https://doi.org/10.36315/2025v2end086
p-ISSN: 2184-044X e-ISSN: 2184-1489 ISBN: 978-989-35728-8-7 © 2025

REDEFINING WORKPLACE LEARNING: SLASHING ERRORS BY USING AUGMENTED REALITY

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Abstract

Integrating Augmented Reality (AR) in workplace training offers new opportunities to enhance learning efficiency and reduce errors. This study examines AR's impact on assembly performance through a field experiment with a partnering company, comparing HoloLens 2-guided instructions with traditional paper-based assembly plans. Two groups (n=20) assembled a prototype drive unit under controlled conditions. Results indicate that AR users required fewer assistances, but statistical significance was not confirmed ($p = 0.734$). Learning retention was assessed through a second assembly without assistance, showing a minor error reduction ($p = 0.754$, insignificant). However, AR significantly improved assembly speed, with users completing tasks 9.12 minutes faster ($p = 0.011$). While usability challenges exist, AR boosts motivation and holds strong potential for Industry 4.0. Future research should explore optimization, cost efficiency, and long-term effects.

Keywords: *Augmented Reality, workplace training, learning efficiency, error reduction, industry 4.0.*

1. Introduction

Companies must continue training and onboarding new employees, which is often time-consuming and costly. Advances in digitalization and improved access to AI systems are opening up new opportunities, mainly through virtual (VR) and augmented reality (AR). Since their market launch, these technologies have offered potential for production, remote support, and digital training.

This paper examines the implementation of AR technology in companies, particularly concerning the necessary expertise, costs, and hardware requirements. One focus is on the advantages and disadvantages of AR in training and education. The methodology analyses the extent to which the use of a HoloLens 2 contributes to reducing the error rate and increasing time efficiency in a given assembly line.

Company processes are becoming increasingly complex, making onboarding new employees more difficult and causing high costs and time expenditures. AR technology, such as the HoloLens, offers the opportunity to digitalize training and further education and make them more efficient. Implementing AR technology creates innovative learning methods through the visual support of work steps.

The first part of this paper deals with the basics of AR technology, its advantages and disadvantages, and its difference from VR. It also examines the potential that implementation offers companies. In the third part, a field experiment is conducted within our partner company to analyze the efficiency of the HoloLens in prototype assembly. The focus is on error reduction, learning behavior, and the technology's expandability. Finally, the potential of AR integration and the insights gained will be evaluated.

2. Basics of augmented reality – Advantages and disadvantages

Augmented Reality (AR) is a computer-assisted technology that overlays digital information onto the physical environment in real-time. This allows users to interact with virtual objects while maintaining a connection to their real-world surroundings (Deppe et al., 2022, p. 351). The concept was first introduced in the early 1990s (Thomas, Metzger & Niegemann, 2018, p. 15). Unlike Virtual Reality (VR), which immerses users in a completely artificial environment, AR enhances the existing reality with digital elements (Zobel et al., 2018, p. 31).

As AR technology evolves, its application across various industries continues to expand, making exploring its advantages and disadvantages essential. Some key benefits of AR technology include its support for training and education through 3D visualization, which enhances knowledge retention and engagement (Roopa, Prabha & Senthil, 2021, p. 3861). Additionally, AR devices such as smart glasses offer hands-free interaction, allowing users to operate them through voice commands and gestures, thereby reducing the need for traditional input devices (Kind et al., 2019, p. 65). Another significant benefit is real-time data integration, enabling immediate data visualization, particularly useful in industries like healthcare and manufacturing (Bellalouna et al., 2022, p. 314). Unlike VR, AR also minimizes the risk of motion sickness, as it does not require full immersion, reducing the likelihood of VR-induced nausea (Kind et al., 2019, p. 67).

Despite its numerous advantages, AR technology presents several challenges that must be carefully considered before implementation. One significant drawback is the high cost associated with AR, including expensive hardware like the HoloLens 2 (approximately €4,000) and additional costs for custom software development (Radu & Schneider, 2019, p. 10). Technological limitations also pose a challenge, such as inferior performance in low-light environments and the limited accuracy of GPS systems (Zender et al., p. 6). The complexity of implementing AR solutions further complicates adoption, as these applications often require multidisciplinary collaboration, increasing development efforts (Zender et al., p. 6). Data privacy and security concerns arise from using AR devices like smart glasses, which can collect and store real-time user data, raising questions about anonymity and security (Acharya, 2020).

