DOI: 10.23977/trance.2024.060609
ISSN 2523-5818 Vol. 6 Num. 6

Integrating Mixed Reality into Graduate Education: A Case Study in Mechanical Assembly

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Keywords: Mixed Reality, Mechanical Assembly, Graduate Education, Case study

Abstract: Traditional instructional design in education is increasingly challenged by the widespread adoption of new media technologies, such as mixed reality. Wearable technologies are being embedded into mechanical engineering courses at Shanghai University of Science and Technology, and empirical research conducted with students participating in these courses has further verified and expanded upon previous findings, particularly regarding the impact on student motivation, learning, and organizational transformation. Our control experiment also identified the limitations of using HoloLens 2 in course design, highlighting the need to overcome these limitations in order to optimize the application of mixed reality-assisted manufacturing systems. This study also emphasizes the need for significant improvements in the integration of this system with manual processes to ensure that the technology's use is not limited to specialized users and early adopter student groups.

1. Introduction

The application of engineering creativity and innovation within the graduate education system is pivotal to ensuring the sustained prosperity of China's high-end equipment manufacturing industry, advancing the development of a comprehensive system for cultivating interdisciplinary engineering talent, and solidifying China's status as a global manufacturing powerhouse [1]. This system goes beyond equipping graduate students with mechanical engineering knowledge and skills; it emphasizes developing critical thinking abilities and fostering innovative talent, setting it apart from the objectives of undergraduate education.

Mixed Reality (MR), an immersive 3D digital technology, facilitates seamless integration between offline physical classrooms and online digital spaces, creating a novel, interactive "metaverse" teaching environment [2]. Looking at advancements in multimedia education technologies, MR has increasingly empowered computer-aided manufacturing approaches, evolving into a cutting-edge method for manufacturing skills training. Typically, after completing classroom instruction, in-class practical assessments conducted by lecturers often fail to accurately reflect the level of knowledge-to-practice transfer among graduate students. Supported by digital manufacturing scenarios presented in 3D models, MR can engage with students through tangible 3D process animations and multimodal inputs, such as gestures, eye tracking, and voice commands. This interaction stimulates students' latent creative thinking, while mitigating risks associated with direct supervision, such as cognitive overload [3] and limited problem-solving approaches.

2. Benefits of mixed reality in educational informatization

According to wearable device industry data disclosed by Forrester Consulting [4], the primary advantages of MR include skills training, remote team collaboration, classroom task visualization, and design and decision-making processes. MR enhances spatial reasoning for 3D modeling and situational judgment in manufacturing processes [5]. Compared to 2D CAD drawings, MR-based designs can convey over 20% more engineering information to graduate students. These advantages align directly with the demands of training in human-machine hybrid manufacturing technologies [6], as learning manufacturing knowledge requires graduate students to gain hands-on experience in physical part processing while deeply reflecting on theoretical manufacturing processes to develop innovative approaches. Recent studies, such as those by Eswaran et al. [7], have validated this premise. Their research indicates that AR/MR-assisted manufacturing systems enable lecturers to assess skill transfer among students, allowing the customization of learning content to address specific skill gaps. Similarly, Tian et al. [8] found that MR-based remote collaboration tasks improved the manual skill acquisition quality of local trainees through interactive 3D geometric animations. Further research by Wang [9], Chu [10], and Yan [11] into the scope of MR simulation applications in graduate education highlighted the widespread adoption of Microsoft's HoloLens 2, launched in 2018, particularly in aircraft maintenance. This device has demonstrated various advantages in graduate programs requiring the development of assembly skills and professional judgment. Additionally, MR avoids some negative effects associated with Virtual Reality (VR), such as nausea, headaches, or blurred vision caused by a lack of spatial awareness or complete VR immersion.

3. Method

3.1. Objectives of case study

We conducted an instrumental case study to explore graduate students' experiences with a proposed MR-assisted manufacturing teaching system (MRMTS) and to evaluate the potential implications of such an environment for mechanical engineering courses. The study focused on the following key questions:

1) What skills do graduate students acquire from the engineering information provided in the virtual-physical integration framework?

2) Does this exploratory knowledge prompting enhance their confidence and self-efficacy?

3) Do they perceive a transfer of technical knowledge from MR simulations to real-world classroom applications?

