



Designing a virtual reality-support for the thesis supervision meetings: A case of a Sino-British international university in China

Yiming Luo^{b,1}, Shuling Sun^{a,e,1}, Yihong Wang^a, Di Wu^c, Yuanbing Ouyang^a, Yushi Li^{d,**}, Yushan Pan^{a,*,2}

^a Xi'an Jiaotong - Liverpool University, Renai Road 111, Suzhou, 215123, China

^b Xidian University, No. 2 South Taibai Road, Xi'an, 710071, China

^c Norwegian University of Science and Technology, Høgskoleringen 1, Trondheim, 7034, Norway

^d The Hongkong Polytechnic University, Kowloon, TU428, Hong Kong, China

^e Changzhou Vocational Institute of Mechatronic Technology, Ming Xing Road, Changzhou, 213164, China

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ABSTRACT

Thesis supervision is a crucial teaching activity in higher education that plays a vital role in assisting students in completing their studies. The outbreak of COVID-19 has necessitated the transition to remote, synchronous interactions for supervising academic papers. However, existing tools for conducting these remote sessions often fall short of meeting the requirements of both teachers and students. This paper focuses on an investigation into the utilization of virtual reality (VR) technology for conducting remote thesis supervision meetings at Xi'an Jiaotong-Liverpool University (XJTLU), a Sino-British institution located in Suzhou, China. Through a year-long qualitative inquiry involving two teachers and five students who participated in the project both in Liverpool and Suzhou, this research examines how actual collaborative work is conducted during remote supervision via a research-developed tool. The results of this study emphasize the need for improvements in the current design to better align with the practical requirements of teachers and students during such meetings. Furthermore, this research provides insights into the design considerations for VR applications tailored to specific use cases and offers a set of implementation details to guide the development of VR-based remote collaboration tools for thesis supervision meetings.

1. Introduction

Thesis supervision is a common one-to-one collaborative relationship between 'supervisors' and students in higher education (Wisker et al., 2008; Wood & Louw, 2018). With their academic expertise and experience, supervisors guide students to complete a thesis that meets specific academic requirements (Wisker et al., 2008). Recent studies have shown that the quality of thesis supervision plays an essential role in the completion rate (Petersen, 2007), and supervision meetings are vital for effective communication and collaboration (Abiddin & West, 2007a). Face-to-face meetings, in particular, allow supervisors and students to discuss important content intensively and facilitate thesis development (Zaheer & Munir, 2020).

However, not all supervision can take place on-site. The COVID-19 pandemic, which led to policies of social distancing and restricted movement, forced supervisors and students to shift from face-to-face offline meetings to remote online meetings (Djarmika et al., 2022; Pokhrel & Chhetri, 2021). Additionally, distance learning in international campuses across different countries involves online supervision for years. For instance, universities in China such as Xi'an Jiaotong-Liverpool University (XJTLU), the University of Nottingham (Ningbo), New York University (Shanghai), Keen University (Wenzhou), Duke University (Kunshan), Technion-Israel Institute of Technology (Guangzhou), and Moscow University (Shenzhen MSU-BIT University) are strongly connected to their parent universities worldwide. In addition to other significant factors, the primary reason for focusing on these

* Corresponding author.

** Corresponding author.

E-mail address: Yushan.Pan@xjtlu.edu.cn (Y. Pan).

¹ Yiming Luo and Shuling Sun contribute equally to this paper.

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cases is that all these universities either confer degrees from both parent universities or exclusively offer foreign degrees. For instance, XJTLU students receive dual degrees at the undergraduate level and solely University of Liverpool degrees at the postgraduate level. Therefore, coursework and thesis work, to some extent, must align and adhere to the same requirements as those of the University of Liverpool (XJTLU, 2022). Similar rules apply to other international joint universities as well (Duke, 2023; Kean, 2023; NYU Shanghai, 2023; UNNC, 2021; Technion, 2023; MSU-BIT, 2019). To facilitate supervision in such cases, tools like videoconferencing and teleconferencing are used, but they often transmit less variety, volume, and speed of information (Purvanova, 2014; Koester, 2022).

To address these problems, researchers have proposed using virtual reality (VR) to enhance the supervision experience. The application of VR in higher education seems promising (Altbach, 2009). For example, Li et al. (2022) investigated the effectiveness of distance learning calligraphy through VR applications, while Chen et al. (2021) developed a VR-based remote education platform focusing on rendering improvements. Ying et al. (2017) proposed VREX, a VR-based educational platform, to support education in different disciplines. VR enables teachers to communicate various types of information without the limitation of physical screens, such as voice, images, text, and three-dimensional objects (Jin et al., 2022). VR also improves students' understanding of teaching content and enhances social presence, communication, and interaction between teachers and students (Dzardanova et al., 2022; Pellas et al., 2021). The visually appealing three-dimensional dynamic scenes and immersive interactive experiences in VR can enhance students' motivation and engagement (Lau & Lee, 2015; Pellas et al., 2021). However, existing studies in higher education have mostly focused on the use of VR for single-student learning or remote collaborative learning, overlooking the collaborative experience between teachers and students in specific contexts like supervision.

To address this gap, our study focuses on the user experience of supervisors and students and customizes a VR application for thesis supervision meetings to investigate how to improve the design of VR applications for this specific use case. Our research question naturally arises: "How can VR applications be used to support collaborative supervision in thesis work?" We find that designing VR applications for supervision needs to consider the work practices of teachers and students, with particular attention to cultural and power issues, as these components play a significant role in supervision and indirectly influence the user experience of the VR application. Our study contributes to a paradigm shift in the design of VR applications for specific domains. Inline with that, the rest of the paper is organized as follows: Section 2 provides a review of the relevant literature, Section 3 presents the case study conducted for this work, Section 4 describes the empirical setting, and Section 5 introduces the methodology that guided our research throughout the paper. The findings are presented in Section 6, followed by a detailed discussion of the results in Section 7. Section 8 provides an implementation for design and opens a room for sharing lessons learned. The paper concludes in Section 9.

2. State of the art

2.1. Tool for remote thesis supervision meetings

Before the outbreak of COVID-19, remote thesis supervision was primarily utilized for part-time international students, where the high levels of student diversity and cultural differences significantly impacted their results (Gray & Crosta, 2019; Buckley, 2013). However, with the global spread of COVID-19 at the end of 2020, remote thesis supervision has become a common necessity in higher education. Over the years, most research on remote thesis supervision has focused on exploring the challenges and problems faced by teachers and students in the remote supervision process. However, these studies often provided abroad assessment of all available tools on the market, with extensive

investigation of real-life scenarios through quantitative research involving various remote supervision methods and technologies. While many of these studies identified the limitations of the technology and systems used for remote supervision, they did not delve deeper into the underlying issues of the technology and systems or offer suggestions on how to improve the problems associated with these technologies. Only a few issues related to Internet technology have been highlighted, such as interrupted Internet signal, slow Internet speed, and power failures (Djarmika et al., 2022; Kassegne, 2006; Zaheer & Munir, 2020). However, several underlying issues regarding the use of specific technologies and collaboration systems remain unaddressed. In light of this, a handful of researchers have investigated the application and design of specific tools for remote thesis supervision. These specific tools can be categorized into tools for synchronous and asynchronous interactions, depending on the interaction scenarios. Next, we discuss asynchronous interaction in Section 2.1.1 and synchronous interaction in Section 2.1.2.

2.1.1. Asynchronous interaction

Asynchronous interaction typically involves a delay between sending and receiving information (Serdyukov, 2020). This type of interaction allows participants more time to reflect on complex ideas and refine their contributions (Hrastinski et al., 2010; Kung-Ming & Khoon-Seng, 2005). In the context of thesis supervision, asynchronous interaction is often used for exchanging and transferring complex information or one-way notifications, such as file sharing and meeting reminders (Hansen & Hansson, 2015). Many typical asynchronous interactive communication applications, like email, forums, shared network disks, and shared online calendars, are already available on the market. While much research has been done on asynchronous work tools for thesis supervision, the needs of students and teachers working together in a VR environment go beyond asynchronous interaction. The study highlights specific needs in VR, such as exploring 3D models, highlighting contexts, and expressing emotions, which demand synchronous interaction. Therefore, focusing on synchronous interaction in VR can offer valuable benefits for educational purposes.