To fully grasp AR's role in the digital landscape, it is important to distinguish it from virtual reality (VR). Here are some fundamental differences between these two technologies.AR and VR differ significantly in immersion, hardware requirements, and user interaction. While VR creates an entirely virtual environment that disconnects users from the real world, AR integrates digital elements into the existing environment (Wohlgenannt, Simons & Stieglitz, 2020, p. 456). Regarding hardware, VR requires headsets that block real-world vision, whereas AR typically uses transparent smart glasses (Zobel et al., 2018, p. 31). The purpose of user interaction also varies, with AR primarily enhancing real-world tasks, while VR is mainly used for simulations and gaming (Zobel et al., 2018, p. 31).

While both AR and VR offer immersive experiences, AR’s ability to integrate with real-world tasks makes it particularly valuable for industrial and educational applications. Its growing adoption underscores the need for further research into its long-term impact and technological advancements.

3. Methodology

The methodology analyses how AR technology influences the error rate and learning behavior in new processes and further training in companies. The focus is on comparing conventional learning methods and using HoloLens glasses. Specifically, the study examines whether employees work more efficiently with AR than analog assembly plans when assembling prototypes or non-series production parts.

Important metrics are the number of assists required, the error rate, and the processing time compared between test groups with and without HoloLens. The field experiment was conducted in cooperation with an Austrian company, which provided assembly kits, 3D models, and test personnel.

Two groups (A and B) were formed for the experiment, each with 10 test subjects. Group A assembled the drive unit kit using the HoloLens 2 without access to an analog assembly plan. Instead, they used only the displayed 3D models and digital instructions. Group B, on the other hand, worked with a classic assembly plan printed on paper.

Both groups carried out the assembly on two consecutive days: On the first day, group A worked with the HoloLens 2 and Group B with the assembly plan for training. On the second day, both groups assembled the drive unit without aid. This allowed conclusions to be drawn about the learning behavior and efficiency of the HoloLens 2 in training new work steps.

The experiment is based on an experimental design in which Group B serves as the control group, and Group A represents the manipulated variable. The aim is to investigate the effect of the HoloLens 2 on assembly efficiency. The example drive unit kit used consists of eight individual parts and eight work steps. Initial tests showed an average assembly time of around 20 minutes.

The kit was chosen for its ideal complexity: It requires precise work without errors but remains manageable even for less tech-savvy test subjects. Both groups worked at identical assembly stations with standardized tools, screw containers, and the eight individual parts of the drive unit (see Figure 1).

Figure 1. Test setup assembly site.

The sample consisted of employees of the cooperating company who represented potential drive unit fitters. During the selection process, care was taken to ensure a heterogeneous composition regarding technical affinity and age group. All participants had to have no prior knowledge of drive unit assembly, be considered trustworthy, and be available precisely 24 hours apart on both test days. Participation was also voluntary. A total of 20 test subjects were randomly allocated to the groups to generate 180 data sets for subsequent analysis.

Potential confounding variables were identified and controlled to minimize external influences. Distractions caused by the working environment were to be avoided as far as possible. Therefore, the experiment was conducted in a remote assembly section, and all employees were informed in advance to minimize distractions. Noise was also recognized as a potential disruptive factor, as it could impair the concentration of the participants. For this reason, the quietest possible area was chosen for the experiment.

Another critical aspect was the technical reliability of the HoloLens 2. As a failure of the glasses would have falsified the test conditions, the battery charge was checked every time the participants changed, and the glasses were recharged during short breaks. In addition, the HoloLens 2 software was extensively tested in advance to avoid technical problems during the experiment.

On the first day of the experiment, two test subjects - one from group A (with HoloLens 2) and one from group B (with an analog assembly plan) - were tested simultaneously every 30 minutes. After a brief introduction, the experiment began. Group A was given an additional two minutes to test the controls of the HoloLens 2, including the functions for rotating, scaling, and moving objects. The time measurement then started for both participants.

