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Comparing Avatar and Face-to-Face Collaboration in VR Education: Concept and Preliminary Insights

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***Abstract*—Virtual education is gaining prominence, providing opportunities for dynamic interactive content, such as Digital Twins, and novel collaboration modalities, including options for remote classrooms. In this work, we present a concept that leverages Digital Twins for interactive group work in engineering education through the use of Virtual Reality technology. We propose an experimental investigation to compare diverse collaboration alternatives facilitated by Virtual Reality, specifically face-to-face and avatar-based interaction. Preliminary findings are discussed, along with their implications for the design and implementation of future experiments in this emerging field.**

***Index Terms*—collaboration, digital twins, education, virtual reality**

I. INTRODUCTION

The key fields Industry 4.0 and Internet of Things (IoT) have been significantly growing in recent years, with the Digital Twin (DT) playing an increasingly important role [1]. This not only affects the industrial environment, but also how people can interact and communicate with each other using these technologies [2]. In consequence, the importance of immersive technologies such as Virtual Reality (VR) are becoming increasingly popular. Emerged from the the gaming sector, gamification and its symbiosis with VR technologies receives growing interest and adoption in the engineering and education domains [3], [2], [4]. Within these domains, one key advantage of immersive technologies is the possibility to experience and get in touch with complex topics in a virtual space. For instance, students can get a real impression of industrial plants or explore scientific phenomena like magnetic fields. In some cases, physical access for larger student groups is not possible or restricted at all for facilities located in inaccessible or dangerous areas. Here, immersive technologies offer possibilities to make education more accessible by providing digital representations of physical assets – Digital Twins – with which students can interact naturally and make real-time experiences within a virtual environment. At last, since the COVID-19 pandemic and the associated social distancing rules, it has become clear that educational content should also be virtually available for students. Therefore, the two technologies, VR and DTs, complement each other perfectly: visualization and interaction can be realized in virtual space through VR and mirrored on physical content through the DT system. In this work, we want to outline a coalescence between DT and VR technologies and demonstrate how they can be applied in the educational context. The challenge here is to consider and realize the most various aspects: from the technical obstacles of VR technology through the avatar and interaction design and finally a user-friendly introduction of this technology to students and educators.

In the last years, a significant increase in the popularity of Collaborative Virtual Environments (CVEs) such as the Metaverse or Omniverse can be observed [5], [6], [7]. In CVEs, avatars represent the human collaborators and help to address the loss of the physical body, allowing them to interact with the virtual environment and with each other's avatars [8]. To approximate a natural interaction between the collaborators, as in face-to-face meetings, it is necessary to research avatar-to-avatar interaction in CVEs. In this context, we strive to address the following research questions in our experiments: *How well does avatar-to-avatar group work perform compared to face-to-face group work in Collaborative Virtual Environments? Which factors can improve the performance of avatar-to-avatar collaboration in remote or asynchronous education?*

This paper introduces our concept for studying VR-assisted education, specifically group work with Digital Twins (DTs), comparing face-to-face and avatar-to-avatar collaboration. Our goal is to provide insights for the design of VR education. The related work is summarized in section II, followed by section III presenting our concept and prototype implementation. For validation, the prototype was used in a pre-study as described in section IV. The preliminary results are summarized in section V and discussed in VI further presenting the limitations. Finally, the conclusion is drawn in section VII.

II. RELATED WORK

Various alternative solutions to traditional teaching methods are offered due to the technological revolution supported by Digital Twins and the possibility of entering a true-to-scale world through VR technology, in which the user can navigate as a virtual model in a (nearly) humanoid or abstract form [9]. In 2002, Michael Grieves coined the concept of DTs and laid the foundation for one of the most important technologies for obtaining the optimum processes for production companies. This involves a dual data communication between the physical and digital space. As [10] has shown, there are different definitions and concepts of DTs, in this case the DT is an exact virtual dynamic image of exactly one physical representation [1], [11]. Oda et al. utilizes a DT to remotely guide an on-site worker through maintenance steps of a physical machine [12]. However, the application of DT systems is not limited to the industrial environment. Lehmann et al. [13] demonstrated that such cyber-physical systems can also be used in a scientific context to organize research data. Furthermore, these technological approaches can also be used for knowledge transfer for students and teachers to their advantage. When combined with a virtual learning environment, DTs can be interacted with in real-time via the bidirectional communication interface between the physical and digital space and, with the help of VR technology, create intelligent interactive classrooms [14], [2], [6], [15]. Due to the architectural structure of the DTs, they offer different interfaces for joint collaboration between humans and machines, for which VR systems such as Cave Automatic Virtual Environment (CAVE), Powerwall, or Head-Mounted-Displays (HMDs) are required. Virtual Reality means trying to completely integrate a human in a computerized interactive world and to stimulate several senses (e.g. visual, auditive, haptic, and so on) with suitable actuators in order to create a highly immersive experience [16], [17].

