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EXPERIMENTAL WORK USING MICROSOFT HOLOLENS 2 TO IMPROVE MENTAL WORKLOAD AND TASK PERFORMANCE

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Abstract: The potential of Augmented Reality (AR) and Mixed Reality (MR) applications to enhance learning and comprehension of complex laboratory procedures is being explored in this study. The research investigates the effectiveness of MR and AR applications in conducting experiments on electro-pneumatic systems and assesses the cognitive workload involved. The experiment utilized Microsoft HoloLens 2 and tablets for the electro-pneumatic component. Participants were divided into three groups (A, B, and C) with 30 participants in each group to conduct paper-based instruction experiments, AR experiments, and MR experiments. The NASA Task Load Index was employed to evaluate the performance and effectiveness of MR and AR applications in the electro-pneumatic system experiments. The results indicated that 70% of participants preferred MR over AR due to its provision of clearer instructions with holographic guidelines. Furthermore, the interpretation of the NASA-Task Load Index (NASA-TLX) scores revealed that MR-based applications exhibited the lowest mean mental workload value compared to AR applications.

Key words: Mixed Reality (MR), Augmented Reality (AR), Mental Workload, NASA Task Load Index (NASA-TLX).

1. INTRODUCTION

In engineering education, lab experience is beneficial because it allows students to plan and run real experiments, which helps to develop their skills and abilities. However, students often have trouble with complicated lab equipment, which increases the amount of mental work they have to do, which leads to increasing time taken and error.

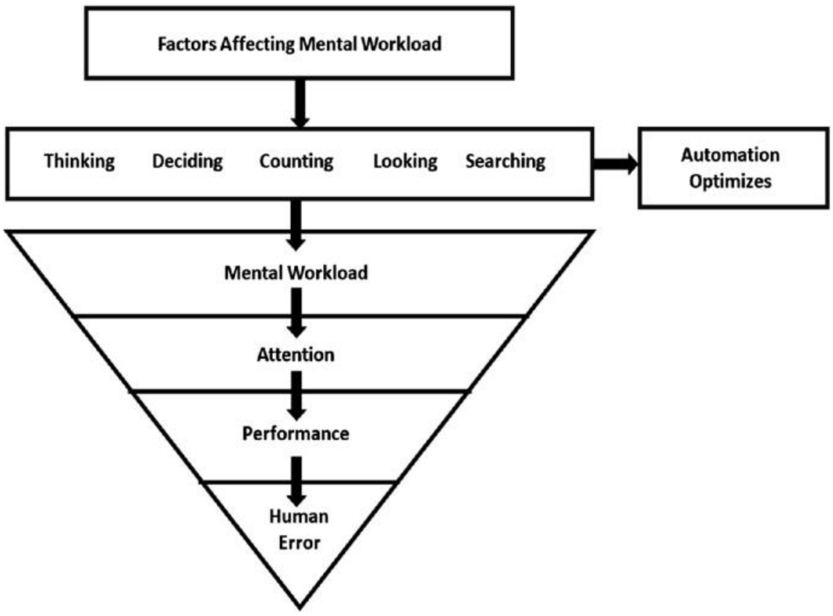


Fig. 1. Mental Workload framework, [1]

Reading and understanding written instructions can make it harder for workers to focus on the task at hand, [1] have developed a framework as Figure 1, to understand the relationship between factors affecting the mental workload, and how this affects the attention of the workers and their performance which then leads to human errors.
The extra mental workload of reading, understanding, and following instructions can also make workers tired, which can lead to mistakes, blunders, and accidents. In this case, AR and MR might be the solution for this problem.

1.1 Augmented Reality and Mixed Reality Application

The influences of the Industry 4.0 Revolution (IR 4.0) on human capital development and consumer behaviour has been identified by [2] which are shifting the work environment and the drivers for human capital development and consumer behaviour. [3] stated that augmented reality (AR) currently plays an important role to undertake the challenges in integrating technologies to expedite the march towards Industrial Revolution 4.0. Mixed reality (MR) environments contain a combination of real and virtual world information. MR can be utilized to visualize information, remote collaboration, human-machine interface, design tools as well education and training. [4] introduced the reality-virtuality continuum that defines mixed reality and identified a series of variations of technologically modified forms of reality that correspond to today's augmented and virtual reality technologies as Figure 2.

