BOARD # 372: From Single-User to Multi-User Mixed Reality: How Collaborative MR Enhances Teamwork and Problem-Solving in STEM Education?

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Abstract

This study, funded by the **NSF RIEF and Ideas Lab programs under awards #2204919 and #2431980**, aims to advance collaboration during assembly tasks by utilizing Mixed Reality (MR) technology as a training tool for promoting teamwork and problem-solving among STEM students. In prior research, our team developed an immersive single-user MR training module for hydraulic grippers, which significantly enhanced STEM students' spatial visualization, technical abilities, diagnostic skills, and comprehensive perception. Building on these promising results, we upgraded the MR module to a multi-user experience to enable a collaborative environment for advancing teamwork and problem-solving capabilities. Thus, this study introduces the new design for the collaborative MR module and investigates the impact of collaboration within MR-shared settings on learning dynamics. The study involved 103 participants enrolled in a Fluid Power course, utilizing the new collaborative MR module to expose students to the design and assembly of a hydraulic bike. The collaborative MR environment synchronizes up to four MR headsets (HoloLens 2), allowing multiple users to collaborate within the same MR scene on shared assembly tasks. Team dynamics and collaboration survey is utilized to assess participants' collaborative problem-solving skills considering performance and teamwork.

Keywords: Collaborative MR, cognitive workload, assembly, multi-user, fluid power

1. Introduction

Collaboration and teamwork skills play a crucial role in students' success in STEM fields, as they enable the resolution of complex challenges and tasks across various disciplines [1]. The adaptation of collaborative learning environments has been shown to enhance student engagement and factual knowledge retention [2]. Thus, building the students' abilities to work effectively in diverse teams is essential for pursuing careers in STEM, allowing graduates to address the multifaceted challenges of the rapidly evolving technological world. To this end, educators have been adapting cutting-edge technological tools, particularly those in the realm of Extended Reality (XR) [3]. XR encompassing virtual reality (VR), augmented reality (AR), and mixed reality (MR), offer unique capabilities for enhancing collaborative learning experiences. For instance, VR immerses users in a completely computer-generated environment, allowing for highly interactive and engaging simulations [4]. AR, despite not being as fully immersive as VR, allows users to overlay virtual data onto the physical environment, merging the real world with virtual elements [5]. The state-of-the-art MR blends VR and AR, resulting in spaces where physical and digital objects coexist and interact seamlessly in real time [6]. Among these technologies, MR stands out for its potential as an engaging learning tool in STEM education [7]. This technology has demonstrated its capability to seamlessly integrate virtual objects into the physical environment, making it particularly suited for hands-on, team-based learning scenarios conducted in safe and controlled environments. In one of our previous studies, we developed an immersive single-user MR training module centered on the design and assembly of hydraulic grippers, which effectively enhanced STEM students' spatial visualization skills and technical abilities [8]. Building on these results, we have upgraded the module from a single-user to a multi-user to study the impact of MR on students' collaboration skills. Thus, this study introduces the upgradation from the single-user to the multi-user collaborative MR module, examining its impact on learning dynamics. It involves 103 participants enrolled in a Fluid Power course who utilized the new collaborative MR module to explore the design and assembly of a hydraulic bike.

2. Multi-User MR Module for Collaborative Experience

2.1. Upgrading from Single-User to Multi-User

Building on our previously tested and validated MR-single environment, which focused on enhancing students' spatial skills in STEM fields [8], this new synchronized MR-shared environment enhances the learning experience by transitioning from a single-user to a multi-user interface. It incorporates an MR multi-user module that replaces the hydraulically actuated gripper module with more complex tasks centered on the design and assembly of a hydraulic bike, enabling up to four users to communicate and collaborate with minimal latency. This upgrade involves synchronizing the Unity scenes to allow for real-time collaboration. The MR-shared environment is developed using Photon and Azure packages, as integrated into Unity, where C# scripts are customized, and setup is tested in Unity's Play Mode. Once validated, the environment is deployed to HoloLens 2 devices, leveraging their spatial mapping and hand-tracking capabilities to support collaborative learning in STEM education.

2.2. Module Capabilities

The MR module engages users in the design and assembly of a hydraulically actuated bike, a system selected for its complex mechanical and hydraulic components. The module consists of two sections (see **Error! Reference source not found.**): (1) **Tutorial Session** and (2) **Assembly Lab**, both of which support up to four users collaborating in a synchronized virtual environment.