In terms of collaboration, VR systems such as CAVE or Powerwall are different from HMDs. While CAVEs and Powerwalls offer an in-person VR group experience with the possibility for face-to-face collaboration, HMDs isolate the users from their real environment. As a consequence, HMD users do not see other collaborators, even if being in the same room. Thus, for group experiences, HMD users have to be visualized by avatars within the virtual environment, replacing face-to-face collaboration with avatar-to-avatar interaction. Avatar-based collaboration can lead to a shift of emotional awareness and affect the collaboration [18]. Thus, there are efforts to improve the expressiveness of avatars and support high fidelity non-verbal expressions by tracking body movements of the users, hand gestures and facial expressions [19]. Kruzic et al. investigate how avatars affect the conversational outcome in VR and show that facial expressions have a greater impact on virtual conversations than body movements [20]. How avatars can affect group performance in CVEs has been researched by Greiner et al. [18]. VR collaboration seem to benefit from visualizing avatars and achieve similar results as face-to-face collaboration in terms of completion time of the tasks. Furthermore, between avatars a higher cooperativeness was observed, as well as a lower need for additional communication [18].

The current research is limited to small group sizes, with experiments showing collaboration between two participants. In our education use cases, a collaboration of larger student groups is required, with at least three but preferably more participants. Furthermore, we want to focus on effective group work with the DT in co-local and remote class scenarios.

III. CONCEPT AND IMPLEMENTATION

As a measure to improve our engineering lectures, participants get the opportunity to experience and work with Digital Twins in interactive group work sessions. According to Guc et al. [15] and Sala et al. [21] the students should get a better understanding of DTs and improve their skills utilizing it. To enable interaction with the DT while keeping the human-to-human interaction as natural as possible, a CVE is to be created using VR technology. Within the CVE students can interact with the virtual scene, including the DT, while still being able to communicate and interact with each other to solve group tasks. There are several design options for collaborative work to be considered, in the time, space [22] and Extended Reality dimension [23]. With a focus on synchronous collaboration with VR, we aim to research the differences between face-to-face (*f2f*) collaboration, limited to co-located group work, and avatar-to-avatar (*a2a*) collaboration, which allows remote group work. Therefore, a VR environment will be implemented to compare the *f2f* and *a2a* modalities as depicted in Figure 1.

In the *f2f* modality, large immersive screen setups will be used to run the CVE. There, the students can meet in person within a shared space and interact with the DT through the VR system. Although, only one person is able to interact with the virtual environment at the same time.

In the *a2a* modality, the students wear VR HMDs, isolating them from the real environment. Since the students can not see and hear each other, we use this modality to study remote collaboration setups, where other participants are visualized by 3D avatars. In this work, we present our concept to address the research questions stated in section I and the results of a pre-study to validate our VR prototype and test the experiment design. The results of the pre-study will be used to improve our future experiments. For simplicity, the *f2f* condition is implemented with a stereoscopic VR wall system (Powerwall) instead of a CAVE in the pre-study. To evaluate, the group

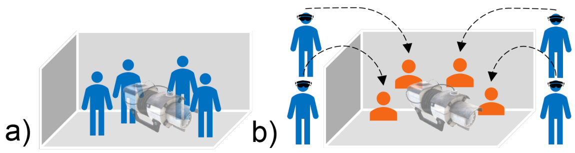

Fig. 1. VR collaboration with a Digital Twin: a) Face-to-face collaboration in a CAVE system between in-person participants. b) Avatar-to-avatar collaboration in a VR environment between distant participants wearing HMDs.

work modalities, the CAVE system will be used in future experiments since it is more immersive.

The pre-study is based on ViewR, a state-of-the-art Virtual Reality software for the industry from CMC Engineers GmbH, which supports multi-display VR systems operated on a single node, but also different HMDs such as Oculus Quest or Varjo XR-3. The software supports the Unity game engine which was used to create the 3D environment, as visualized in Figure 2, and to integrate the DT infrastructure. The VR setup for ViewR consists of a 6x2m passive stereo powerwall and a VR-enabled computer. Within the VR scene, users are represented by avatars, visualized by 3D geometry for head and hands. For interaction and navigation within the VR scene, HTC Vive 2.0 controllers were used in Powerwall and HMD setups.