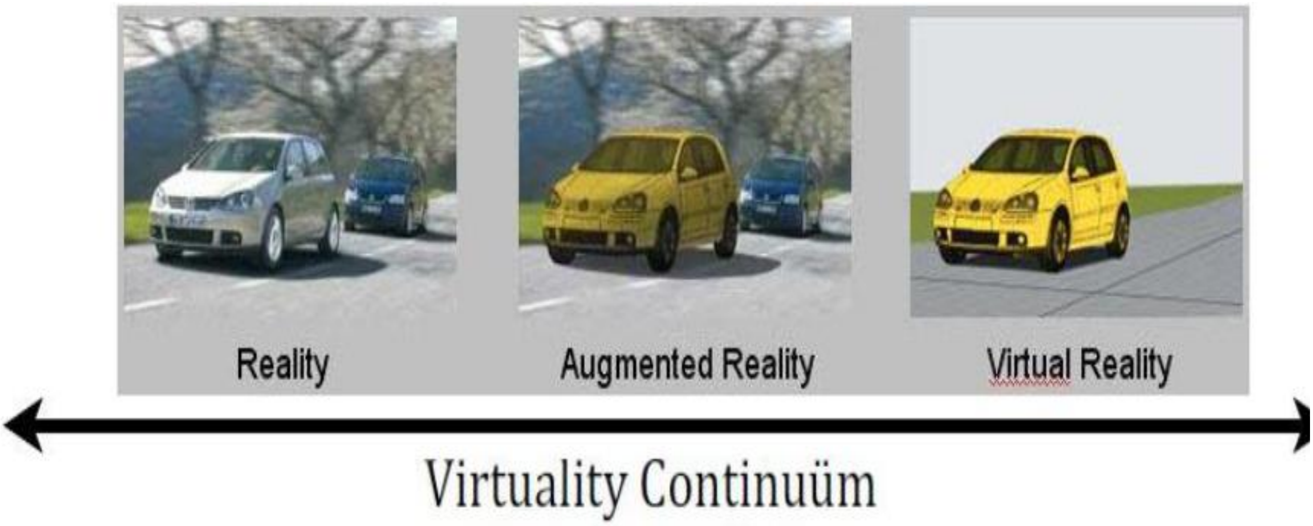


Fig. 2. A virtuality continuum, [4]

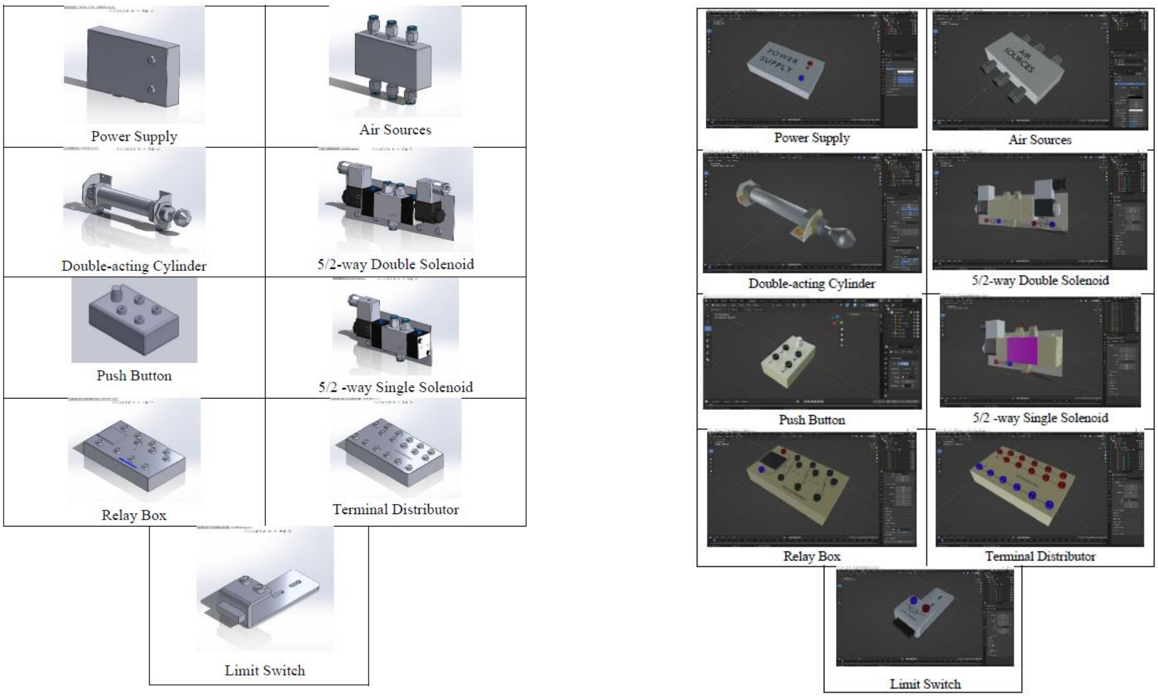
Study shows that AR and MR in the educational field can boost students' motivation, engagement, achievement, and capacity for critical thought, [5]. The goal of this project is to provide an alternate teaching strategy as a fresh approach to studying an experiment provided by the Department of Mechanical Engineering. Assisting engineers or printed instructions were often used in the experiments to advise pupils on how to carry out the steps. To build practical skills and reduce the knowledge gap between theory and practice, lab experiences are crucial to engineering education.

