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Article

Distance Tutoring in Chemistry Education: A Qualitative Study of the Usability of Head-Mounted-Displays

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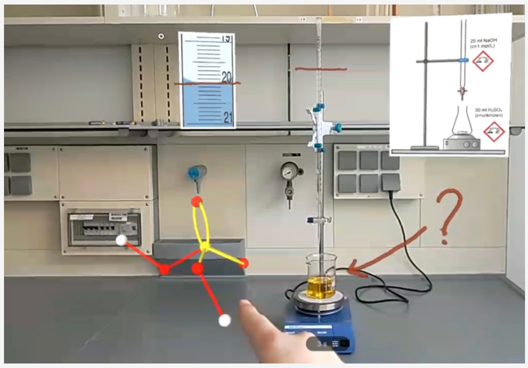
ABSTRACT: This qualitative study examines the potential of head-mounted displays (HMDs) for providing remote support in a university setting. It focuses on whether immersive technologies, such as HMDs with augmented reality (AR), could be a useful addition to or alternative to traditional remote support formats, particularly for practical, action-oriented activities, such as laboratory work. Three case studies in which students were supervised as part of their final theses or examinations were conducted to document and evaluate user experiences, challenges, and potential. Following initial skepticism regarding the technology, particularly regarding technical aspects, the participants' attitude turned largely positive with increased use. HMDs proved particularly helpful in laboratory environments, enabling intuitive, present, and context-sensitive support. Key advantages included real-time communication, visual participation from a first-person perspective, support through digital additions to the field of view using AR, and hands-free operation. At the same time, it was demonstrated that the technology is particularly effective in small settings. These results suggest new perspectives for the use of immersive technologies in digital university teaching, particularly for remote supervision of practical activities.



KEYWORDS: *Graduate Education/Research, Laboratory Instruction, Distance Learning/Self Instruction, Multimedia-Based Learning, Collaborative/Cooperative Learning*

1. INTRODUCTION

In today's digital world, augmented reality (AR) plays a significant role across many areas, including the automotive industry,[1] retail, medicine,[2] and gaming.[3] In these areas, AR is used with smartphones, tablets, or Head-Mounted-Displays (HMDs) in varying application contexts.

Possible applications of HMDs and AR with communicative potential include medicine and industry. In these two areas, various studies have demonstrated the potential of remote support using HMDs and AR.[4,5] The main advantage is the ability of experts to assist from a distance, offering greater flexibility. An expert can remotely guide people wearing an HMD on site by receiving a feed of their field of view, enabling more targeted instructions and the display of Supporting Information in the field of view using AR. Unlike conventional video conferencing, HMDs allow instructions to be integrated directly into the user's field of view via text, markers, 3D models, or video while the hands remain free to work.[6,7]

In medicine, this application context mainly involves support and guidance during surgery and surgeon training, thereby reducing errors and improving training.[2,8−16]

In the industry, HMD remote support and guidance in repair and maintenance tasks have been tested for a few years now, with promising results.[5,17−19]

This study investigates whether this proven medical and industrial applications of HMDs and AR could be adapted for use in higher chemistry education. This approach is based on the extensive research on the use of AR (and HMDs) in chemistry education, where AR is used to visualize abstract concepts, facilitate experiments, and enhance paper-based learning with digital content.[20,21] In recent years, AR has become increasingly popular in education due to more powerful devices and easier content creation using authoring tools.[22] When implemented properly, AR has the potential to improve teaching and learning processes in chemistry education, as demonstrated by various studies.[23,24] However, these studies have only examined the promotion of communication within AR environments, not AR itself as a medium for communication, for example, such as remote support situations in medicine and industry. Furthermore, research in the context of science education has so far mainly investigated how AR can support experimentation, but not

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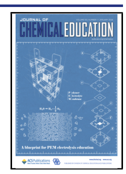

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Transfer of prior experience (Case 1 → Case 2) Transfer of prior experience (Case 2 → Case 3)

	Case 1	Case 2	Case 3
Participants	Student 1, 24-year-old female	Student 2, 28-year-oldemale	Student 3.a, 23-year-old female Student 3.b, 28-year-old female
Objective	Supervision of master's theses		Enabling participation in an exam which otherwise cannot be taken due to physical limitations
Case focus	Written part of the theses, office work, conducting interviews	Laboratory work, development of experiments	Laboratory work, supervision of students
Used technology	Microsoft HoloLens 2		Apple Vision Pro
Case duration	3 months	7 months	2 days
Data collection	Pre-Post-Interviews		
	Diary study		Extra interview after the first day