2.1.2. Synchronous interaction

In synchronous interaction, face-to-face communication is widely accepted as the most effective channel for information exchange (Koester, 2022). However, with the impact of COVID-19 eliminating the possibility of synchronous human interaction, the demand for synchronous collaboration technology has risen (Augustsson & Jaldemark, 2014). Teachers and students now often resort to using existing teleconferencing and videoconferencing applications (Chandrasena Premawardhena, 2021). Much of the research has also concentrated on similar systems or directly explored the experiences of typical applications available on the market. While several thesis support system studies include online videoconferencing functions within asynchronous collaboration (Almeatani et al., 2019; De Rezende et al., 2006; Hansen & Hansson, 2015), there is minimal research that specifically focuses on synchronous collaboration.

Königs et al. (2016) observed regular group meetings of students from different countries through video conferencing software, while Iwasaki et al. (2019) compared the use of Skype for remote supervision with face-to-face supervision.

Several studies have shown that other traditional technologies convey much less variety, volume, and speed of information than face-to-face communication (Purvanova, 2014; Koester, 2022). Thus, there is a need for new technologies that can better transmit information. Iwasaki et al. (2019) attempted to use the Orihime robot for thesis supervision, which allows communication between students and a teacher via voice and delivers video of the student to the operator through a camera. The teacher controlled the robot's movement and direction of view to interact with the students, but this interaction aspect seemed to be overlooked as it was beyond the scope of education.

In synchronous interaction, real-time exchange of information takes place (Kung-Ming & Khoon-Seng, 2005). This type of interaction enables participants to experience a greater sense of social presence and be more active and engaged (Hrastinski et al., 2010; Kung-Ming & Khoon-Seng, 2005). In the context of thesis supervision, synchronous interaction is typically facilitated through 'meetings' (Abiddin and West, 2007a, 2007b; Karunaratne, 2018). During meetings, teachers and students engage in focused and intense discussions of specific content for 30–120 min. Meetings of various sizes are held throughout all stages of thesis supervision, serving as a primary method of critical communication and promoting the progress of thesis completion. As such, in our research, we will use 'meetings' as a proxy for synchronous interaction in thesis supervision.

2.2. Remote cooperative work in virtual reality

The VR discussed in the present study refers to a purely virtual environment created through computer technology simulations, which provides interactive feedback on the user's actions and allows the user to feel immersed or present in the virtual world (Pimentel & Teixeira, 1994; Sherman and Craig, 2019). Depending on the level of immersion, VR systems used in current research can be categorized as follows: Low Immersive Desktop Virtual Environments (DVE): These VR systems offer a basic level of immersion and interaction and are typically experienced through a computer screen or a small display (Martirosov et al., 2022; Miller & Bugnariu, 2016). Semi-Immersive Virtual Environments: These VR systems provide a moderate level of immersion and interaction, often using larger displays or projection screens to create a more immersive experience (Martirosov et al., 2022; Miller & Bugnariu, 2016). Fully Immersive Virtual Environments (IVE): These VR systems enable a high level of multi-sensory immersion, offering a more realistic and compelling experience for the user (Pedersen & Koumaditis, 2020). Over the last decade, research has predominantly focused on fully immersive virtual environments (IVE), as they provide the highest level of immersion and offer users a more realistic and engaging experience. Fully immersive VR systems aim to create a sense of presence and transport users into a virtual world where they can interact with virtual objects and environments in a natural and intuitive way.

With the advancement of communication technologies, the interactivity of VR has expanded to support multiple users collaborating in the same virtual space, known as the collaborative virtual environment (CVE) (Benford et al., 2001). CVEs find applications in various fields of remote real-time interaction, including gaming, entertainment, education, therapy, healthcare, design reviews, and job interviews (Beti et al., 2019; Jerald, 2016; Perez-Marcos et al., 2012). However, in the context of higher education, much of the research on using VR has focused on single-student learning experiences in fully immersive virtual environments (IVEs). Only a few studies have begun to explore multi-player remote learning in IVEs.

For instance, Šašinka et al. (2019) developed a collaborative immersive virtual environment (CIVE) for geography education and conducted qualitative research to investigate the cognitive and social dispositions of pairs of learners as they engaged in collaborative tasks. However, this study was conducted in a laboratory setting with randomly recruited groups of participants. Jackson and Fagan (2000) integrated a study into offline classroom activities for participating students, where they worked individually or in pairs to perform tasks in the immersive virtual learning environment.

It is worth noting that the above-mentioned studies mainly focused on student-student collaboration in IVEs and did not involve the teacher's active participation. Only Pietroszek and Lin (2019) studied student-teacher collaboration in VR, where they developed a unique virtual reality remote classroom system called UniVResity. In this system, students experienced the fully immersive environment of a simulated classroom and saw the teacher in action through head-mounted displays (HMD). However, the teacher only saw and interacted with the

behavior of students' 2D avatars through the real interactive whiteboard.

Despite simulating communication scenarios through specific laboratory tasks, the real-life applicability and usefulness of these applications are still under exploration (Ahn et al., 2021; Le et al., 2020). Further research is needed to determine the effectiveness and potential of such collaborative virtual environments in educational settings.

3. The case: remote thesis supervision meetings

3.1. The study

To contribute to the computer and education literature, this study focused on remote thesis supervision meetings at Xi'an Jiaotong-Liverpool University in Suzhou, China. The participants selected for the study were senior students majoring in virtual reality and their assigned supervisors, both locally in Suzhou and remotely in the UK. Senior students were chosen to create a natural setting where students were actively working on their thesis projects, and the supervisors were willing to participate and tried out the developed application for supervision purposes.

The thesis project's schedule aligned with the typical one-year duration for thesis work, making it suitable for this study. A group of five students in the class was formed to design and develop VR projects. Due to the nature of university forums, students and teachers must meet and communicate either locally or virtually. In cases where the supervisor was located in the UK, videoconferencing was the typical means of communication. While several participants initially expressed interest in the project, in the end, only five students and two teachers participated due to various considerations, including privacy and personal issues. All participants provided informed consent, and they were informed of their right to withdraw from the study at anytime, in accordance with the university's ethical rules.

3.2. The procedure, instruments and artefacts in the study

In this section, we present the procedure of the study, including the instruments, artefacts, the participants and study procedures. The supervision work commenced in August 2022 and concluded in April 2023, with a total of 22 rounds of supervision meetings during this period. Each round of meetings involved one-to-one thesis supervision between the teachers and each of the five students in the virtual space, lasting about 1 h. The supervision covered various aspects of VR application development for student projects, literature review, writing, and presentation. The teachers and students had the flexibility to arrange the meetings according to their preferred supervision style and needs.

Fig. 1 illustrates the two different rooms where students could join individually, and the teachers could remotely participate in the meeting, either locally or in the UK. VR devices and applications were provided to users in China to facilitate their immediate use. The supervisor in the UK used their own device to remotely join the designed application. As all teachers and students had prior experience using VR



Fig. 1. The Teacher and Student in different classrooms. Photo by Shuling Sun.

devices, no significant challenges were encountered during the course of the project.

In this case, the VR device utilized was the Oculus Quest 2, which comprises an HMD headset and two controllers. The research team developed a VR collaborative application to assist teachers and students in their respective research contexts. Despite the participants' prior experience with VR, a pre-brief session was conducted to introduce the application step by step. During this pre-brief session, feedback and support were provided as needed to ensure a smooth and effective transition to using the application for remote thesis supervision meetings.