1.2 Background study

The primary goal of engineering education is to cultivate proficient engineers capable of operating machinery and tools. In the Department of Mechanical and Manufacturing Engineering at Universiti Putra Malaysia, before conducting experiments, students are provided with written instructions or a lab manual, classroom theory sessions, and tutor demonstrations. However, a survey revealed that 70% of final-year mechanical engineering students found the lab manuals to be unengaging and repetitive, as the content has remained unchanged for several years due to the standardized curriculum. This lack of interactivity and immersion in the lab guides has been noted by researchers, leading to difficulties in understanding procedures and increased errors. Consequently, this study aims to assess the effectiveness of Mixed Reality (MR) and Augmented Reality (AR) applications with holographic guidelines in comparison to traditional paper-based instructions for conducting pneumatic lab experiments. With the advancements in technology, MR has become more sophisticated and accessible, with tools such as the Microsoft HoloLens and AR programs like Pokémon Go and Snapchat filters being prime examples of MR technology.

2. MATERIALS AND METHODS

The development of the applications used several software which are Solid Work for 3D model to develop the electro-pneumatic components as Figure 3a, then animated to fbx extension using Blender 3.4. software as Figure 3b.



(a) (b)

Fig. 3. (a)The electro-pneumatic components illustrated in 3D model and (b) The electro-pneumatic components animated to fbx format

Once the 3D model is completed, a cross-platform game engine by Unity 3D was being used to develop the AR and MR application as Figure 4. Then, a Vuforia engine software was being used to transform the model to kit (SDK) and UI Toolkit were installed beforehand.

2.1 Build Application for AR and MR display

"Given its robust hardware and versatile features, the Samsung Galaxy Tab A8 serves as an exceptional platform for augmented reality (AR) experiences. In contrast, the Microsoft Hololens 2 utilizes specialized hardware as a Head Mounted Device (HMD) for Mixed Reality applications. Figure 5a depicts the AR application displayed on the tablet screen, while Figure 5b showcases the Microsoft Hololens 2 application display. Various User Interface (UI) objects were employed to guide user interactions and provide instructions. Scripts were compiled, scenes were rendered, and the file was subsequently exported to the smart glasses. The completed application was then tested by participants to validate its effectiveness."