Figure 1. Summary and overview of the three cases discussed.

how AR can support supervised experimentation or supervision during experimentation itself.[25−28] Several studies have shown that head-mounted displays (HMDs) offer important advantages in experimental settings. These include a closer connection between digital content and the real setup, as well as greater flexibility, as learners can work hands-free. For these reasons, HMDs were also used in the present study. The research further indicates that HMD-based AR systems allow students to view digital overlays directly and in context on the experimental apparatus. In addition, hands-free interaction—compared to interacting with a tablet screen—makes it easier to manage and complete complex tasks.[29−33]

The need for various remote support options was revealed by the pandemic, especially in laboratory settings, where viable alternatives remain lacking. Attempts to simulate lab work through at-home experiments or predefined data analysis have failed to replicate hands-on experience.[34] This study focuses on two key aspects: the remote supervision of natural science master's students during their thesis work (cases 1 and 2), with an emphasis on lab-based research; and enabling lab participation for a student with physical impairments (case 3). In these contexts, the possibilities offered by HMDs were explored. The main aim is to assess the feasibility and effectiveness of HMD-supported supervision and participation and to determine whether such tools can add value to thesis supervision and lab work. This leads to the following overarching evaluation question:

Evaluation Question 1: What opportunities do HMDs present for the remote supervision of students?

The following subordinate evaluation questions are asked to address this:

Evaluation Question 1.1: What are students' expectations before a supervision situation involving HMDs?

Evaluation Question 1.2: How do students rate the use of HMDs in these situations?

Evaluation Question 1.3: Does the students' attitude toward the use of HMDs change as a result of the supervision situations?

Evaluation Question 1.4: What potential advantages and disadvantages do students see in the use of HMDs?

Guided interviews were conducted before and after use, and prestructured diaries were used during the final theses to answer the formulated evaluation questions. This publication presents the research in detail and provides insights into the findings obtained to date.

2. THEORETICAL FOUNDATIONS

2.1. Augmented Reality (AR)

Milgram et al.[35] define augmented reality (AR) as part of the reality-virtuality continuum. This extends from the real environment to a purely virtual environment (VR). The area between these two extremes is referred to as mixed reality, where real and virtual objects are displayed together. AR describes the part of the continuum in which virtual objects are added to the real environment. According to Azuma,[36] technical implementation must fulfill certain criteria: a combination of reality and virtuality, real-time 3D registration, and interactivity.

2.2. Head-Mounted Displays (HMDs)

Head-mounted displays (HMDs) are wearable screen systems. According to Shibata,[37] HMDs are compact, lightweight, customizable, interactive, integrated into the user's field of view, and equipped with a see-through mode for AR applications. There are two types of HMDs: video see-through (VST-HMD) and optical see-through (OST-HMD).[38]

VST-HMDs capture the environment via a camera and display the image with overlaid digital content on the screen, meaning users only perceive the real world indirectly.[39] In contrast, OST-HMDs use semitransparent mirrors or lenses to overlay digital elements, allowing a direct view of the physical environment.[38]

For this study, cases 1 and 2 used the Microsoft HoloLens 2 (OST-HMD), while case 3 used the Apple Vision Pro (VST-HMD).

2.3. Remote Supervision

"Remote" refers to interaction with people or objects in a different location. In a university setting, remote supervision involves supporting students' learning and research from a distance.[40] It increases flexibility by enabling individuals to choose their own time and place.[41] The relevance of remote supervision increased significantly during the pandemic-induced shift to digital teaching. Even after returning to in-person teaching, it became evident that students benefit from a broad range of virtual offerings.[42]

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However, remote teaching often lacks direct feedback and real-time support. This can lead to misunderstandings that negatively impact learning outcomes and the quality of results.[43−45] These challenges are particularly pertinent in lab settings due to potential safety risks.[46] Effective guidance is essential when learning new techniques or correcting mistakes.[47]