Particular attention was given to how the use of MR classroom environments fosters positive feedback on learning confidence and how the novel learning experiences compare with students' practical, hands-on activities.

3.2. Experimental Design

From the perspective of humanistic learning theory, we are particularly interested in how the Mixed Reality Manufacturing Teaching System (MRMTS) interprets and empathizes with students' learning difficulties and how it helps them self-motivate to unlock their skill-learning potential. The system continuously adapts to the professional backgrounds and learning experiences of its users, delivering engineering information tailored to the needs of new participants as they join the program. MRMTS allows participating graduate students to take on the role of an instructor in environments without active teaching intervention. They can analyze course challenges, manage their acquired skills, and edit subsequent course content independently. Each participant can reset the program and restart their learning process at any time. This flexibility enables them to revisit specific knowledge areas repeatedly until they feel satisfied with their skill transfer outcomes. Additionally, MRMTS operates silently and responds in real time when activated by voice commands. It functions similarly to a real classroom instructor by analyzing process-related issues, explaining complex concepts, and providing extended information.

An example of how MRMTS utilizes MR is its ability to convert 2D schematics of aircraft cable harness layouts into 3D digital animations displayed within a smart classroom. This allows students to "walk through" their designs at a 1:1 scale on actual terrain and infrastructure, as illustrated in Figure 1. This approach introduces students to the technical applications of the HoloLens 2 in aircraft final assembly manufacturing projects. As noted by Shahrabadi et al. [12], immersive engineering information like this can be applied to tasks such as spatial positioning of cable harnesses, installation path planning, and conflict detection in design. Unlike fully immersive VR experiences that lack real-world context, MR combines spatial representation with the physical world's context, offering an enriched learning environment for graduate education. This integration of virtual and physical settings is a key advantage, providing students with a more expansive and practical learning space.

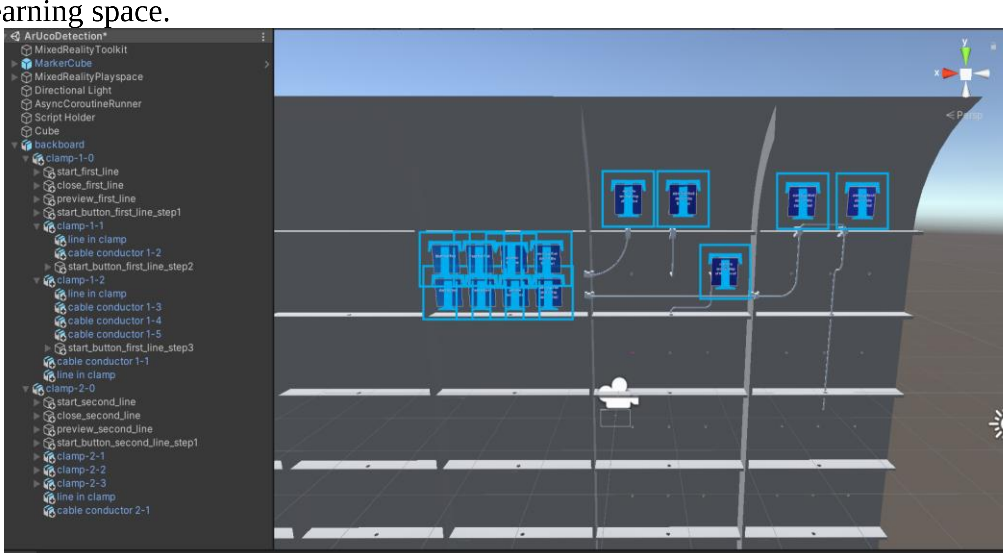

Figure 1: Visual cues for aircraft cable harness assembly.

Our case study conducted a survey using quantitative data collection methods, targeting 50 first-year master's students enrolled in the Mechanical Engineering program at the University of Shanghai for Science and Technology. HoloLens headsets were utilized during a “Augmented Reality-Assisted Manufacturing Technology” course taught in the first semester of 2023 (September to December). Feedback on the impact of mixed reality on their learning of manufacturing skills was collected using the online survey tool "Questionnaire Star." Data were gathered at the end of each tutorial session, with responses submitted voluntarily and recorded anonymously. Participants were asked to rate their perceptions of the HoloLens experience on a 7-point Likert scale, ranging from 1 (no change) to 7 (strongly agree). An example of the questions rated by students is presented in Table 1.