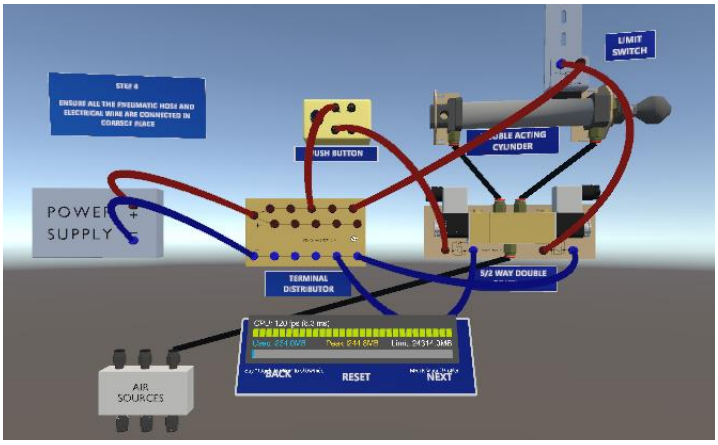


Fig. 4. The holographic pneumatic hose and electrical wires in Unity 3D

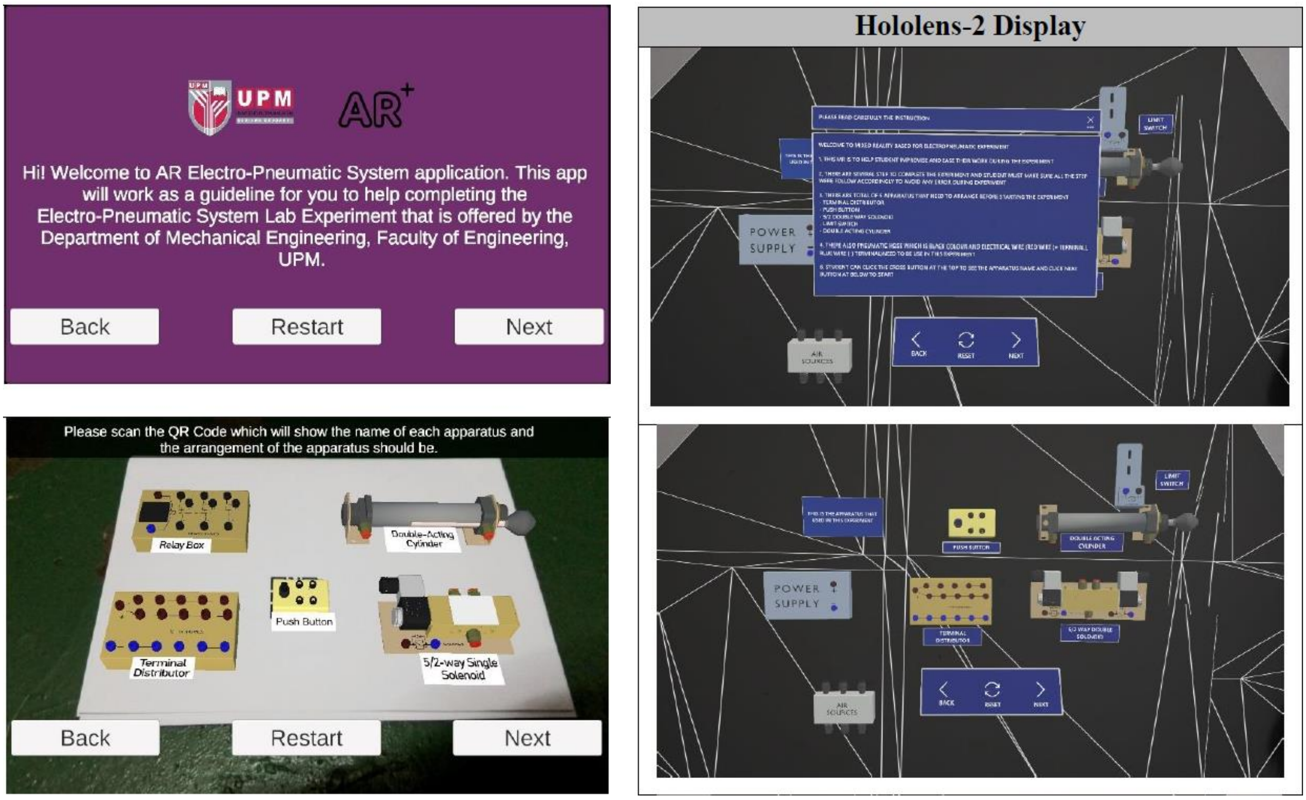


Fig. 5. (a) AR application display in TAB screen and (b) Mixed reality in Hololens-2 display

2.2 Experimental procedure

A cohort of 30 students from the mechanical department of Universiti Putra Malaysia was chosen to experiment on electro-pneumatics using paper-based, AR-based instructions, and MR-based instructions. Throughout the experiment, data on Time Completion Time (TCT) and error count were collected. Subsequently, the participants were asked to complete a survey and the NASA Task Load Index to provide feedback on their experience under the three experimental conditions. The participants were then divided equally into three groups to run the experiments based on the workflow as Figure 6 named Group A, Group B and Group C.

The experiment was conducted to test the participants in three ways which are solving the exercise using paper-based instruction, Augmented Reality (AR) based instruction and Mixed Reality (MR) based instruction. Three types of data were collected during the testing day which is Task Completion Time (TCT), error counts in completing the exercise and the number of hints used to complete the exercise to make a statistical analysis of the data collected. All three types of data collected in finishing the exercise were the variables recorded in this experiment to determine the effectiveness and task performance for MR-based, AR-based and paper-based instruction during experimenting [10]. A parametric test is required to determine whether the data either has a normal distribution or not. After that, a non-parametric test or a Mann-Whitey U test is required to test for the significance of the data. This is crucial to avoid any evidence of bias in all the data [11].