IV. VALIDATION

The primary objective of the experimental study is to evaluate the effectiveness of the VR collaboration in education, specifically comparing *f2f* and *a2a* modalities. This comparison is essential for advancing our understanding of the dynamics inherent to collaboration within immersive environments. To substantiate this claim, a preliminary study was designed and executed, which serves as a prelude to more extensive studies in this domain. The methodology and findings of these experiments are described in the subsequent sections.

All participants are studying the Master's programme *Engineering and Management* and take part in *Digital Business Technologies* at Mannheim University of Applied Sciences. It is a heterogeneous group with different backgrounds in electrical engineering, computer science, information technology and economics. Prior to the experiments, an introduction to digital transformation and how it can be realized as a business idea took place as part of the lecture, where definitions and terms were explained related to DTs. During the experiment, the participants were free to split into two groups and informed that the following three different tasks would not be evaluated. One group worked with HTC Vive HMDs to evaluate the *a2a* condition, while the other group worked with a Powerwall to assess the *f2f* condition.

During the experiments, participants had to work on three tasks, which were addressing the topic of DT differently and helped to evaluate how well the students could comprehend the topic. Therefore, a physical measuring station (PM) unit was used, which can measure time, temperature, CO_2 and humidity was provided, as well as a DT of the measuring station (DTM) which could be interacted with in VR.

TABLE I
NASA TLX AND SUS RESULTS FOR THE *a2a* AND *f2f* CONDITIONS
(*STATISTICALLY SIGNIFICANT DIFFERENCE)

Category/Item	**f2f Mean ± SD**	**a2a Mean ± SD**	**p-value**
NASA TLX Scores			
Mental Demand	5.15 ± 1.52	6.25 ± 1.71	0.12
Physical Demand	3.0 ± 1.96	4.5 ± 1.91	0.1
Temporal Demand	4.23 ± 2.8	5.75 ± 3.4	0.19
Performance	6.0 ± 2.0	8.0 ± 1.41	0.04*
Effort	4.92 ± 1.5	5.5 ± 1.29	0.25
Frustration	3.92 ± 2.1	2.25 ± 0.96	0.07
SUS Scores			
SUS Score	55.31 ± 18.67	66.5 ± 14.25	0.06

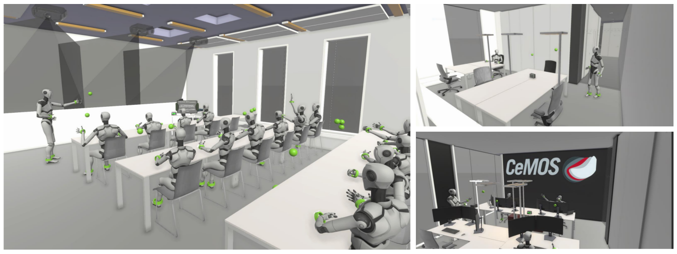

Fig. 2. Different views on the VR environment where the study participants had to interactively complete the group tasks.

The first two tasks took place in VR, while the last task provided creative freedom in which the students could freely decide to utilize VR and the DT or not. The first task aimed to teach the students the interplay between DT and VR. Therefore, they had to interact with the PM as well as with the DTM to solve the tasks. One interaction was to turn on and off the display light of the PM, which was only possible by interacting with the DTM. For comprehension assessment, the students were asked to identify and write down the differences between the PM and its DT and to argument whether the DTM is an ideal DT. In the next exercise, the participants were asked to develop a cost-efficient concept of monitoring the temperature and CO_2 using VR. Eight additional virtual twin models were available on demand, which could be distributed. In the final task, the groups had to design a rough business model for the DT as a Service use case.

V. PRELIMINARY RESULTS

This pre-study collected qualitative feedback from 17 students (5 females, ages 21-34), 50% of whom were casual computer gamers and 52.9% VR novices. Feedback, collected via post-experiment questionnaires (including the System Usability Scale (SUS), NASA Task Load Index (TLX), and a custom questionnaire), will guide the refinement of our implementation. Both modalities demonstrated marginal usability, with SUS scores below 70. The cognitive workload was reported higher for the *a2a* group, although it was perceived as offering better performance and lower frustration as depicted in Figure 3. In the custom questionnaire 28 criteria were defined to assess the six categories (*Engagement*, *Verbal Communication*, *Satisfaction*, *Ray-Tool*, *Sketch-Tool*, and *Digital Twin*) using a 5-point Likert-scale. Statistical analysis was performed using t-tests, employing Welch's test for significant variance differences and the independent samples t-test otherwise. The results are summarized in Tables I and II.