After the pre-brief session, the teachers and students began using the VR application in their daily thesis supervision tasks. Before the scheduled meetings, students sent their current thesis work to the teachers. The teachers had the option to add annotations to the thesis document using Office Word or explore the design of the VR application related to the student's project. During the meetings, the teachers shared the annotated thesis and elaborated on their suggestions for improving the students' technical designs in more detail.

Additionally, during thesis presentation meetings, each student shared their presentation document and conducted a mock thesis presentation. Following the presentation, the teachers provided valuable feedback and advice to further enhance the quality of the thesis work.

An essential aspect to mention is that both teachers collaboratively worked on the thesis supervision, given the interdisciplinary nature of the thesis work crossing domains. One teacher provided domain-specific knowledge and guidance to support the students in completing their thesis work, while the other teacher primarily focused on evaluating the quality of the thesis and offering academic support. This collaborative approach ensured comprehensive supervision and support for the students, combining expertise from different domains to enrich the learning experience and thesis outcomes.

4. The empirical setting

The empirical setting of our study consists of two main components: a web platform and a virtual collaboration space. Given that the thesis topic is on bioinformatics, one teacher is responsible for the engineering aspects, while the other teacher specializes in biological knowledge. On the web platform, both teachers and students can upload documents and videos from their computers to their personal net disk (Fig. 2(a)). They also have the option to customize their avatars' appearance, including choosing their avatar's color and gender (Fig. 2(b)). The web platform serves as the central hub for managing and sharing materials for supervision meetings.

The virtual collaboration space, accessed via VR devices, offers various types of virtual environments related to the field of

bioinformatics. For thesis writing meetings, participants can choose an enclosed room setting (Fig. 3(a)), while an open-air venue is available for thesis pre-presentation meetings (Fig. 3(b)). These virtual spaces are enriched with 3D models, including 3D structures of organs and other relevant objects. In this virtual environment, both teachers and students can move freely and interact with the uploaded files and materials. They can browse, turn pages, and play videos within the virtual space. Participants have the flexibility to resize and reposition the documents for comfortable reading.

Moreover, the teachers and students have the option to use virtual pens to draw and write on the whiteboard, notebook, or even directly on uploaded documents (Fig. 4). These annotations and modifications are saved to a web drive and can be downloaded to their computers via the web platform. While there are additional tools available in the Tools menu (Fig. 5), such as the whiteboard, pinboard, and timer, they are infrequently used by the users.

Communication in the virtual collaboration space primarily occurs through voice calls, using spatial audio where the volume changes with the speaker's distance. Participants can see each other's head and hand movements through their avatars (Fig. 2(c)) and can browse and interact with each other's placed documents and materials. The combination of the web platform and virtual collaboration space creates an integrated and immersive environment for remote thesis supervision, allowing for efficient document sharing, collaborative discussions, and real-time interactions between teachers and students.

5. Methodology

5.1. Data collection

Fieldwork is the chosen method for investigating the experiences of teachers and students in thesis supervision (Randall et al., 2007). This method allows for a comprehensive understanding of the 'experience' and 'problem' within the real-world context, allowing for detailed documentation and interpretation (Randall et al., 2007). The decision to use fieldwork is driven by two main reasons. Firstly, it enables a focus on the experiences of thesis supervision from the perspectives of both teachers and students (Bentley & Randall, 1994). Secondly, it facilitates an iterative design process, allowing for continuous improvement of the VR application.

To ensure a non-destructive and non-interventionist approach, the research is seamlessly integrated into the natural process of thesis supervision. Researchers sit together with the participants during the study, which provides direct insights into how supervision takes place and the natural work practices of the teachers and students, even in the collaborative VR environment. The fieldwork was conducted between August 2022 and March 2023. The university ethics committee approved the research before we began our work. The primary data collection method involved observing and interviewing the participants immediately after each round of supervision. In addition, researchers wore VR devices to actively participate in the virtual environment, allowing for firsthand observation, listening, and even experiencing the supervision process. This approach yields richer data for the researchers to understand the entire picture of the ongoing events. Table 1 outlines the procedure and details of data collection during the fieldwork, which involves close and direct engagement with the participants to gather comprehensive and valuable insights into their thesis supervision experiences.

During the fieldwork, semi-structured interviews were conducted with the participants. The purpose of these interviews was to gather information about their thesis project schedules and their previous experiences with thesis supervision, including the environment and process they used before using the VR-based application. In addition to the general interviews, detailed interviews were conducted with seven selected participants who had experience supervision meetings in a VR-based environment. These seven participants consisted of two teachers

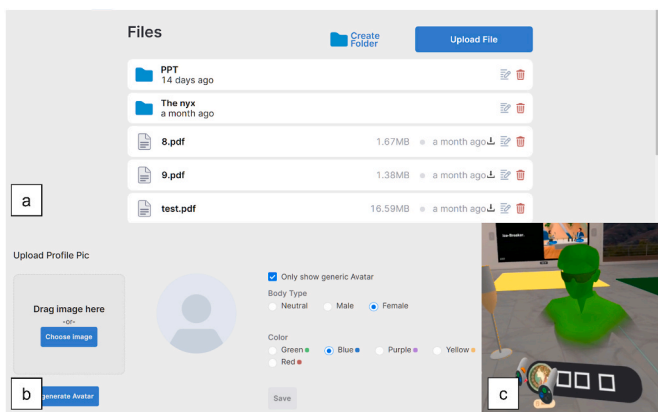


Fig. 2. File uploading and Avatar in the developed application (a) Net Disk, (b) Customized Avatar, (c) in VR environment. Photo by Shuling Sun.

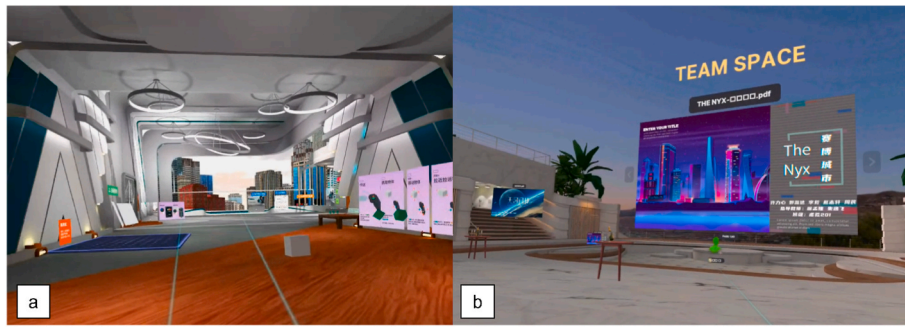


Fig. 3. Virtual Space provided by the application. (a) Enclosed room, (b) Open-air venue. Photo by Shuling Sun.

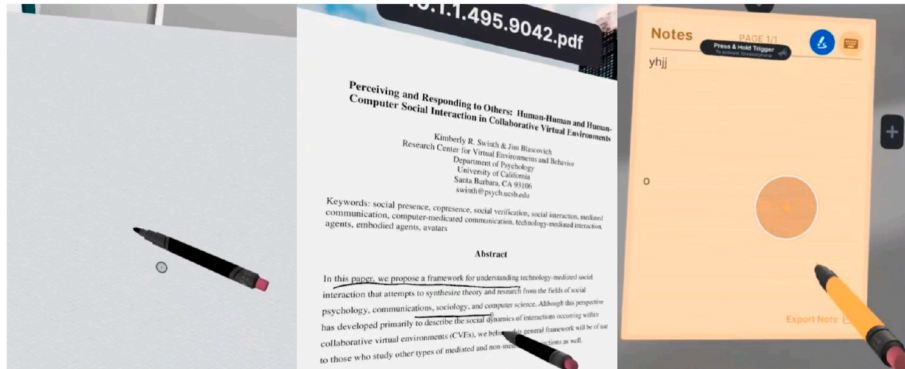


Fig. 4. Tool menu. Photo by Shuling Sun.