3. RESULTS AND DISCUSSION

The participants consist of 30 students, men and women from the Department of Mechanical and Manufacturing Engineering ranging from 20 to 27 years old. The mean and standard deviation of age is 22.97 and 1.35 respectively. Based on the Task Completion Time as Table 1, number of errors and number of hints. The data obtained was used to analyze and find potential significant differences between these three instructions.

Table 4.1. Data of Task Completion Time (TCT)

Groups	Mean	Variance	Standard Deviation
Mixed Reality-based instruction	6.0250	0.5216	0.7222

Augmented Reality-based instruction	5.3261	1.0244	1.0121
Paper-based instruction	7.1944	3.2719	1.8088

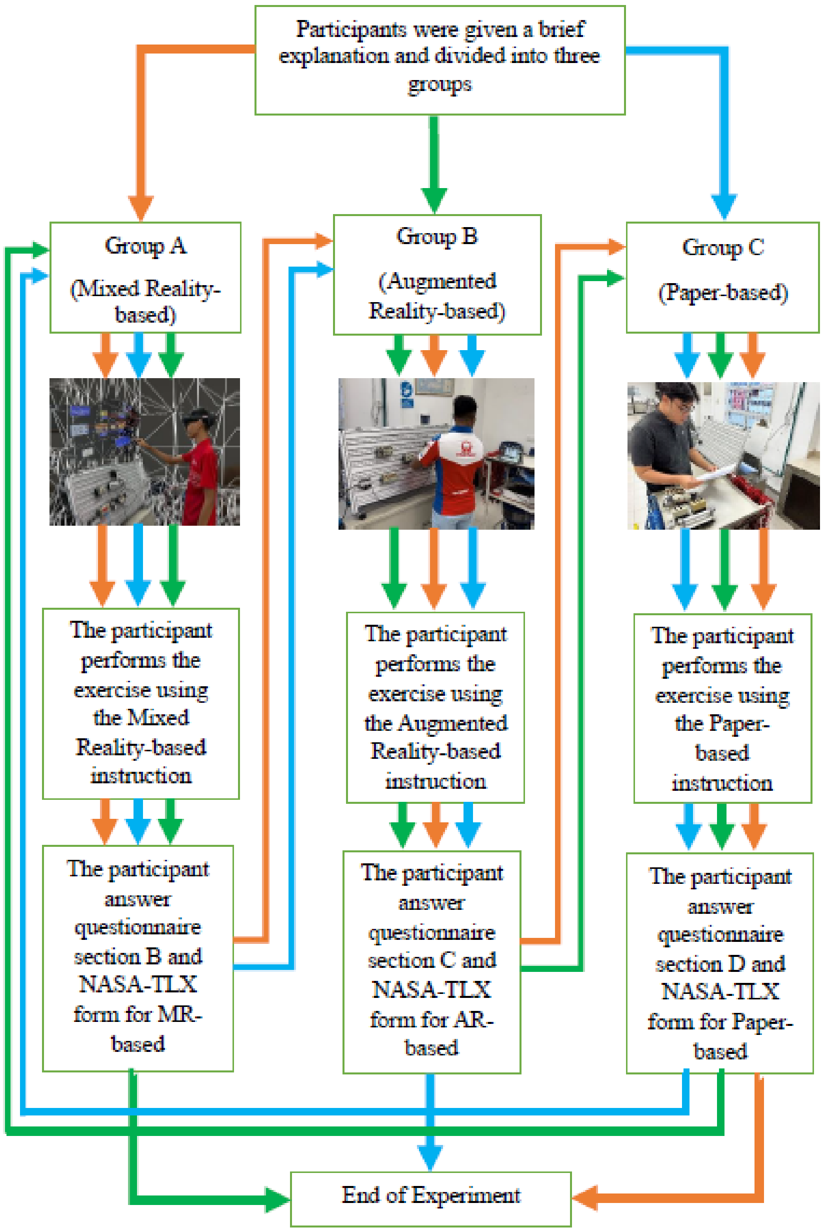


Fig. 6. Workflow of the experiment

A percentage of Improvement (POI) for mixed reality-based and augmented reality-based compared with paper-based instruction are calculated using the formula (1) and (2).

$$\text{Percentage of Improvement for AR} = \frac{\text{Score for AR Based Instruction} - \text{Score for Paper Based Instruction}}{\text{Score for Paper Based Instruction}} \times 100\% \quad (1)$$

$$\text{Percentage of Improvement for MR} = \frac{\text{Score for MR Based Instruction} - \text{Score for Paper Based Instruction}}{\text{Score for Paper Based Instruction}} \times 100\% \quad (2)$$

The data of the Percentage of Improvements (POI) for both MR and AR are represented in Table 2 below.