VI. DISCUSSION AND LIMITATIONS

Overall, the a2a modality performed slightly better in all categories of the custom questionnaire, except for the *Ray-Tool*. Especially the *Engagement* and *Verbal Communication* were perceived well by the participants in both modalities.

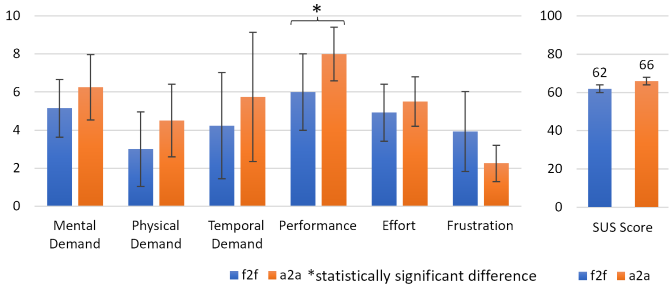

Fig. 3. NASA TLX results and total SUS Score by modalities.

TABLE II
CUSTOM QUESTIONNAIRE RESULTS FOR THE *a2a* AND *f2f* CONDITIONS
(*STATISTICALLY SIGNIFICANT DIFFERENCE)

Criteria	**f2f** $M \pm SD$	**a2a** $M \pm SD$	p**-value**
Engagement	**4.21 ± 0.56**	**4.69 ± 0.38**	**0.07**
Group Participation	4.08 ± 0.95	4.5 ± 1.0	0.23
Individual Participation	4.15 ± 0.8	4.75 ± 0.5	0.09
Inclusion in Group	4.23 ± 1.3	4.75 ± 0.5	0.23
Recognition by Group	4.38 ± 1.12	4.75 ± 0.5	0.27
Verbal Communication	**3.82 ± 0.46**	**4.25 ± 0.17**	**0.05**
Ease of Communication	4.54 ± 0.52	4.75 ± 0.52	0.25
Discussion Dynamics	3.69 ± 0.95	4.0 ± 0	0.27
Focus on Solution	3.23 ± 0.44	4.0 ± 0	0.002^{*}
Satisfaction	**3.48 ± 0.47**	**3.89 ± 0.09**	**0.005^{*}**
Group Interaction	4.15 ± 0.38	4.25 ± 0.5	0.34
Individual Performance	3.69 ± 0.75	4.25 ± 0.5	0.09
Team Performance	3.85 ± 0.55	4.75 ± 0.5	0.005^{*}
Solution Quality	3.69 ± 0.48	4.25 ± 0.5	0.03^{*}
VR Technology	3.15 ± 1.07	4.0 ± 0	0.007^{*}
VR Environment	3.15 ± 1.28	4.0 ± 0	0.17
Task Difficulty	3.0 ± 1.15	3.75 ± 0.5	0.12
Given Time	3.13 ± 0.95	2.75 ± 0.96	0.16
Provided Information	3.31 ± 0.85	3.0 ± 0.82	0.27
Ray-Tool	**3.58 ± 0.47**	**3.13 ± 0.32**	**0.05**
Group Usage	4.15 ± 0.69	3.5 ± 0.58	0.05
Individual Usage	3.23 ± 0.93	3.5 ± 0.58	0.3
Utility	3.23 ± 1.09	3.5 ± 0.58	0.32
Usage Difficulty	3.69 ± 0.75	2.0 ± 0.82	$<0.001^{*}$
Sketch-Tool	**2.21 ± 0.38**	**2.69 ± 0.9**	**0.09**
Group Usage	2.62 ± 1.19	2.25 ± 1.26	0.3
Individual Usage	1.77 ± 1.01	2.25 ± 1.26	0.22
Utility	1.92 ± 0.86	3.0 ± 0.82	0.02^{*}
Usage Difficulty	2.54 ± 0.88	3.25 ± 0.5	0.07
Digital Twin	**3.29 ± 0.68**	**3.56 ± 0.55**	**0.24**
Group Usage	3.54 ± 0.66	4.0 ± 0.82	0.13
Individual Usage	3.46 ± 0.97	4.0 ± 0.82	0.17
Utility	3.38 ± 0.65	3.5 ± 0.58	0.38

Meanwhile, the *Sketch-Tool* received the worst rating from the participants in both modalities.