Fig. 5. The use of pen. Photo by Shuling Sun.

Table 1

Procedure and details of data collection.

Setting	Participants	Interview	Hours of observation	Dates/year
In their online meeting	Teachers and students	16	—	2022.10.13-2023.2.28
Technical issues of student project via VR-based supervision	Teachers and students	16	66	2022.10.20-2023.2.28
Thesis writing supervision meeting in VR	Teachers and students	22	52	2022.10.21-2023.2.16
Thesis presentation supervision meeting in VR	Teachers and students	22	52	2022.11.11-2023.3.1

(one male and one female) and five senior-year college students (three males and two females). All of these participants had prior experience using.

several single-user VR-based applications, but none of them had ever engaged in meetings within a VR-based environment. The focus of these interviews was to understand their experiences with VR, how they conduct thesis supervision in the VR environment, and their perspectives on the benefits and disadvantages of using the VR application for

supervision. The interviews were audio-recorded, and transcriptions were made immediately after each round of interviews.

In addition to interviews, observations were conducted in the VR environment during the thesis supervision meetings. Researchers documented their observations by writing and drawing to capture any specific issues or notable aspects of the supervision process. These observation materials were later used to follow up with additional questions during the interviews, ensuring a more comprehensive understanding of the participants' experiences with VR. By directly observing the teachers and students in the VR environment, the researchers aimed to avoid any discrepancies between what the participants said and what they actually did during the supervision process. Video recordings were also made through the Oculus recording function, capturing the first-person view of the teachers and students in VR during the meetings. Additionally, observations were made of the participants' behavior and reactions in the real-world setting. Photographs and recordings of vital points were taken to provide additional context and evidence of significant user behavior while using VR devices and applications.

To encourage participants to express themselves freely and avoid confirming each other's preconceptions about the application, the interviews were conducted individually, not in a group setting. This approach aimed to uncover the deeper reasons behind their behavior in the VR environment and their attitudes toward the VR-based supervision meetings. While a combination of interviews, observations, notes, and drawings was used for data collection purposes, the main intention was not to generate a deeper theoretical frame but to organize subsequent focused studies and support the interpretation of the findings. The primary focus was on gathering practical insights and understanding the participants' experiences in the VR-based thesis supervision context.

5.2. Data analysis

During the data analysis phase, we employed thematic analysis to gain insights and understand the set of experiences, ideas, and behaviors across the datasets (Braun, & Clarke, 2006; Braun & Clarke, 2012). All collected materials, including interviews, observations, drawings, and audio recordings, were translated into documents for analysis, resulting in a total of 195 pages of notes. To ensure confidentiality, any identifiable participant information was anonymized. As there was no relevant theory or theoretical framework in place, we conducted an inductive approach to distill the coding framework from the dataset (Braun, & Clarke, 2006). The project team used Visio to illustrate the relationships and classifications between all the codes, emerging themes, and sub-themes. This process involved iterative discussions among all authors throughout the project. As new data was collected, the codes, coding framework, and themes were continuously reviewed and adjusted.

Ultimately, the project team reached a consensus on the sub-themes and their parent themes, which are presented in Table 2.

Reaching an intra-subjective agreement among the research team through the identified themes is crucial for ensuring a comprehensive understanding of the data and its implications. By collectively analyzing and interpreting the themes, the research team can align their perspectives and insights, enabling a unified understanding of the experiences and needs of the teachers and students in the VR-based thesis supervision. This agreement is especially valuable for guiding the improvement of the VR application. By basing the improvements on the themes derived from the teachers' and students' experiences, the application can be tailored to meet their specific needs and preferences. This user-centered approach ensures that the VR application is designed with the end-users in mind, leading to a more meaningful and satisfactory user experience.

Furthermore, the intra-subjective agreement allows the research team to prioritize the perspectives and feedback of the teachers and students over purely technical or engineering-driven considerations. While the engineers' insights are valuable for creating a technically sound application, the focus on user experience ensures that the VR application is both effective and enjoyable for its intended users. By embracing the identified themes and incorporating the users' needs, the research team can foster a collaborative and iterative development process, continually refining and enhancing the VR application to better serve the teachers' and students' supervision needs. The ultimate goal is to create a VR-based supervision platform that facilitates efficient and engaging thesis supervision meetings, promoting a positive and productive learning experience for both teachers and students.

6. Finding

Based on thematic analysis, we have identified a series of issues associated with the VR application in thesis supervision. These issues can be summarized into the following four themes: translating supervision Work into virtual, hidden Interests of supervision, emotional interaction and collaboration, and the emphasis on supervision efficiency. These themes will be introduced in the following sections.

Table 2
Themes and sub-themes.

Parent theme	Definition	Sub-themes
Collaboration	Easy to manipulate the document together	Read the document together,
Cooperation		communication Drawing,
Emotional interaction		Dragging
Supervision Efficiency		Talk, tone, and rhythm
	Show 3D models	Moving, highlighting,
	facial expression	discussing
	Direct approach	

6.1. Translating supervision work into virtual

Our initial findings highlight the challenge of resource transmission between computers and the VR application, which impacts the efficiency and convenience of thesis supervision meetings in VR. Both teachers and students have established stable mental models and workflows for their personal thesis work, including writing, grading, and developing VR projects. However, when using the VR application for supervision, they faced difficulties in viewing and utilizing these personal work materials, leading to frustration and discomfort.

The inefficiency in resource transmission was attributed to three main reasons. Firstly, the VR application had limited support for file formats, making it difficult for teachers and students to directly display their work materials within the VR environment. This necessitated extra time spent on converting files into formats compatible with the application. Secondly, the file transfer process from computers to the VR application was cumbersome, involving uploading files to a net disk and then downloading them within the VR environment. This process, coupled with unstable internet speeds, often took several minutes. Lastly, the frequent need to switch between the computer and VR devices during the transmission process added to the inconvenience. Adjusting head straps and controllers when wearing VR headsets took nearly a minute each time.

These challenges resulted in teachers and students feeling uncomfortable and frustrated, leading some of them to give up sharing specific resources during the supervision meetings. It is evident that resolving these resource transmission issues is crucial to enhance the overall user experience and make the VR-based thesis supervision more efficient and effective. As one of the teachers indicated:

"I really wanted the student to showcase the settings parameters in Unity for their biological model. However, it dawned on me that capturing dozens of screenshots and painstakingly transferring them one by one to VR would be an absolute time sink. Not to mention, it would totally disrupt the flow of the meeting. I guess it's best to wait until the meeting is over and just view it on the computer."(T1)

In addition, the interaction paradigm in this VR application differed from the teachers' and students' past cognitive patterns and behavioral habits, which made them feel confused and uncomfortable. For example, when teachers zoomed in on a document in the VR application, many students felt that the document suddenly got too close to them, thus feeling uncomfortable. This was because, in the real world, the size of a document could not be enlarged. It could only appear larger by getting closer. Teachers and students also encountered phenomena within the application that did not exist in reality, such as object clipping. In addition, the VR applications' interaction paradigm differed from the tools they had used in the past, just like those work on computers, papers, etc. When students flipped one page forward from the first page of the PDF in VR, the document jumped to the last page. However, when students previously viewed the PDF on a computer or mobile phone, they couldn't flip the first page forward. As a result, they needed sometime to adapt to these differences.