HMD-based remote support has already shown its potential in medicine and industry, as explained in previous research, especially through its ability to display information within the field of view using AR. In addition, the use of HMDs with AR overlays leads to lower cognitive load,[48,49] and the split attention effect can be avoided because information is presented spatially integrated within the field of view.[50,51] This is also consistent with the principle of the Cognitive Theory of Multimedia Learning, in particular, spatial contiguity, which AR overlays can fulfill[52,53]

3. METHODS

3.1. Design of the Study

The study takes a design-based research approach and comprises three case studies, each with a different focus, illustrated in Figure 1. The case study methodology is based on Taber,[54] who advocates this idiographic approach to exploratory research due to its naturalistic character, enabling the cases to be studied in a university context rather than an experimental one.[54,55]

To enable comparison of the cases, they were analyzed individually first and then examined across cases. The basic idea behind the study is based on the application contexts in medicine and industry. The aim was to examine the transfer of these application examples from the coronavirus pandemic to the supervision of master's theses. Cases 1 and 2 took place during the pandemic, and in both cases, the entire thesis was to be supervised via HMDs. For this purpose, both students were provided with an HMD, which transmitted their field of view to the supervisor's laptop. In return, the supervisor could add or overlay information via AR into the students' field of view. Cases 1 and 2 overlapped partially toward the end of case 1, allowing insights from case 1 to inform case 2.

Originally, the plan for cases 1 and 2 was to supervise the master's theses comprehensively using HMDs, covering office-based meetings, testing and evaluating AR tablet applications developed as part of the thesis, and laboratory experimentation.

During case 1, however, it became apparent that the use of HMDs in office settings offered no added value compared to conventional video conferences. Since case 1 did not involve experimental development, and technical difficulties arose with the initially used software, the HMD was not used in the laboratory. Instead, its use was tested in interview scenarios in which Student 1 could not be physically present. In these interviews, the supervisor or the interviewed teacher wore the HMD, and the video was transmitted to Student 1. This was intended to create a stronger sense of presence, allowing Student 1 to follow notes and sketches made during the interview.

Based on the findings from case 1, the use of HMDs in office settings was no longer pursued in case 2; instead, the focus shifted to laboratory work. The goal was to develop and comprehensively test a new experiment for school instruction. As the master's thesis involved collaboration between universities, the laboratory work was successfully supervised remotely via HMD during several sessions.

The first two cases (remote supervision with HMDs) were conducted as a diary study comprising three phases of data collection: initial interview, diary during the theses, and final interview.

The analysis of cases 1 and 2 showed that HMDs offer promising possibilities in laboratory contexts, particularly for guided experimentation in case 2. During this evaluation, a problem arose in a chemistry education seminar that could be addressed using insights from cases 1 and 2. Successful completion of the seminar required passing a practical exam involving supervision of students in the lab. One student (3.a) was temporarily unable to enter the laboratory due to physical limitations. Therefore, Student 3.b entered the lab wearing an HMD and was "remotely controlled" by Student 3.a. The HMD was not given directly to students for instruction by Student 3.a, as data protection regulations restricted this, and safety risks would have been too high without on-site supervision.

Interviews were conducted before the start of the examination, after the first day, and upon completion. All interviews were transcribed for analysis in accordance with the transcription rules set out by Kuckartz.[56] No unexpected or unusually high safety hazards were encountered.

3.2. Participants per Case

Case 1: Student 1 is a 24-year-old female in her 12th semester of a high school teaching degree at the University of Konstanz, undertaking a three-month thesis in Chemistry Education.

Case 2: Student 2 is a 28-year-old female in her 11th semester of a secondary school teaching degree at a neighboring, cooperating university, undertaking a seven-month cross-university thesis in Chemistry Education.

Case 3: Student 3.a is a 23-year-old female in her ninth semester of a high school teaching degree at the University of Konstanz, currently taking her final course in Science Education. Due to a physical impairment, she was unable to access the lab for the exam. The lecturers, therefore, gave her the opportunity to guide Student 3.b (a 28-year-old female in her 17th semester of a high school teaching degree) remotely in the lab using a head-mounted display (HMD). The two students did not know each other before the study began.

None of the four participants had any previous experience with AR-HMDs. Contact with VR HMDs was limited to a maximum of two private or study-related uses. All participants signed a consent form agreeing to the anonymous use and publication of their data before the study began.