Table 1: Online survey questions aligned with LOES-S [13].

Category	Online survey question wording with 7-point Likert scale response
Learning	• Has MRMTS improved your understanding of the aircraft cable harness assembly process? • Do you think that participating in the aircraft assembly process course under the guidance of MRMTS helps prepare you to deepen your understanding of the concept of tooling intelligent transformation?
Design	• At the beginning of the course, how comfortable were you with using HoloLens 2 device and viewing 3D model animations of cable harnesses?
Engagement	• Did MRMTS increase your interest or motivation in learning more about the subject?

At the end of the survey, an open-ended question was included to collect qualitative data. This study provides baseline data on first-year students' experiences and plans to continue the investigation throughout their second year of coursework. As an educational technologist supporting graduate advisors in using MR technology, the first author recorded field notes (observational content). During the course tutorials, students used the HoloLens 2 to interact with a 3D model of an aircraft cable harness. Two classroom activities were arranged: one conducted in a laboratory and another in a classroom setting, both focusing on the same topic. Students performed virtual simulations of cable installation positions and harness routing paths. The engineering information provided by MRMTS (3D models/animations) could be hidden, scaled, moved, or manipulated via a virtual menu by the students. The information could be displayed at a 1:1 scale or larger dimensions (see Figure 2).

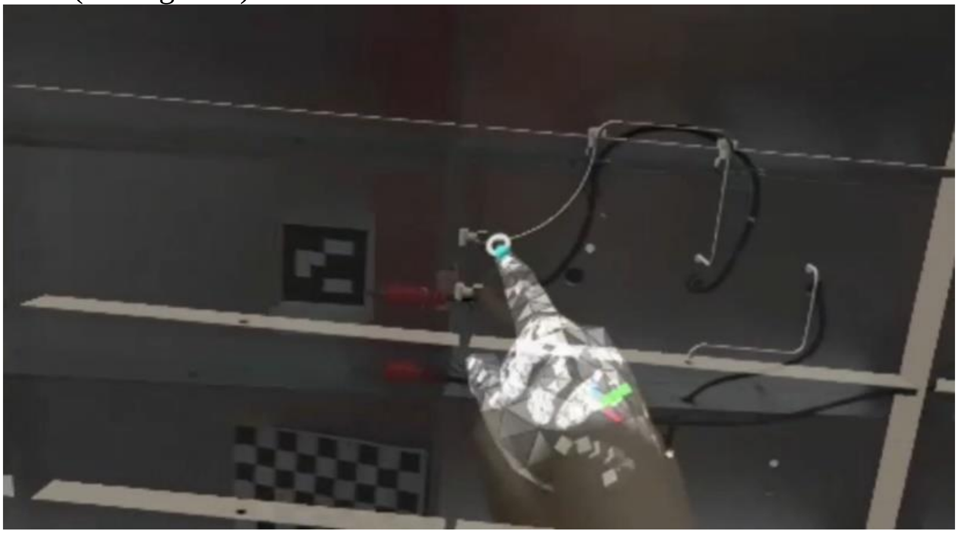

Figure 2: 3D Model Animations of Aircraft Cable Harnesses.

4. Result and discussion

4.1. Comparative experiment test

During the learning process using MR, it was observed that 58% of course learners, while wearing the HoloLens 2 headset, exhibited what is called "innovative craftsmanship attempts." This usually occurs when they see abstract or two-dimensional cable harness design drawings being spatially displayed or presented with a sense of presence. Our team grouped participants based on their technical background as graduate students and observed statistically significant differences through a control experiment. Research-oriented graduate students have a relatively longer learning curve in becoming familiar with the headset, but subsequently, they often exhibit stronger feelings or effects toward using the technology, such as increased motivation or interest in learning advanced manufacturing processes for aviation. On the other hand, teaching-oriented graduate students adapt to the use of the headset more quickly and rapidly shift to exploring manual assembly content and UI menu interaction options. This suggests that participants' digital literacy could be an important dimension in measuring graduate students' acceptance or engagement with MR experiences.