Moreover, the VR-based interaction paradigms caused misunderstandings, leading to negative consequences. For example, the teacher's controller could emit a laser beam in this VR application. Since real-world objects were visible to everyone, the teacher assumed that the students could also see the laser beam. He used it as a tool to highlight important points. However, in reality, only the teacher could see this laser beam, which made the teacher feel angry. As the teacher said:

"I'd just realized that I was the only one who could see this laser, and it felt incredibly unreasonable. I'd been relying on it to highlight key points. However, the students likely had no clue about what I was trying to convey. It was as if I was playing the role of a fool."(T1)

As a result, this VR collaboration disrupted teachers' and students'

existing workflow and mental models. The existing workflow and mental model allow teachers and students to make decisions and take action efficiently in similar situations. However, when individuals attempt to use new tools and technologies that are inconsistent with their established patterns and workflows in VR, these automated processes and patterns are disrupted. Individuals need to bear the additional learning and cognitive costs and adjust their mental models, which may lead to discomfort, confusion, and even resistance. Additionally, the issue of resource transfer between computers and VR applications created a disconnect between individual work and collaborative work. This is not a problem in the physical world because there is no need to transfer resources. The students can show them to the teachers locally, via email, or similar means. However, VR applications bring a situation that causes inconsistent interaction between VR applications and the real world and builds up cognitive burdens and learning costs for teachers and students. To some degree, the quality of the meetings declines due to this technical issue and, of course, leaves the participants feeling fatigued and dissatisfied.

6.2. Hidden interests of supervision

The traditional Chinese culture emphasizes hierarchy and respect in interpersonal relationships. Even though the university is an international venture, the cultural issue still plays a strong role in everyday teaching and research activities. Indeed, English culture influences everyday work practices; however, due to most students being Chinese, respect and obedience to elders and superiors remain fundamental moral concepts in the workplace. Therefore, students often regard teachers as authorities and leaders, while students need to follow the teacher's guidance and regulations.

In this case, we observed that the teacher seemed to be constantly exercising their authority over the students during the supervision meetings. First of all, the process of the supervision meeting was completely controlled by the teachers. Only when the teachers issued instructions did the students begin to perform various tasks related to thesis supervision, such as file downloads and thesis presentations. In addition, the teachers continued to check the students' status and execution. We noticed that the teachers would frequently turn their heads to look at the students' avatars when explaining the thesis. The teachers would also repeatedly ask if the students understood during the explanation. Although most students followed their teachers' instructions carefully, they rarely took the initiative to make requests and perform work. For example, when the teachers explained the thesis, students used vocal fillers (e.g., "um," and "am") to indicate they were listening and seldom asked questions proactively. Only when teachers asked students questions would they respond actively.

The teachers stated that they have two reasons for exercising their authority over the students in this way. First, they bore significant responsibility for the students' thesis work results. They needed to ensure that the students could efficiently complete the required thesis work, which was also linked to their teaching performance. Secondly, they believed that many students lacked the ability to complete a high-quality thesis and did not have a sufficient sense of responsibility for their own thesis work. Without effective control over students, they were likely to become distracted and not listen carefully during the thesis supervision meetings, resulting in difficulties ineffectively revising the thesis.

Despite this, the teachers also hoped that the students could actively participate in the thesis supervision meetings by asking questions and making requests. On the one hand, the teachers found it challenging to judge the students' level of understanding and engagement from their expressionless avatars and vocal fillers. On the other hand, the teachers acknowledged that active questioning and interaction from the students could improve the depth of discussion and the quality of guidance provided. Therefore, students' active questioning and interaction could also enhance the depth of discussion and the quality of guidance. As one

of the teachers said:

"The entire meeting felt like a one-man show. I was the only one speaking, while they just nodded and said, 'Uh-huh.' I could only guess if they understood what I meant, but they wouldn't speak up if they had any questions, they wouldn't speak up... It was exhausting. By the end of the meeting, I found it difficult to determine how much they actually absorbed...(T2)."

The students seemed not eager to interact with the teachers and were willing to focus on following the teachers' guidance. On the contrary, the teachers' attention toward them created pressure and fear. They were also hesitant to ask questions or express dissent toward the teachers. As one of the students said:

"My heart was pounding as I noticed the teacher's avatar turning towards me. It felt like his eyes were fixated on me. I didn't dare move or fidget. The pressure was overwhelming." (S1) "Just now, the teacher was blocking my view. I really wanted to say something, but I didn't dare to because he's my teacher. It is not the same as if it were a classmate, and I would have spoken up directly then." (S2)

The moral values of respecting teachers and education in Chinese society have shaped a unique power dynamic and collaboration mode between teachers and students. Teachers use their power to control students in order to ensure adequate thesis supervision. Meanwhile, this power dynamic makes students afraid to speak up or express dissent. However, the excessive strictness of this power dynamic ultimately reduces communication efficiency and quality between teachers and students and further diminishes the quality of academic paper supervision.

6.3. Emotional interaction and collaboration

We also observed minimal interaction between teachers and students in VR, which lacked warmth. During the virtual meetings, they tended to deliver their ideas individually with limited conversation. For instance, when teachers spoke, students would use vocal fillers to show they were listening, but there was little active engagement from the students unless prompted by questions from the teachers. Furthermore, only the teachers frequently turned their heads to look at the students' avatars, primarily for supervisory purposes. In contrast, the students rarely looked at the teacher's avatar and seemed to listen passively, resulting in one-way interactions.

Teachers expressed their belief that interactions with VR students were less active compared to offline classes. The main reason for this observation was the absence of emotional interaction methods, such as physical contact, that could liven up the atmosphere in traditional classroom settings. To improve the interaction and warmth in virtual classrooms, it is essential to explore alternative means of fostering engagement and emotional connections. Utilizing various interactive tools within the VR platform and encouraging students to actively participate can enhance the overall teaching and learning experience. Additionally, implementing virtual team-building activities and creating opportunities for small group discussions may help establish a more dynamic and engaging virtual learning environment. While VR may lack physical contact, innovative approaches can be employed to compensate for it and create a supportive and vibrant learning atmosphere. As one teacher said:

"When I came across an interesting thesis problem in the face-to-face meeting, I could interact with my colleague through physical gestures like tapping him on the shoulder and saying 'Can you believe this?' As he could respond with his own thoughts, it created a lively and engaging atmosphere. But now we were limited to just talking, which made the atmosphere feel sterile and disconnected (T1)."

We believe that the traditional Chinese culture places great emphasis on etiquette and norms in interpersonal communication. The value of

harmony has become deeply in-grained in people's hearts, resulting in a cautious and polite communication style and a collaborative approach among the Chinese people. However, in the context of virtual reality (VR), the limited information available made it difficult for both teachers and students to accurately gauge each other's current state and emotions. As a result, they tended to be more hesitant and cautious in their interactions, as they worried about the potential of making the other person uncomfortable.

For instance, teachers often needed to continuously adjust their communication style based on the student's emotions and state of mind. However, this became challenging in VR since they could not accurately read the students' body language and facial expressions, which are essential cues for understanding emotional states in face-to-face interactions. To address these challenges, it may be beneficial to explore technological advancements in VR that can capture and convey emotional cues more effectively. Implementing features like emotion recognition algorithms or virtual avatars with expressive facial animations could enhance the communication experience and help bridge the gap between virtual and physical interactions. Additionally, providing training and guidance to both teachers and students on effective communication strategies in a VR environment can further improve their ability to navigate and engage in meaningful interactions. As the teacher said:

"Many times, I felt like I was walking on eggshells trying to balance the emotions of my students. It was crucial for me to gauge their reactions to my teaching and adjust my approach accordingly. But in VR, it was difficult to do so as I had limited information about their emotional state. I was left guessing whether my words were too harsh or too gentle, and I couldn't make any adjustments on the fly. It was frustrating because I could read their facial expressions and body language in a physical classroom to know how they felt instantly (T2)."