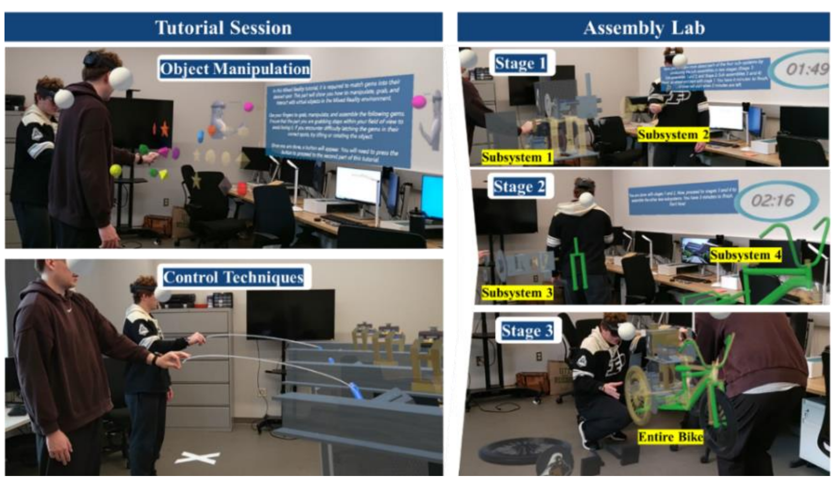

Figure 1. Tutorial session and assembly lab of the MR Module

The tutorial session aims to familiarize users with the MR-shared environment and its interaction techniques through two collaborative tasks: *Object Manipulation* and *Control Techniques*. Throughout the object manipulation tasks, users divided into teams are required to practice assembling virtual components, such as gems, using actions like grabbing, rotating, and scaling. Instructional aids, including gestures and voice commands, are incorporated to guide users in developing manipulation skills for subsequent tasks. During the second task, teams learn to operate virtual UI controls like sliders and joysticks for manipulating mechanical systems.

After the tutorial session, the teams are exposed to the assembly lab, which involves assembling a hydraulic bike through different tasks in three stages (Assembly Stage 1, Assembly Stage 2, and Assembly Stage 3), progressively increasing in complexity. During stage 1, the teams are required to assemble the first and second subsystems of the bike within a time frame of five minutes. A virtual avatar, timer, and visual aids are integrated to support the teams. Following stage 1, the team will be guided to stage 2, which is assembling subsystems 3 and 4 in four minutes. Stage 2 is considered more complex, demanding effective collaboration and precision. Finally, the teams will be guided to the third stage, which is assembling the entire bike in four minutes by integrating the subsystems and additional components, like wheels and cranks.

3. Research Study

The collaborative MR-shared environment is integrated into the MET 230: Fluid Power course syllabus as part of a research study. The study, approved by the institutional review board (IRB Approval Number: IRB-2024-1403), involves 103 enrolled students (6 females and 97 males).

3.1.Team Dynamics and Collaboration Survey

A survey on team dynamics and collaboration, adapted from [9], is utilized to evaluate various aspects of team functionality and interaction within the MR-shared environment. This survey comprises 42 questions that aim to assess critical dimensions of team performance, including task comprehension, role clarity, communication effectiveness, problem-solving, adaptability, and trust among team members.

3.2.Experimental Design

The 103 students were divided into seven lab sections of 15-16 students each, with each section requiring two hours. The MR module, which takes 25-30 minutes, was conducted in the MR-shared environment, allowing up to four synchronized users at a time. Due to the limited number of MR headsets, students form teams of two to three, and the study is conducted over two weeks in the lab. Each session was split into two group, with 8-9 students per group. During the first week, Group 1 participated in three experiments per session, while Group 2 completed the experiments in the second week. Before each experiment, team members were asked to complete a short demographic survey and then collaborated in the MR-shared environment to perform assigned tasks. After completing the MR module, participants filled out the post-surveys. After two weeks, the collected data was cleaned and prepared for analysis and evaluation.

3.3.Summary of Study Outcomes

The MR-shared environment is experienced by all the103 students; however, after data collection, 96 students fully completed the team dynamics and collaboration survey. The results of students’ responses to the survey are shown in Figure 2.

As shown in Figure 2, questions related to task understanding, such as **Q1 (My team has general ideas of specific team tasks)** and **Q3 (My team knows the relationship between various task components)**, consistently received high ratings, with the majority of students reporting “High” to “Very High”. This indicates that the MR-shared environment effectively enhanced the students’ shared understanding of task objectives and relationships between components. Additionally, questions addressing communication, such as **Q11 (My team communicates with other teammates)** and **Q28 (My team informs each other about**

different work issues), were similarly rated, reflecting the module's success in allowing for open and effective communication among team members.