3.3. Hardware and Software

The Microsoft HoloLens 2 was used in cases 1 and 2. The thesis supervisor could follow the students' views on her PC via streaming and interact with them. Due to technical problems, the use of ″TeamViewer″ and the device portal proved to be unsuitable, which is why the software ″sphere″ was used. Case 3 used the Apple Vision Pro with "FaceTime".

3.4. Measuring Instruments

3.4.1. Guided Interviews. Using interview guidelines enables both structured and flexible data collection. This means that all aspects of everyday and scientific knowledge, as well as those related to laboratory and thesis supervision, can be systematically recorded. At the same time, there is sufficient flexibility to respond specifically to individual questions or new findings.[57] This method was suitable for this study to assess expectations and attitudes beforehand and to evaluate overall experiences after using the HMDs (eqs 1.1, 1.3, 1.4).

The preinterviews focused on participants' prior experiences with supervision, as well as their expectations and attitudes toward HMD-supported supervision. In contrast, the post-interviews deliberately avoided referencing earlier interviews or diary entries to prevent bias. Instead, they centered on experiences with the HMDs, perceived benefits and drawbacks, and potential use cases. The complete interview guidelines are included in the Supporting Information.

3.4.2. Diary Studies. In case studies, combining multiple data collection methods helps to generate a multilayered picture.[54] As interviews only provide snapshots, diaries were also kept in cases 1 and 2 to document HMD usage over several months in which remote supervision with HMDs took place as needed and not on fixed days (eq 1.2). This included actual use, conscious nonuse, alternatives, and situations where use would have been beneficial. In case 3, however, a diary was not used because the use of HMDs was clearly defined and limited.

Diary studies allow participants to record experiences independently and regularly, thereby minimizing memory distortion and capturing changes over time. To reduce participant burden and ensure data comparability, a prestructured diary format was used.[58] Notes were taken throughout the day, with diary entries completed each evening. These entries covered work and supervision contexts, situational details, HMD use, perceived pros and cons, alternatives, and subjective value assessments. The diary template is included in the Supporting Information.

Data were analyzed thematically alongside the interview guidelines and diary structures without applying a formal coding system as used in category-based content analysis as described by Mayring[59] or Kuckartz and Rädiker.[60] Instead, the goal was to capture, organize, and compare key themes and lines of reasoning. For this reason, the recommendations of Kaiser[61] and Hopf[62] for small case numbers were followed in the evaluation of the data, combining thematic synthesis with systematic analysis along the guidelines. For each case, a structured summary was created to identify similarities, differences, and distinctive features, allowing for an in-depth analysis of each case while enabling the recognition of cross-case patterns.[63]

4. RESULTS AND DISCUSSION

In the preliminary interviews, it became evident that the participants had little or no prior experience with head-mounted displays (HMDs). When such experience existed, it was limited to brief interactions with simple VR games. All participants expressed a certain degree of skepticism regarding both the technical implementation and the potential application scenarios of such systems, but they also showed initial curiosity prior to the study and before the use of the unfamiliar technology.

The skepticism largely diminished through practical use. While doubts regarding the added value were replaced by a generally positive attitude as experience with the technology increased, recurring technical issues reinforced skepticism in this specific regard.

For clarity, the central findings were consolidated and grouped into six thematic areas: usage contexts and application scenarios, technical aspects, user experience and operation, functions and interaction, collaboration and communication, and physical strain.

Detailed analyses of the three investigated cases are documented in the Supporting Information.

4.1. Usage Contexts and Application Scenarios

In case 1, remote supervision using HMDs was examined in the context of the written part of the master's thesis. Due to poor transmission quality, HMDs were considered unsuitable in this setting, as written content was unreadable. Additionally, HMD use in interview situations was tested, and participants reported a stronger sense of presence, making the application generally favorable.

The use of HMDs in laboratory contexts, as seen in cases 2 and 3, was described very positively and identified by all participants as the primary context in which HMDs should be employed in comparable scenarios. HMDs enable more intensive supervision by sharing the field of view and overlaying information. Because users' hands remain free, laboratory work is not restricted.

The use of an HMD in the teaching-related case 3, where effective communication between the two students and the pupils was central, was also evaluated as successful overall. This was attributed, among other factors, to a stronger sense of presence and more direct communication with the students.

A proposed future application scenario extending beyond the three cases involves collaborative, location-independent work on 3D structures, such as complex molecules, that can be explored and discussed more vividly and immersively through HMDs than via tablets or shared screens.