Due to the power dynamic between teachers and students, students might have some fear or apprehension toward their teachers. When they were unable to determine the teacher's emotional state, they might become even more cautious and hesitant to speak up. As one student put it:

"It was really frustrating when I could not see my teacher's facial expressions. All I can read was their tone; it sounded like they were disappointed with my writing. I started to wonder if my paper was really that bad and whether my teacher was unhappy with me. The situation made me nervous, and I didn't feel comfortable speaking up or asking questions. (S5)"

The Chinese traditional value of "harmony" encourages teachers and students to be attentive to each other's words and expressions, leading them to choose appropriate ways of interaction. However, the VR environment provides very limited information and feedback compared to face-to-face interactions. As a result, they find it challenging to accurately convey their emotions and perspectives, as well as confirm each other's feelings and viewpoints. In traditional settings, Chinese culture relies on tactful language, facial expressions, and body language to express opinions and thoughts effectively. Unfortunately, VR significantly restricts many of these avenues of expression, leading to difficulties in communicating emotions and perspectives. This limitation makes interactions more cautious and reserved, as they are unsure of how their messages are being received.

The power dynamics at play further exacerbate the issue, as students feel even less confident in expressing themselves openly. The combination of limited expressive means and unequal power dynamics creates a vicious cycle of poor interaction, hindering the establishment of a positive and harmonious communication atmosphere. To break this cycle and foster a more positive communication atmosphere in VR, it is crucial to explore and implement solutions that compensate for the limitations of the medium. This could involve incorporating non-verbal

cues in the virtual avatars, developing real-time emotion recognition technologies, and providing training to both teachers and students on effective communication strategies in a VR setting.

Additionally, creating a supportive and inclusive learning environment where students feel encouraged and empowered to express their thoughts and emotions openly can help overcome the challenges posed by the power dynamics. By addressing these issues, it is possible to create a more harmonious and constructive communication atmosphere that enhances the overall teaching and learning experience in VR.

6.4. The emphasis on supervision efficiency

We observed that although the VR application provided several tools that could meet the teachers' and students' needs, their use frequency in the supervision process was very low. The teachers and students often chose to use tools that were difficult to meet their needs but more efficient or even gave up meeting their needs. For example, the teacher and students needed to annotate key points on the thesis document and even take notes during supervision. Our original design idea was to provide users with a brush tool for annotating documents in VR. However, the teachers found the process of using the brush tool to be too complicated and inefficient. Instead, they preferred to use a direct approach by grabbing and moving a 3D object in the scene to highlight important points in documents. At the same time, both teachers and students had to give up taking notes. As the teacher said:

"I tried using the stupid paintbrush tool, but it was an absolute nightmare! First, I had to navigate through a labyrinth of menus to enable file editing. Then, I had to awkwardly hold my hand close to the canvas to summon the paintbrush while constantly fiddling with the brush size and position. It was a complete waste of time, and I could have been using that time to teach valuable lessons to my students. It's clear that the benefits do not outweigh the costs."

In addition, some necessary functions with no alternative were also very inefficient to use, which made teachers and students deeply impatient when using them. For example, teachers and students usually needed to share multiple resources to facilitate their communication, such as thesis documents and presentation slides. The original design idea was to create these resources on their computers and then upload them to the VR application through a net disk. However, due to the hassle of device switching and slow internet speed, the file transfer process took about 3–5 min. After the successful file transfer, they could then put on the device to continue their supervision in the virtual environment. As the teacher said:

"In the past meetings, all I had to do was display my computer or screen share on video conferencing software. But now, in VR, I'm stuck wasting my time in endless waiting. It's frustrating and disheartening (T1)"

The popularity of the Internet and the digitization process has led people to communicate and exchange information at a faster pace. China's rapid economic development and modernization have instilled a cultural value of 'high efficiency and fast decision-making.' As a result, individuals are expected to accomplish numerous tasks within limited time frames. This culture of high efficiency has also influenced the thinking patterns and work styles of teachers and students in higher education, particularly in the context of thesis supervision. Chinese cultural values that prioritize efficiency also underscore the importance of efficient thesis supervision in higher education. Teachers face two specific reasons for this emphasis. Firstly, they are responsible for supervising a considerable number of students simultaneously, and time constraints are extremely tight. If one student's thesis supervision meeting is delayed, it can disrupt the teachers' entire work schedule, requiring them to allocate additional time outside their regular working hours for supervision. Secondly, teachers must ensure that students complete their required graduation thesis within a specified timeframe,

which puts further pressure on optimizing the time spent during each meeting to help students absorb sufficient knowledge.

The pursuit of efficiency in thesis supervision can be both beneficial and challenging. On the one hand, it motivates teachers to make the most of their time to provide comprehensive guidance to students. On the other hand, it may also create pressure for both teachers and students to cover vast amounts of information in limited interactions. To strike a balance, it is crucial for educators to focus on effective time management and utilize technology and innovative teaching methods to enhance the efficiency of thesis supervision without compromising the quality of guidance. Encouraging open communication, setting realistic goals, and providing support to students can foster a positive learning environment that optimizes the thesis supervision process while maintaining educational excellence.

Students also hoped to optimize their thesis through thesis supervision efficiently. However, due to the power dynamic between teachers and students, students lacked a sense of responsibility for thesis supervision compared to teachers. Their pursuit of efficiency was more influenced and controlled by their teachers. For example, when the teacher's attention was not on the students, they might have wandered off and explored the virtual environment. They were curious about the complex functions of the application. However, when the teacher explained the thesis content to the students, the students were influenced by the power dynamic and dared not try inefficient functions but focused on listening to the teacher's explanation. As one student said:

"I was thinking of using the brush tool to take some notes, but I gave up. On the one hand, it was too slow to record everything, and I couldn't keep up. On the other hand, I was afraid of seeming like I was slacking off and disrespecting the teacher."

This application's design has not considered the pursuit of efficiency by teachers and students. Some designs make it difficult for users to find and access the corresponding tool when needed quickly. Some functions have too many fine-grained settings, making the operation cumbersome. Additionally, some designs have not taken into account the potential time consumption caused by unstable external information devices.

7. Discussion

Based on the data of our fieldwork, our research findings align with several earlier studies, revealing key aspects of the design of VR-based remote education applications. In the following sections, we will conduct an in-depth analysis of these key aspects and propose several design recommendations.

7.1. The power relations of stakeholders

Compared to traditional single-user applications, remote education applications usually involve the participation of multiple stakeholders who exhibit varying social roles and positions. This study specifically involves two distinctly different stakeholder groups: teachers and students. Their unique power relationship results in their different needs and interaction methods. Based on the findings, we can preliminarily outline the approach to analyze and understand stakeholders' power and power relationships from specific cultural backgrounds. Furthermore, we offer valuable insights into addressing the latent interests and needs of different stakeholders during the design process.

A variety of social positions are embedded within the social system, each serving as a predefined social role (Isaac, 1987; Symonds, 2021). This system assigns different powers to these roles, establishing diverse power relationships among them. During the process of socialization, individuals come to occupy various social positions and are endowed with different powers corresponding to their respective social roles (Fairclough, 2013; Isaac, 1987). This power provides the possibility of action for individuals. In the context where learning occurs, the role of teachers and students is recognized as two typical social roles (Isaac,

1987). In our case, the supervisor and student roles correspond to these two roles, respectively. However, given the long-term existence of teachers and students, a powerful and historically ingrained power relationship gradually develops (Isaac, 1987). The characteristics and behavioral expectations of this relationship have been thoroughly established and naturalized within the educational context (Symonds, 2021).

However, this power relationship varies under the influence of different societies and groups it is situated. Firstly, different cultural environments give rise to different values and attitudes within these groups (Plocher et al., 2021, chap. 10). Power distance is a significant attitude that influences power relationships, referring to a culture's attitudes towards inequality among individuals in society (Hofstede et al., 2010). In this regard, China has a relatively high power distance and maintains a traditional culture emphasizing respect for teachers (Bond & Hwang, 1986; Shengnan & Hallinger, 2021). The results of our study seem to reflect this unequal teacher-student power relationship, where the process of the thesis supervision meetings is entirely controlled by the teachers, with students fully obeying the teacher's commands and lacking the courage to express their own opinions. However, the influences of the national culture are often overshadowed by the influences of organizational culture (Plocher et al., 2021, chap. 10). Different educational organizations and departments establish various rules and regulations, such as the grading rights between teachers and students and the encouraged teaching method (Shengnan & Hallinger, 2021). Consequently, it is evident that the unequal power relationships between educational institutions and teachers also affect remote education: teachers need to follow the rules and regulations in order to meet the learning outcomes. Therefore, in this case, while the teachers hoped that students could take a more active role in leading the thesis meetings and expressing their ideas, the school's regulations determined that the teachers needed to exert strong control over students.