Table 2. The data of Percentage of Improvements (POI)

Data	Mixed Reality-based Instruction (%)	Augmented Reality-based Instruction (%)
Task Completion Time (TCT)	16.25	25.97
No. of Errors	92.31	61.54
No. of Hints	78.57	62.86

The Performance of Improvement (POI) data shows that the augmented reality-based method resulted in a 25.97% improvement in Total Completion Time (TCT), surpassing the 16.25% improvement seen with the mixed reality-based instruction. This outcome can be attributed to the participants' familiarity with mixed reality (MR) and augmented reality (AR) technologies. Both MR and AR methods led to a shorter TCT compared to the paper-based method. Additionally, the error count POI decreased to 92.31% for the mixed reality-based method, while it was 61.54% for the augmented reality-based method. This indicates that MR is more effective in helping participants complete the experiment with fewer errors compared to AR and paper-based instruction. Furthermore, the number of hints required decreased by 78.57% for the mixed reality-based method compared to the augmented reality-based method. This suggests that MR provides clearer instructions, leading to fewer requests for hints compared to AR and the paper-based method. Overall, these findings highlight the significant improvements and reductions achieved with the mixed reality-based method, positioning it as a reliable approach for conducting engineering experiments and enhancing task performance.

Throughout the experiment, participants' perceived mental workload was assessed using the six dimensions of the NASA-Task Load Index (NASA-TLX): mental demand, physical demand, temporal demand, effort, performance, and frustration level. Each dimension was evaluated using a 100-point Likert scale. The study compared the results of MR, AR, and paper-based instructions for each dimension as participants completed the task using these three methods. Since the data are on an ordinal scale, a one-way ANOVA was employed to analyze the significant differences between the three methods. Figure 7 and Table 3 show the results of mean score for each dimension of NASA-TLX for three methods, mixed reality-based, augmented reality-based and paper-based instructions.

Table 3. Results mean score of NASA-TLX 6-dimensions questions

Method/ Dimensions	Mental	Physical	Temporal	Performance	Effort	Frustration
MR	102.50	68.33	68.33	57.33	95.00	25.00
AR	103.00	93.33	65.00	56.67	90.50	24.83
Paper	195.00	120.00	116.33	246.13	193.50	66.67