Furthermore, 47 independent online surveys were considered valid (3 surveys with conflicting answers were removed). Among them, 61.7% of students strongly agreed that MRMTS enhanced their understanding of aircraft assembly processes, while 17% of graduate students reported no or only slight changes. The students were then asked whether the course increased their interest or motivation in learning the subject; 72% of participants strongly agreed, while 14% indicated that their motivation had not changed or only slightly changed. All graduate students indicated that the course was relevant to them, and 67% strongly agreed that MRMTS would be helpful for their future creative work, although no specific application scenarios of the technology in their future career development were provided or described. Before using the equipment, participants watched an introductory task video; 61% of students felt comfortable or very comfortable, while 15% still felt uncomfortable or slightly uncomfortable, or did not receive sufficient support during equipment use. The remaining students held a neutral stance.

4.2. Collaborative aspect of course design

Introducing mixed reality into graduate-level courses provides an opportunity to achieve strategic goals by bringing significant transformations to the learning environment and format, as well as the content, helping students transition from knowledge receivers to knowledge experiencers and creators. MRMTS offers all graduate students the ability to create new mixed reality scenarios, with these interactive tools being deliverable in both campus classrooms and real manufacturing site environments. This decouples teaching practices from specific classrooms or laboratories and opens up the potential to reduce reliance on electronic instructional documents as student resources. However, further integration of these independent learning experiences is needed to ensure that access to the technology itself does not distract from the skill learning experience. Furthermore, introducing mixed reality in the process of learning manufacturing skills provides broader collaborative opportunities for course delivery, ensuring consistency in teaching quality. One of the core goals of the research team is to provide all graduate students enrolled in the course with fair and consistent outcomes, becoming providers of teaching resources driven by innovation, collaboration, and teaching excellence. This opens up new opportunities for innovative iterations in course design.

4.3. Data security in course design

Experimental data indicates that mixed reality has a positive impact on graduate student engagement, but there are still some technical limitations or constraints that must be overcome for broader adoption of MR as a new skill-learning enhancement method. The process from picking up the hardware to accessing 3D craft content needs to be designed more smoothly to allow users to focus more on the course content. As part of the Microsoft product suite, the HoloLens 2 headset easily connects to Shanghai University of Science and Technology's Azure AD and business intelligence applications, providing a comprehensive technical platform for establishing course practice projects related to craft knowledge both on and off campus. Additionally, we are developing learning content for the full functionality of MRMTS. However, some of the features of the HoloLens 2, such as portability, flexibility, and independent wearable computing, may conflict with campus security policies and control measures. The challenge for educational environments lies in how to seamlessly integrate the innovation and personalization capabilities of MR platforms (like HoloLens 2) into the campus network, which can also create content.

5. Conclusions

The continuous development of MR in education, as well as the redefinition of the roles of augmented reality and mixed reality in course design, needs to be reexamined. There is an opportunity to integrate MR into more specialized and practice-oriented learning, as well as into the learning continuum of learners. In MRMTS, student motivation and engagement have been significantly enhanced, and this paper focuses on how HoloLens 2 improves students' skill transfer capabilities in course design. Moreover, the MR experience has brought significant changes to students' learning methods, locations, and formats, shifting from simple knowledge acquisition to higher-level autonomous assessment. Considering that not only students benefit but also organizations require commitment in the design, integration, and implementation process, the priority of this research should be to determine the extent to which MR contributes to students' experimental skills development. The findings of this study can assist mechanical engineering course designers in deciding when to incorporate MR experiences into certain aspects of the curriculum and support educators in their decision-making when considering new skill training methods for campus and foundational research learning.

Acknowledgements

This project is supported by the Ministry of Education of the People's Republic of China Higher Education Division Industry-University Cooperation Collaborative Education Program (Grant No. 230900487263953), the Shanghai Education Commission's "2023 Shanghai University Youth Teacher Development Funding Program" (Grant No. 10-24-304-006), the Shanghai University of Science and Technology Graduate English-taught Course Development Program (Grant No. EC202409), and the Shanghai University of Science and Technology Integrated Undergraduate and Graduate Course Development Program (Grant No. BY202405). Additionally, we would like to thank the graduate students in Mechanical Engineering at Shanghai University of Science and Technology for their participation in this MRMTS research.

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