This power relationship also varies according to the individual circumstances of teachers and students, such as the teacher's teaching style and the student's personality and abilities. In this case, some students who had a closer relationship with the teachers dared to make jokes and requests. Nevertheless, as Fairclough (2013) stated, the naturalization of power is "the most formidable weapon in the armory of power" because it establishes a common-sense order of social relations and creates resistance to change (Symonds, 2021). In this case, despite their individual performances, students still showed respect and obedience toward the teachers.

7.2. User behaviors, attitudes, and interactions in VR applications

Communication methods, work rhythm, and processes also influence user behaviors, attitudes, and interactions with the VR application. First, the communication methods among users are highly correlated with power relationships. Within specific institutions, power relationships shape orders of discourse (Fairclough, 2013). These orders will limit and constrain the ways of communication and knowledge construction about the topic (Hall, 1997). Individuals will learn the orders of discourse in the process of occupying these subject positions and gradually consider them natural (Fairclough, 2013). In this case, the 'unequal' power relationship between teachers and students made students more obedient and cautious in their communication with teachers. Meanwhile, teachers often naturally communicated with students in a commanding tone.

Furthermore, although the work pace and process seem to be a completely personalized choice of the teacher and the student, the power relationship can cause one party's work rhythm and process to be influenced and dominated by the other. In this case, on the one hand, the high workload assigned to teachers by the school, along with the strong correlation between teacher performance and student grades, leads to the teacher's pursuit of high efficiency. These factors also influence the planning of the teaching process by teachers. On the other hand, out of

obedience to the teacher, students generally try to keep up with the teacher's pace and proceed in accordance with their teacher's plan. We can effectively identify their hidden interests and needs by analyzing and understanding the power relationship among stakeholders in specific cultural and educational contexts. However, we ameliorate the "unequal" power relationships in education through design rather than ensuring that all stakeholders can fully share their knowledge, ideas, and needs during the design process. Thus, it is necessary to effectively negotiate and balance the needs of stakeholders, thereby enabling informed decisions.

However, based on the findings from this study, the traditional user-centered design method provides limited space for different stakeholders to share their ideas and needs. Therefore, the design of VR remote education applications necessitates the involvement of users and their extensive-expression regarding "how they work and how they use technology to perform activities" to broaden the openness and diversity of potential solutions (Robertson & Wagner, 2012). We need to invite potential users to participate in every stage of the design process as co-designers, contributing their professional knowledge of the context in which the new technology will be integrated (Bratteteig & Wagner, 2014). This process particularly emphasizes addressing the power relationship between users and designers. In the current design process, users served merely as sources of information for designers or testers of prototypes. However, as designers, our privileged knowledge of VR applications and user needs marginalizes the knowledge and position of users. Foucault once proposed the concept of power/knowledge (Foucault, 1982). Discourse defines and generates the objects of our knowledge, establishes the classification or normative frameworks within, and delineates the acceptable and understandable way of speech and behavior (Hall, 1997).

Consequently, anything that does not conform to the expected classification or normative frameworks is marginalized. In this study, our understanding of the users is limited during the VR application design process, and the users' understanding of this application stems only from the tutorials we provide and the visible application interface. Therefore, users' potential actions within this application are also restricted. As a result, several tasks that users cannot perform within the application are naturally overlooked. It's easy for regulators to assume the classification or normative frameworks of the application are self-evident. However, the users' intended use of functions in the application might not align with its original functionality definition. For instance, users once used the laser originally intended for grabbing to highlight critical points in documents. If we hadn't happened to hear about this issue during the user interview, it would have been easy to overlook it. Therefore, we need to critically examine classification and normative frameworks, constantly questioning and challenging current norms.

7.3. Designing emotional expression in virtual reality

For multi-user VR applications, the communication methods of users have been one of the focuses of design. As discussed previously, we have conducted a preliminary analysis of the communication needs in VR remote education by considering power relations. The findings have indicated that the power relationships in education and certain cultural backgrounds caused teachers and students to be extremely cautious in communication, paying particular attention to each other's emotions and states. The inability of VR applications to enable users to effectively express and perceive emotional states has become a primary concern in communication.

This relates to the concept of interpersonal communication (Simard & Ammi, 2012) that can help better explore the key issues of communication and the path to solutions. The information exchange between partners in synchronous collaborative space can be classified into four levels: direct communication, control and feedback, feedthrough, and understanding. From a real-world perspective, remote collaboration

blocks direct communication between users. Teachers and students can only communicate indirectly through the 'artifact,' VR. In this case, users perform actions such as speaking, moving, and controlling objects in the virtual world through VR devices. Then, the VR application transforms these user inputs into 'feedthrough,' modifying the information perceived by other users to report the actions performed by one user (Hill & Gutwin, 2003).

Therefore, the capability of VR devices in input and output greatly impacts the communication process. In this case, VR applications and devices carry the function of language communication through microphone and earphone components, providing users with auditory feedback. Users can capture limited emotional clues from the content and tone of voice. However, when it comes to the communication of changing moods and emotional states, nonverbal information is far more important than verbal information (Fabri et al., 1999). Non-verbal information mainly includes facial behavior, gaze, spatial behavior, gestures, and body language (Fabri et al., 1999; Knapp et al., 2013).

In our study, the VR devices only captured the position and direction of the user's head and hands. Users could only express attention to each other by gazing or making simple hand gestures. Additionally, users rarely used these gestures due to the device's weight and the environment's constraints. That leaves the communication quality wholly dependent on the users' understanding of each other. In the present study, the teachers sometimes unintentionally turned their heads to look at the student, which can cause students to worry if they have done something wrong. In comparison, richer information can reduce users' misunderstandings. One direct approach is to use facial expressions (Fabri et al., 1999), allowing humans to pay great attention to the information received from others' faces. In addition, body posture is also a powerful indicator of emotion, which can transmit clear signals in different cultures (Argyle, 2013).

From this perspective, When such direct communication is limited, we can design objects in the virtual world to serve as 'artefacts,' conveying feedback to supplement emotional cues. Several studies focus on replicating or enhancing non-verbal information from the physical world. For instance, Baloup et al. (2021) have explored controlling the facial expressions of avatars through selectable menus, gestures, and voice interactions on the VR device without facial tracking capabilities. Roth et al. (2018) explored enhancing the transmission of gaze and joint attention through color highlighting and floating bubbles in VR. However, the design of communication methods in VR does not necessarily have to be confined to the existing channels and experiences in the physical world (Roth et al., 2018). We need to conduct a macro-level study of the supervision process. Additionally, we should prioritize providing customized tools based on different user needs in various usage scenarios, ensuring that users can quickly find the desired functions according to their needs (McVeigh-Schultz et al., 2018; VIVE Tutorials, 2021), such as avatar's appearance (hair growth, color, brightness) (Bernal & Maes, 2017). In this manner, it would be fruitful to enable both teachers and students can emotionally express their feelings during the supervision.