Overall, the scenarios tested in cases 2 and 3, remote laboratory supervision across larger distances and enabling participation in practical activities for individuals with physical limitations, were identified as central applications for HMDs in university contexts.

4.2. Technical Aspects

In case 1, the TeamViewer program was initially used but exhibited poor video quality and high latency. The setup was then switched to the HoloLens 2 device portal, which also enabled video transmission. However, this connection proved unstable, and the device portal frequently crashed. Both programs showed issues not entirely attributable to weak Internet connections. Consequently, for the last four sessions in case 1, the program "sphere" was adopted. Since cases 1 and 2 overlapped, "sphere" was also used from the second session onward in case 2. This switch proved beneficial, as transmission problems with audio and video were significantly reduced and were mostly due only to poor Internet connections. Despite hardware limitations of the HoloLens 2 and weak image stabilization, the video quality via "sphere" was sufficient for experimental guidance; however, small objects or written content remained difficult to read. The students also criticized the field of view in which AR content can be displayed as being too small.

In case 3, minor connection issues occurred during setup. Transmission quality was much better with the Vision Pro and FaceTime, although written text was again hard to discern. Because multiple people worked in the same room in case 3, poor noise suppression was noticeable, occasionally hindering communication. Peripheral vision limitation was also criticized, though only in this case.

Regarding software operation, the hand gesture control of the HoloLens 2 was initially described as challenging in the

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first two cases but improved with practice. Further issues arose in case 2, as the HMD sometimes interpreted hand movements during lab work as input, unintentionally opening menus. In case 3, no major operational problems were reported; however, the students noted that hand gestures appeared unusual. The headset's automatic brightness adjustment was perceived as distracting.

A central factor in prolonged use is battery life. In Cases 2 and 3, the HoloLens 2 and Vision Pro each lasted about 2 h. In Case 2, this was sufficient, as sessions did not exceed this duration. In Case 3, where use lasted three to 4 h per day, the battery had to be replaced midsession.

4.3. User Experience and Operation

In the first two cases, setting up and operating the HoloLens 2 and Sphere software were initially perceived as complex. With increasing familiarity, the operation became intuitive and reliable. Similarly, using the Vision Pro in case 3 required a brief familiarization phase but was unproblematic afterward. Overall, after initial adaptation, operation was smooth in all cases, and user experiences with the devices varied initially but were consistently rated positively after a short familiarization period.

Moreover, factors such as shared field of view, heightened sense of presence and immersion, closer perceived supervision, free hands, and facilitated visual communication through annotations, contributed to an overall positive user experience, albeit sometimes limited by technical issues and physical strain.

4.4. Functions and Interaction

In all cases, the shared field of view was perceived as particularly advantageous. Users did not have to adjust an external camera position, as would be necessary with a laptop webcam. Especially in the lab contexts of cases 2 and 3, visual participation enabled targeted instructions and a better understanding of workflows, setups, and processes for the remote participant, as it was always clear what was being discussed. This shared situational awareness opened new possibilities for collaboration. Student 3.a described her experience as immersive, feeling actively involved in the situation. Student 1 similarly reported this impression during HMD-based interviews.

In laboratory use, communication became more visual, reducing the need for verbal descriptions and minimizing misunderstandings. The supervisor could react directly to actions and provide precise instructions. The ability to keep both hands free was especially beneficial for practical lab work. This combination of shared field of view and annotation capability was particularly emphasized in case 2, as it allowed full focus on laboratory tasks without managing camera perspectives or laptop displays.

The function of overlaying or drawing annotations directly into the field of view was only partially usable in the first two cases due to technical issues and was absent in the third due to the software used. Nevertheless, all participants considered this feature essential for effective HMD use and emphasized its importance for future applications.

4.5. Collaboration and Communication

In cases 1 and 2, this sense of presence was an important factor in communication and collaboration, as it conveyed stronger spatial and social proximity. In case 1, this was highlighted during interviews conducted via HMD, as the altered communication situation generated a stronger sense of presence than when Student 1 participated via laptop video conference. In case 2, the annotation function was noted to enable more direct and visual communication and supervision compared to traditional video conferencing. Spatial and temporal flexibility was also valued, as synchronous collaboration was possible independent of location.

