart.

6 CONCLUSIONS

This study resulted in valuable trends that show both benefits and complications of using MR to train on technical equipment. While timing efficiency of MR instructions was moderately better than written instructions, the reduction in extra actions used was significant and supports the notion that MR can enable a user to perform complex tasks with little to no domain knowledge with comparable efficiency to traditional methods. It is likely because using MR visualization addresses ambiguity of instructions and allows users to notice details. It was also seen that task efficiency does not necessarily equate to knowledge retention, and relying solely on MR instructions may cause users to miss actually learning the process they perform. It seems users who are trained using MR succeed at replicating they see with or without understanding what they are doing, often with fewer errors. This supports that when task comprehension is not critical MR could be used to accelerate a user's training. The ability of MR to enable a new user unfamiliar with either the MR headset or the 3D printer to complete a sophisticated setup with minimal mistakes shows its potential for training on new equipment. Further, participant perceptions of complexity, comprehension, and experience all support using MR for instructional training. However, several limitations of using MR for instructions were found due to only having one-way information exchange. Specifically, participants relied heavily on the MR visuals instead of intuition or comprehension of what they were doing, leaving them stuck without no means of clarification if the visual was unclear. These limitations point to XR needing communication between the human and computer counterparts.

ACKNOWLEDGMENTS

The authors wish to thank Thien Vy Tran for their support in designing several of the test animations.

REFERENCES

[1] E. Azimi, A. Winkler, E. Tucker, L. Qian, J. Doswell, N. Navab, and P. Kazanzides. Can mixed-reality improve the training of medical procedures? In 2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), pp. 4065–4068, 2018. doi: 10.1109/EMBC.2018.8513387
[2] S. Borsci, G. Lawson, and S. Broome. Empirical evidence, evaluation criteria and challenges for the effectiveness of virtual and mixed reality tools for training