7.4. Enhancing efficiency

In the evaluation of VR applications, efficiency is another key factor that contributes to the experience of teachers and students in supervision. "Efficiency" is abstractly defined as the resource consumption related to the accuracy and completeness of user goal achievement (for Standardization, 1998). Therefore, in lots of VR research, the usage efficiency of VR applications is often translated into measurable variables, such as click counts and task completion time (Arora et al., 2017; Liang et al., 2019). Researchers evaluate efficiency in laboratory settings by controlled measurements of these variables. However, the use of VR applications in remote education is affected by the real world and user characteristics, such as the usage environment, cultural background, and workflow. These complex conditions are difficult to reproduce in a

laboratory. Moreover, this laboratory-style evaluation is more suitable for specific pre-set tasks, such as navigation, drawing. Tasks in remote education are often unpredictable. Therefore, we need to place VR applications in the real education process and environment to deeply describe their "usefulness" (Randall et al., 2007). Fieldwork used in this study is an effective design method to explore the "usefulness". While we have identified some efficiency issues in VR applications through fieldwork, it remains challenging to discern solutions and design directions.

In the present study, we found that the efficiency of document annotation was low. By breaking down its process, we can find that users cannot directly locate the tool in the environment. Instead, they need to open multi-level menus to find the 'document editing' button and then control their arms to approach the document. It also takes more time for a user to write a recognizable word. Since VR devices have a teacher's height, when considering the usage efficiency of VR applications, we need to consider the consumption of time and the consumption of users' physical strength. For example, hand movements while documenting a teacher consume users' physical strength. In addition, teachers cannot guarantee that users will complete specific tasks like in laboratory evaluations, and several tasks may be aborted halfway due to users' negative pre-assessment of functional efficiency and effectiveness. However, we should catch issues from these aborted tasks. Furthermore, we can adapt the list of usability questions proposed by Sutcliffe and Kaur (2000) as a reference for several interviews in fieldwork. These questions aid in uncovering detailed insights into user psychology and behavior, thereby providing empirical evidence for user instruction of our interaction models.

Therefore, by using the above model to address users' current efficiency issues, we can clarify the direction of efficiency optimization and design in VR applications. On the one hand, we can reduce the number of steps in the user process. For instance, the document could always be designed to remain editable, bypassing the step to open multi-level menus. On the other hand, we can reduce the consumed time and physical strength in several steps. For example, using voice input to annotate documents is both fast and energy-saving. Furthermore, we can create multiple interaction methods and design schemes for each user requirement to improve efficiency. It is important to note that the VR application needs effective allocation of functions from the overall system design level. This manner will bring a positive experience to the stakeholders and in turn, will make the stakeholders at the center of the design process.

8. Implementation for design

Mark Stefik emphasizes that the seamlessness between individual work and team collaboration will be one of the key directions for the next-generation collaborative technologies (Ishii & Miyake, 1991). Thus, in order to guide the future implementation of VR applications, it is essential to explore design paths that others can take when doing similar work in the field of computers and education.

8.1. Presentation integration

In our study, the application we designed takes cues from 2D interface design guidelines and commonly used syntactic vocabulary, thereby achieving appearance integration. Concurrently, we have factored in ergonomic considerations for users, enabling them to maintain an appropriate height for various actions, hence achieving behavior integration. In that sense, we should enable users to apply experiences from their everyday work practices. A number of literature and practices in the VR field attempt to better replicate physical space and traditional interface design experiences in VR, as this can lower learning costs of users (Cha et al., 2020; Jerald, 2016). However, we believe this is a "lay" design approach. On the one hand, several patterns of the real world or interfaces may not be suitable for the virtual world

(Jerald, 2016). On the other hand, simply replicating the interaction patterns in physical space may reduce the use of VR's unique features (McVeigh-Schultz & Isbister, 2022). High-fidelity interactions are easy to learn, but low-fidelity interactions such as flying over scenes and grabbing distant objects can provide users with experiences that cannot be obtained in the real world (Jerald, 2016). As Hollan and Stornetta (1992) pointed out, the transformative nature of communication technology does not come from face-to-face encounters but from providing new opportunities to go beyond 'being there.'

Hence presentation integration is more about enhancing the intuitiveness of the VR interface and aids in constructing consistent mental models for supervision purposes (Jerald, 2016). Our study shows that the VR interfaces' intuitiveness comes from the computer's mouse cursor, which is only visible to the user. We need to establish effective learning and feedback mechanisms to mitigate the inconsistencies in mental models that users normally rely on (Jerald, 2016; Norman, 2013).

8.2. Data and control integration

VR interfaces for thesis supervision are more than providing an environment. Importantly the detailed data integration must come from the in-situ experience of teachers and students (Thomahs, 1992). In our case, data exchange between the VR application and the computer requires additional file format conversions and cumbersome transfer steps, resulting in low data exchange integration. Furthermore, other properties, such as the effectiveness of data synchronization (Synchronization integration) and the potential presence of significant data duplication (Non-redundancy integration), can be considered higher requirements for data integration. This results in that the control integration complements data integration overlooked the sharing of functionalities (Thomahs, 1992). In our case, users are unable to access various file editing tools on the computer through VR, indicating a low level of control integration. Users can only indirectly control VR by converting software into files that can be transferred to VR. Additionally, both data and control integration need to be considered in a bidirectional manner, not only how to use VR to receive data from a computer and use its functions, but also how a computer integrates data from VR and uses VR's functions.

Moreover, compared to the integration between desktop tools, the integration between VR applications and personal tools involves switching between different devices. Ishii and Miyake (1991) have initiated an early discussion on tool integration that involves device switching. In our case, the tool integration involving the switch between devices should ideally overlap and integrate the images of both ends. However, these features currently only offer basic sharing capabilities, and there is still space for improvement and expansion in terms of integrating finer details. For example, desktop sharing does not currently allow dragging and manipulating files from the computer into the VR environment, which is required for 3D files. Thus, we should consider integrating VR applications with AR, MR, or desktop mirroring features to achieve a significant leap in enhanced data and control integration (Billinghurst et al., 1998).

8.3. Process integration

Last, the design of VR applications should also consider the process integration of users (Thomahs, 1992). In our case, for example, the PDF file transfer process from the computer end to VR, and the file transfer functions of VR and the computer, can not be successfully imported and storage of PDF during the supervision process. The file sizes are different for computer and VR applications. VR cannot effectively present the file size supported by the computer. Indeed, if we carefully consider the process of supervision regarding various subjects, it is not hard to find that process integration is about bringing back the users' work contexts and experiences. It calls back to the presentation integration that each

solution for VR technology should be based on in-situ work practices. Such an idea was also suggested by Jerald (Jerald, 2016); Jerald indicated that the emphasis in facilitating rapid learning and acceptance of VR interactions by users should be on assisting users in swiftly creating mental models that align with the application. In that case, our presentation integration will be supported by natural affordances and clear signifiers that guide actions and elucidate processes, timely and useful feedback, and apparent and comprehensible mappings (Jerald, 2016).

9. Limitation and advanced value

Every research endeavor has its limitations, and our study is no exception. In this research, we have indeed identified several design flaws in the VR application within the context of thesis supervision. However, it's crucial to acknowledge that our findings may not be universally applicable to all VR applications. We must emphasize that design research should prioritize in-situ work practices, where various stakeholders involved in a project contribute to shaping technology design to ensure not only usability but also high-quality usefulness. One potential critique that may arise is the question of the practical implications of our work. As mentioned, one of the key takeaways from our research is the need to educate VR developers about the absence of a one-size-fits-all design solution. Customization of design for each unique context of use is of paramount importance. This research serves as a reminder that tailoring VR applications to specific use cases is vital for their success and effectiveness.

10. Conclusion

This study aims to answer the challenges students and faculty face when conducting remote dissertation supervision sessions via VR. The current VR application still has many system design and technology deficiencies. The study suggests improvement of the VR technologies for supervision purposes in many ways, including enhancing the continuity of VR applications, customizing the information architecture and interaction details of VR applications, and giving consideration of cultural differences of user groups. In addition, the paper reflects on the design of VR applications for supervision purposes. A set of design implementations is offered with the purpose of opening rooms for others who might share similar research interests in VR-based computer and education purposes.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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