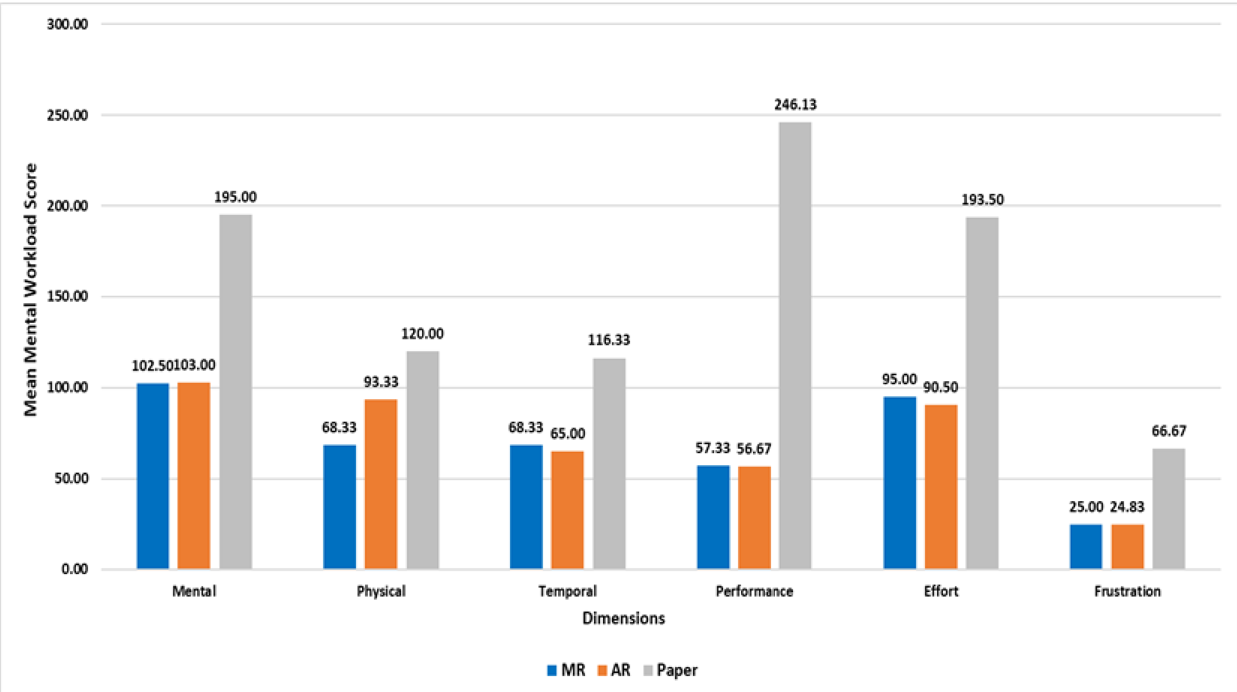


Fig. 7. The graph result of mean NASA-TLX 6-dimensions scores for each method

The overall rating of mental workload for each of the three methods used in this experiment will be determined by calculating the value of each dimension from the 6-dimension NASA-TLX questions and comparing it with the NASA-TLX interpretation score. The results indicate that participants experienced a higher mental workload when using the paper-based method, with an average score of 59.66. In contrast, the MR-based method had the lowest mental workload score at 27.77, followed by the AR-based method with an average score of 28.89. These findings align with the data from the 6-dimensions NASA-TLX questions, which showed that the paper-based method scored higher across all dimensions compared to the augmented reality-based methods. These results are depicted in Figure 8, which illustrates the overall rating of mental workload for the mixed reality-based, augmented reality-based, and paper-based methods.
For the TCT data, the mean time for the paper-based group is 7.1944 minutes, while the AR-based method has a mean of 5.3261 minutes and the MR-based method has a mean of 6.025 minutes. This data illustrates a decrease in the mean time taken by the AR-based method to complete the task. Regarding error counts, the mean number of errors for the paper-based and AR-based groups was 2.167 and 0.833, respectively, while the MR-based method had a mean of 0.167 errors. This data indicates a decrease in errors when using the MR-based method to complete the task. Lastly, in terms of the number of hints, the mean hints obtained for the paper-based and AR-based groups were 4.67 and 1.63, respectively, while the MR-based group had a mean of 1 hint. The MR-based method showed a reduction in the number of hints provided compared to the augmented reality-based and paper-based groups.