operators of car service maintenance. Computers in Industry, 67:17–26, Feb. 2015. doi: 10.1016/j.compind.2014.12.002
[3] S. S. Esfahlani. Mixed reality and remote sensing application of unmanned aerial vehicle in fire and smoke detection. Journal of Industrial Information Integration, 15:42–49, Sept. 2019. doi: 10.1016/j.jii.2019.04.006
[4] M. Gonzalez-Franco, R. Pizarro, J. Cermeron, K. Li, J. Thorn, W. Hutabarat, A. Tiwari, and P. Bermell-Garcia. Immersive mixed reality for manufacturing training. Frontiers in Robotics and AI, 4, Feb. 2017. doi: 10.3389/frobt.2017.00003
[5] Q. Guo. Learning in a mixed reality system in the context of industry 4.0. Journal of Technical Education (JOTED), 3(2), Dec. 2015. doi: 10.48513/joted.v3i2.60
[6] L. E. Hafi, S. Isobe, Y. Tabuchi, Y. Katsumata, H. Nakamura, T. Fukui, T. Matsuo, G. A. G. Ricardez, M. Yamamoto, A. Taniguchi, Y. Hagiwara, and T. Taniguchi. System for augmented human–robot interaction through mixed reality and robot training by non-experts in customer service environments. Advanced Robotics, 34(3-4):157–172, Oct. 2020. doi: 10.1080/01691864.2019.1694068
[7] D. Johnson, D. Damian, and G. Tzanetakis. Evaluating the effectiveness of mixed reality music instrument learning with the theremin. Virtual Reality, 24(2):303–317, June 2020. doi: 10.1007/s10055-019-00388-8
[8] A. D. Kaplan, J. Cruit, M. Endsley, S. M. Beers, B. D. Sawyer, and P. A. Hancock. The effects of virtual reality, augmented reality, and mixed reality as training enhancement methods: A meta-analysis. Human Factors, 63(4):706–726, Feb. 2021. doi: 10.1177/0018720820904229
[9] F. Ke, S. Lee, and X. Xu. Teaching training in a mixed-reality integrated learning environment. Computers in Human Behavior, 62:212–220, Sept. 2016. doi: 10.1016/j.chb.2016.03.094
[10] S. Kim, G. Lee, W. Huang, H. Kim, W. Woo, and M. Billinghurst. Evaluating the combination of visual communication cues for hmd-based mixed reality remote collaboration. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, p. 1–13, 2019. doi: 10.1145/3290605.3300403
[11] S. E. Kirkley, S. Tomblin, and J. Kirkley. Instructional design authoring support for the development of serious games and mixed reality training. In Interservice/Industry Training, Simulation and Education Conference (I/ITSEC), pp. 6–9, 2005.
[12] H. F. Moore and M. Gheisari. A review of virtual and mixed reality applications in construction safety literature. Safety, 5(3), Aug. 2019. doi: 10.3390/safety5030051
[13] M. Ostanin, R. Yagfarov, and A. Klimchik. Interactive robots control using mixed reality. IFAC-PapersOnLine, 52(13):695–700, Aug. 2019. doi: 10.1016/j.ifacol.2019.11.307
[14] A. H. Sadeghi, S. el Mathari, D. Abjigitova, A. P. M. Maat, Y. J. J. Taverne, A. J. C. Bogers, and E. A. Mahtab. Current and future applications of virtual, augmented, and mixed reality in cardiothoracic surgery. The Annals of Thoracic Surgery, 113(2):681–691, Feb. 2022. doi: 10.1016/j.athoracsur.2020.11.030
[15] Y. Tang, K. Au, and Y. Leung. Comprehending products with mixed reality: Geometric relationships and creativity. International Journal of Engineering Business Management, 10:1847979018809599, Nov. 2018. doi: 10.1177/1847979018809599
[16] Y. M. Tang, K. M. Au, H. C. W. Lau, G. T. S. Ho, and C. H. Wu. Evaluating the effectiveness of learning design with mixed reality (mr) in higher education. Virtual Reality, 24(4):797–807, Feb. 2020. doi: 10.1007/s10055-020-00427-9
[17] M. Träskbäack and M. Haller. Mixed reality training application for an oil refinery: User requirements. In Proceedings of the 2004 ACM SIGGRAPH International Conference on Virtual Reality Continuum and Its Applications in Industry, p. 324–327, 2004. doi: 10.1145/1044588.1044658
[18] J. T. Verhey, J. M. Haglin, E. M. Verhey, and D. E. Hartigan. Virtual, augmented, and mixed reality applications in orthopedic surgery. The International Journal of Medical Robotics and Computer Assisted Surgery, 16(2):e2067, Dec. 2020. doi: 10.1002/rcs.2067
[19] M. Walker, T. Phung, T. Chakraborti, T. Williams, and D. Szafir. Virtual, augmented, and mixed reality for human-robot interaction: A survey and virtual design element taxonomy. In arXiv:2202.11249, 2022.
[20] E. Wu and H. Koike. Futurepose - mixed reality martial arts training using real-time 3d human pose forecasting with a rgb camera. In 2019 IEEE Winter Conference on Applications of Computer Vision (WACV), pp. 1384–1392, 2019. doi: 10.1109/WACV.2019.00152
[21] S. Henderson, and S. Feiner. Exploring the benefits of augmented reality documentation for maintenance and repair. IEEE transactions on visualization and computer graphics, 17(10):1355-1368. Oct. 2011. doi: 10.1109/TVCG.2010.245
[22] R. Palmarini, J. Erkoyuncu, R Roy, and H. Torabmostaedi. A systematic review of augmented reality applications in maintenance. Robotics and Computer-Integrated Manufacturing, 49:215-228. 2018. doi: 10.1016/j.rcim.2017.06.002
[23] S. J. Henderson and S. Feiner. Evaluating the benefits of augmented reality for task localization in the maintenance of an armored personnel carrier turret. IEEE International Symposium on Mixed and Augmented Reality. 8:135-144. 2009. doi: 10.1109/ISMAR.2009.5336486
[24] Y. Ghazwani and S. Smith. Interaction in Augmented Reality: Challenges to Enhance User Experience. International Conference on Virtual and Augmented Reality Simulations (ICVARS). 4:39-44. 2020. doi: 10.1145/3385378.3385384
[25] O. Oyekoya. A Comparative Study of Smartphone, Desktop, and CAVE Systems for Visualizing a Math Simulation. International Conference on Virtual and Augmented Reality Simulations (ICVARS). 5:31-37. 2021. doi: 10.1145/3463914.3463919
[26] R. Rafael, J. Herrema, and J. Oliver. Augmented reality-based manual assembly support with visual features for different degrees of difficulty. International Journal of Human-Computer Interaction. 31(5): 337-349. 2015. doi: 31. 10.1080/10447318.2014.994194.
[27] M. Fiorentino, A. Uva, M. Gattullo, S. Debernardis, and G. Monno. Augmented reality on large screen for interactive maintenance instructions. Computers in Industry. 65(2): 270-278. 2014. doi: 10.1016/j.compind.2013.11.004
[28] R. Zhu and Y. Wang. Design and Realization of Virtual Classroom. Journal of Advances in Information Technology, 3(1):24-28, Feb. 2012. doi: 10.4304/jait.3.1.24-28
[29] J. Han, Q. Zheng, and Y. Ding. Lost in Virtual Reality? Cognitive Load in High Immersive VR Environments. Journal of Advances in Information Technology, 12(4):302-310, Nov. 2021. doi: 10.12720/jait.12.4.302-310