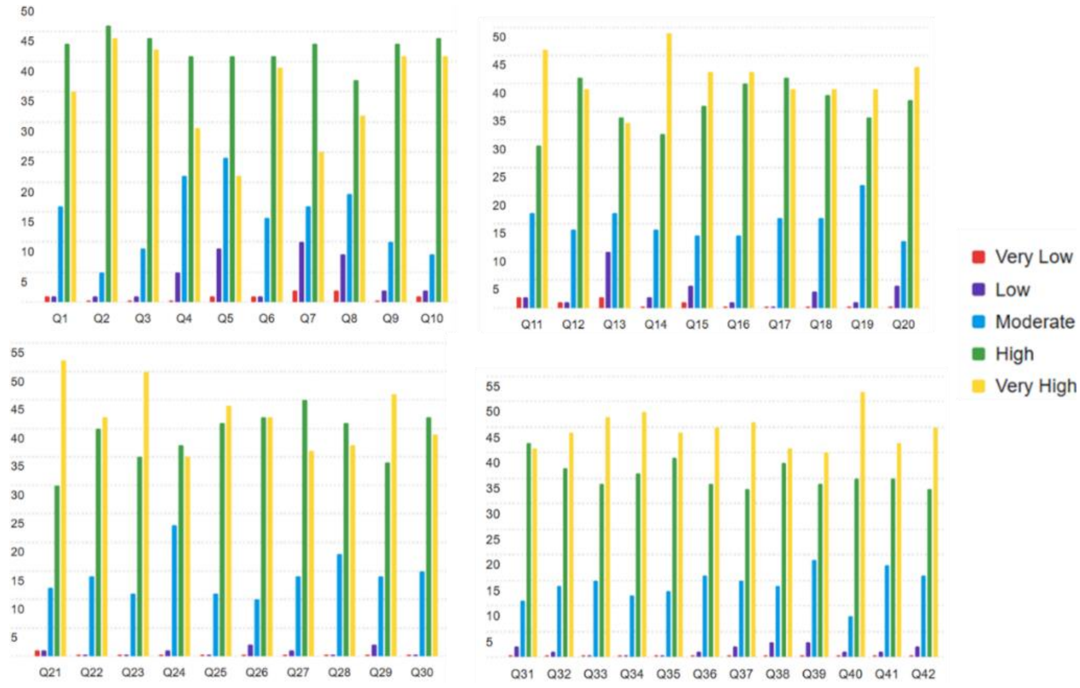

Figure 2. Results of the Students' Responses to the Team Dynamics and Collaboration Survey

Responses to **Q23 (My team is committed to the team goal) and Q29 (My team is likely to make a decision together)** demonstrated a strong sense of commitment and collaborative decision-making, as the majority of responses rated as "High" or "Very High". This shows that the MR module fostered a unified approach to achieving team objectives, enabling students to make collective decisions effectively. Other questions related to trust and the overall team atmosphere like **Q34 (There is an atmosphere of trust in my team)** and **Q40 (My team has a positive team climate),** received high ratings as well. The results further confirm that the MR-shared environment created a supportive and inclusive space where participants could collaborate confidently, contributing to a productive and positive team experience.

Questions centered on problem-solving and adaptability, such as **Q33 (My team solves problems that occur while doing various team tasks)** and **Q30 (My team can flexibly adapt to any role within the team)**, were also highly rated. These results indicate that the module promoted effective problem-solving skills, allowing team members to adapt to dynamic roles and collaboratively address challenges encountered during the tasks. Other questions like **Q38 (My team often utilizes different opinions for the sake of obtaining optimal outcomes)** reveal that the environment encouraged teams to leverage diverse perspectives. This collaborative approach allowed teams to achieve more effective outcomes. Although students' responses to most questions were positive, a few areas, such as **Q7 (My team discusses its goal and attains the agreement of teammates)** and **Q13 (My team defines its communication channels at the start of various team tasks)**, showed lower ratings compared to other questions. This reveals that the environment, despite supporting collaboration, requires some refinement with the goal of addressing aspects such as goal-setting discussions and predefined communication strategies to further enhance team coordination.

4. Conclusion

This study introduced a collaborative multi-user MR module, expanding on prior research by transitioning from single-user to multi-user MR environments. The goal was to examine how collaboration in MR impacts assembly tasks by fostering teamwork and problem-solving. Up to four users collaboratively designed and assembled a hydraulic bike in a shared MR setting. A team dynamics survey assessed the module's effectiveness, revealing improvements in collaboration and problem-solving. High ratings in trust, adaptability, and decision-making highlight its potential for training in assembly tasks.

5. Acknowledgement

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