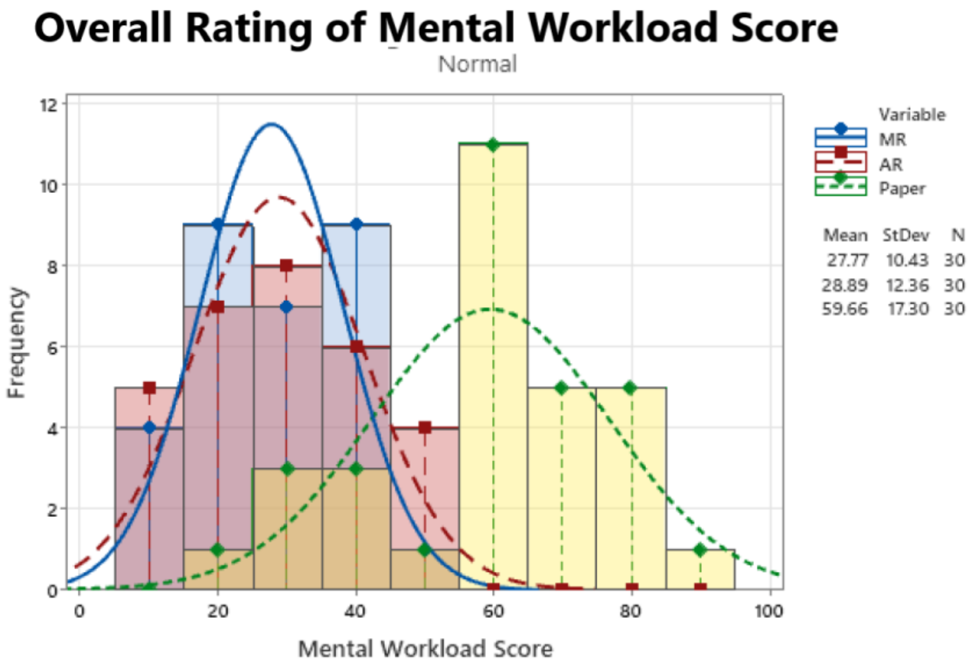


Fig. 8. Overall rating of mental workload

The Percentage of Improvement (POI) results reveal a 25.97% reduction in TCT for the AR-based group. In contrast, the MR-based method showed impressive reductions of 92.31% and 78.57% for the number of errors and number of hints, respectively. As for mental workload, the NASA-Task Load Index (NASA-TLX) interpretation score indicates that the MR-based approach has the lowest mean mental workload value at 27.77, classified as medium, followed by the AR-based method at 28.89, also within the medium level of mental workload. In contrast, the paper-based approach resulted in the highest mental workload, scoring 59.66, which denotes a high level of mental effort and concentration. This suggests that the paper-based method is more demanding and requires a significant amount of mental effort compared to the MR and AR-based methods, which are more manageable for the participants.

4. CONCLUSIONS

The use of Mixed Reality (MR) and Augmented Reality (AR) has a few implications for the society and environment. The use of Mixed Reality (AR) and Augmented Reality (MR) applications has reduced the use of electricity as the Electro-pneumatic system experiment consumed direct electricity. These technologies require less electricity consumption and also reduce the time taken for usage. Reducing electricity lowers the demand for fossil fuels, which in turn reduces atmospheric carbon dioxide levels. Augmented Reality (AR) and Mixed Reality (MR) have the potential for physical harm to society as the application might draw the user's attention away from their surroundings. This is because the user pays less attention to their environment and has less time to respond before an unforeseen incident occurs. Mixed Reality and Augmented Reality have the potential to revolutionise training programmes by producing immersive and interactive experiences. This technology can simulate real-world situations, allowing individuals to hone their abilities in a safe and controlled setting. By reducing cognitive load during training, students can focus more on acquiring and retaining information. The Sustainable Development Goal can be achieved by examining the challenges, possibilities, and advancements made in implementing Information and Communication Technology (ICT) in education, concentrating on AR and MR environments and their potential in the classroom.

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REFERENCES

1. Berlin, C., Adams, C. (2017). *Production Ergonomics: Designing Work Systems to Support*, Ubiquity Press, ISBN 9781911529132, 296.
2. Sima, V., Gheorghe, I. G., Subić, J., Nancu, D. (2020). *Influences of the industry 4.0 revolution on the Human capital development and consumer behavior: A systematic review*, Sustainability (Switzerland), 1210), 4035.
3. Abdul Rani, N., Abdul Aziz, F., Hairuddin, A. A., Ahmad, S. A., Hemdi, A. R. (2022). *Augmented reality: capabilities and challenges in machining industry aligned with industry 4.0,* Advances in Materials and Processing Technologies, 8(1).
4. Milgram, P., Kishino, F. (1994). *A taxonomy of mixed reality visual displays*. IEICE Transactions on Information Systems, E77-D(12), 2–3.
5. Kolecki, R., Pręgowska, A., Dąbrowa, J., Skuciński, J., Pulanecki, T., Walecki, P., van Dam, P. M., Dudek, D., Richter, P., Proniewska, K. (2022). *Assessment of the utility of Mixed Reality in medical education*, In Translational Research in Anatomy, 28(4). Elsevier GmbH.
6. Tuli, N., Singh, G., Mantri, A., & Sharma, S. (2022). *Augmented reality learning environment to aid engineering students in performing practical laboratory experiments in electronics engineering*, Smart Learning Environments, *9*(1), 26.
7. Yesmambetova, K. N. (2019). *Students' lack of interest: How to motivate them?* Universal Journal of Educational Research, 7(3), 797–802.
8. Verma, A., Purohit, P., Thornton, T., Lamsal, K. (2022). *An examination of skill requirements for augmented reality and virtual reality job advertisements*, Industry and Higher Education, 37(1), https://doi.org/10.1177/09504222221109104
9. Seeliger, A., Netland, T., Feuerriegel, S. (2022). *Augmented Reality for Machine Setups: Task Performance and Usability Evaluation in a Field Test*. Procedia CIRP, 107, 570–575.
10. Blattgerste, J., Strenge, B., Renner, P., Pfeiffer, T., Essig, K. (2017). *Comparing conventional and augmented reality instructions for manual assembly tasks*, ACM International Conference Proceeding Series, Part F128530, 75–82.

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