Engagement was assessed by four criteria and was perceived especially positive compared to other categories. The participants rated their participation highly and also perceived their group members as highly engaged. Furthermore, they did not have the feeling of not being perceived or ignored by the others, but rather felt as an active part of the group. Overall, both collaborative VR setups and the tasks, seem to be very engaging to the participants. The *a2a* modality may be even more engaging compared to *f2f*, that may be because Powerwall and CAVE (*f2f*) setups characteristically have one controller for the whole group, while in HMDs setups (*a2a*) everyone has their own controllers and can interact with the CVE and other users simultaneously.

Verbal Communication, rated by three criteria, was, as well, perceived significantly positive in front of other categories. According to the participants, they could easily communicate with other group members, discuss a lot about ideas and solutions within the groups, and quickly find a solution. Although *f2f* verbal communication was assumed to be perceived more positive compared to *a2a*, the preliminary results indicate the opposite. A statistically significant difference was identified in maintaining focus on the solution. The HMD (*a2a*) modality seems to have a greater positive effect on maintaining focus during verbal communication.

Satisfaction was assessed by nine items, according to which participants were satisfied with the interaction between each other with their individual performance as well as the team performance, and with their solution. With the provided VR technology and scenario, the tasks were perceived as easy to solve. The given time was not perceived as positively as other criteria, especially in the *a2a* condition. Nevertheless, the participants were content with the provided information for the tasks. Statistically significant differences were observed in overall satisfaction, with the *a2a* condition being slightly more satisfying. When examining individual criteria, only *Team Performance*, *Solution Quality*, and *VR Technology* utilization displayed significant variations, all favoring the a2a condition. Despite these positive findings, our intention is to explore VR collaboration under more challenging scenarios. In the present study, the participants were encouraged to solve the tasks collaboratively, although they did not explicitly necessitate teamwork. Recognizing this, we aim to design more complex tasks for follow-up experiments which require cooperation.

Ray-Tool, *Sketch-Tool* and the *DT* categories were evaluated based on four criteria. The *Ray-Tool* was frequently used both individually and collectively, and was perceived useful for group work. However, it was reported to be significantly easier to use in the f2f condition than in the a2a condition. The *Sketch-Tool* saw less frequent use and was perceived as significantly less useful in the *f2f* condition, as in the *a2a* group. Despite disagreements about its utility, it was deemed easy to use. The *DT* was frequently used by participants and their groups, but it was seen as relatively complicated to use despite its utility in group discussions. In summary, the tools provided were useful but not necessarily user-friendly. Notably, the Sketch-Tool's usability needs significant improvement for future use. Given that participants had limited time to acclimate to the VR environment and tools, a training scenario should be provided in future experiments.

This pre-study has several limitations. As previously mentioned, the tasks in our study were not sufficiently collaborative and may have been too simple. Additionally, we did not provide a VR training scenario before the experiment, a step that might have aided participants in adapting to VR usage. Given that over 52% of participants were experiencing VR for the first time, their unfamiliarity could have significantly impacted the results. Moreover, in this pre-study, a Powerwall was used for the *f2f* condition, offering a lower degree of immersion compared to a CAVE system. In light of this, our forthcoming study will incorporate a CAVE system, which might lead to different outcomes. Lastly, it's essential to emphasize that our subject pool was relatively small, posing challenges in drawing statistically robust conclusions. These limitations underscore the need for further, larger-scale studies to validate and build upon our initial findings.

VII. Conclusion and Future Work

This study introduced a concept for using Digital Twins in engineering education via VR technology. We examined two interaction modalities for collaborative work in VR: face-to-face and avatar-to-avatar, which we will further evaluate in future studies. This preliminary work validated the VR setups and experiment procedures for both modalities, and we presented implications based on participant feedback. These early insights led to the formation of hypotheses for subsequent studies: (H1) Avatar-to-avatar collaboration in VR is more engaging and satisfying than face-to-face group work; (H2) Avatar design (fidelity, realism, humanoid vs non-human) significantly impacts group work and can enhance task performance and learning outcome; (H3) Difference in non-verbal communication are more significant than in verbal communication when comparing avatar-based and face-to-face collaboration in VR.

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