Each test person assembled the drive unit at an identical, independent assembly station. Any necessary assistance and errors were documented during the process. It was explained to all participants in advance that screws only need to be tightened hand-tight so that this is not categorized as a source of error. The assembly began with the fixing of the cover plate with an M38 pan-head screw, followed by the assembly of the cable clamp with two cylinder-head screws. The holding clamp was then bolted to the wheel holder in the next step with the wheel drive using six bolts. The participants then fitted four guide rollers to the wheel holder using four pan-head screws. The grease was then applied to the pre-assembled bearing plate and retaining plate. In the next step, the bearing plate, wheel holder, and retaining plate were screwed together with six pan-head screws before the wheel was finally mounted with four cheese-head screws.

Once all the steps had been completed, the timing was stopped. On the second day of the test, all participants assembled the drive unit again - this time without the support of the HoloLens 2 or the assembly plan. The aim was to compare the learning behavior of the groups and to analyze the extent to which the use of the HoloLens 2 led to a more efficient way of working. Not only was there a direct comparison between the groups surveyed but also the individual progress of each participant between the first day of the test with aids and the second day without support.

4. Results

The field experiment results were analyzed using SPSS (Statistical Package for the Social Sciences). A total of 180 data sets were collected from 20 randomly assigned test subjects, divided into two groups (A and B). The study aimed to determine whether AR technology improves error rates and learning behavior in new processes and training. The hypotheses were tested using statistical methods.

H1: Group A requires fewer assistances on the first test day than Group B

The number of assistants was analyzed to assess whether the HoloLens 2 facilitates independent work. Group B required 14 more assistances than Group A, with a mean difference of 1.4 assistances. However, the Fisher's Exact Test yielded a p-value of 0.734, exceeding the 5% significance threshold. Thus, no statistically significant difference was found, and the null hypothesis was retained.

H2: Group A demonstrates better learning behavior than Group B

To evaluate retention, errors on the second test day were analyzed. Group B made an average of 0.3 more errors than Group A. However, the Fisher's Exact Test produced a p-value of 0.754, indicating no statistically significant difference in learning performance. Therefore, the null hypothesis is maintained.

H3: Group B completes the assembly process faster than Group A

To assess efficiency, the average assembly time was compared. Group A (with HoloLens 2) had a mean assembly time of 33.17 minutes, making them 9.12 minutes faster than Group B. The standard deviation analysis showed that Group A was, on average, 5.05 minutes faster. A Mann-Whitney U-Test yielded a p-value of 0.011, indicating a statistically significant difference in assembly time. Thus, Group A with the HoloLens 2 was significantly faster.

H4: Generation Z completes the assembly process faster than other generations

The data was analyzed to determine generational differences in efficiency. More than 50% of the participants belonged to Generation Z. A Kruskal-Wallis Test produced a p-value of 0.836, indicating no significant speed difference between generations.

H5: Technical affinity influences assembly speed

Participants rated their technical affinity on a scale from "very low" to "very high." 30% rated themselves as "high," while another 30% identified as "low" in technical affinity. A Spearman's Rank Correlation Coefficient Test resulted in a p-value of 5.4%, slightly above the significance threshold. Thus, no statistically significant correlation was found between technical affinity and assembly speed.

H6: Learning styles influence the number of assistances required

Participants were categorized according to Kolb's Learning Style Model. The Accommodating group (learning through trial and error) required the fewest assistances, whereas Divergent learners required the most. However, a Kruskal-Wallis Test produced a p-value of 0.749, meaning no statistically significant relationship was found between learning style and assistance needs.

5. Conclusion

The field experiment conducted in this study investigated the implementation of AR technology in prototype assembly to determine its impact on error rates and learning behavior in corporate training and new processes. The results provided valuable insights into the advantages and challenges of AR-based training.

The findings indicate that participants using the HoloLens 2 required less assistance than those without AR support. This is likely because they could analyze each work step in detail from multiple angles using the 3D model. However, initial difficulties in object manipulation (rotating, moving, scaling) were observed and mitigated by a two-minute familiarization phase. Furthermore, accommodating learners (learning through experimentation) appeared to benefit the most from AR-based instructions, requiring fewer assistances during assembly.

Another noteworthy observation was the high motivation among HoloLens 2 users, suggesting that AR technology can positively impact engagement. However, the direct relationship between motivation and learning outcomes was not analyzed and remains an open research question.

Finally, a larger sample size could enhance the statistical validity of future studies. However, the potential of AR technology in Industry 4.0 is undeniable. A strong emphasis on user-friendly programming will be key to maximizing its efficiency, a sentiment echoed by positive feedback from participants who worked with the HoloLens 2.

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