In case 3, Student 3.a described her virtual participation in the laboratory exam as an immersive experience with a strong sense of presence. Initially, she found it unusual not to intervene directly, but through good collaboration with Student 3.b, she quickly adapted. She appreciated being positioned "in the middle of the action" thanks to the viewpoint, rather than merely observing through an external camera. This allowed her to give targeted instructions and interact flexibly with other students and pupils, resulting in simpler and more effective communication and collaboration.

In all three cases, using HMDs, compared to conventional video conferencing, enhanced cooperation through increased presence for the HMD wearer and greater immersion for the remote observer.

4.6. Physical Strain

In case 1, reports of headaches and eye strain occurred after less than 30 min of use. Since Student 1 did not wear the HMD for longer sessions, and the supervisor or interviewed teacher who wore it did not report comparable issues, this did not pose a significant problem.

In case 2, the HMD was worn more frequently and for longer durations. Unlike Student 1, Student 2 reported physical discomfort only after up to 3 h of use, mainly related to the headset's wearing comfort, particularly when combined with corrective glasses underneath. She also noted visual fatigue from looking through the headset's prisms over extended periods.

The longest use occurred in case 3, lasting three to 4 h per day, including setup. Student 3.b reported fatigue from eye focusing and headaches after long use. This issue may be related to the HMD type: a VST-HMD was used in this case, whereas cases 1 and 2 used OST-HMDs. As in Case 2, the headset's uncomfortable fit was criticized, being described as too tight and heavy. Due to physical strain, more breaks were introduced on the second day to reduce discomfort.

Overall, physical strain was mainly related to comfort and fatigue, appearing primarily during extended use (except in case 1). This highlights the individual nature of the issue and underscores that ergonomically designed hardware and regular breaks are essential for longer, more comfortable use, as all participating students emphasized. It is important to note that HMD use and duration were entirely voluntary, and participants could take breaks or stop at any time.

5. SUMMARY

In summary, the use of HMDs for remote supervision was generally viewed positively. While the students were predominantly curious and open to using HMDs, they were also skeptical about the benefits, technical implementation, and handling. For the main part, however, this attitude changed for the better with use (eq 1.1). Initial skepticism about added value and ease of use gave way to recognition of the practical benefits, and further potential applications were conceived. However, the technical implementation was viewed more critically than initially (eq 1.3). The HMDs were used in case 1 in an office and interview context, and in Cases 2 and 3 during

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practical work in a laboratory. In cases 1 and 2, this involved supervising final theses, and in Case 3, it involved an examination situation. In the office context, HMD use was not considered very useful, whereas in lab or real-life situations, it was predominantly rated positively. In summary, the three cases described provide insight into the advantages and disadvantages of using HMDs in remote supervision (eq 1.2; eq 1.4). Regarding supervision, the students felt more supported and appreciated the immersive, intuitive real-time communication with the supervisor. While the use of HMDs in the office or for short consultations was not considered useful, their potential was demonstrated in practical laboratory work and action-oriented tasks. Gesture control enables hands-free use, allowing work to be carried out in parallel with supervision. This gives supervisors an authentic insight into students' work processes and allows them to display additional information in the field of vision or draw notes to guide and support students in their work (with the appropriate software). A key advantage is the flexibility of the supervisory relationship, which enables the supervisor and the person being supervised to work productively and collaboratively from any location with Internet. In the context of research, this makes it easier to discuss laboratory setups, conduct experiments in different locations, or work with three-dimensional models using the appropriate software.

Technical problems negatively impacted the work in all cases. In the first two cases, there were repeated instances of poor sound and image quality, along with disconnections. The limited field of vision of the HMDs was criticized, as was the need to familiarize oneself with the unfamiliar controls. Users complained of headaches, eye strain, fatigue, and discomfort from the HMDs during and after prolonged use. The programs used with the HoloLens2 in particular were also criticized for their lack of options. Unintentional entries were made while working in the lab, which interrupted the workflow. The disadvantages mentioned can be used to derive requirements for successful use: HMDs must be comfortable to wear for extended periods, offer high sound and image quality, have the longest possible battery life, and be compatible with the intended applications. Before use, users should receive instructions on operating and handling the HMDs, and clear goals for their use should be set. Those involved should also be open to and accepting of this new type of use. Additionally, the study emphasizes key requirements for software used with HMDs: software must guarantee high transmission stability and quality for audio and video, facilitate intuitive operation, and offer functions for displaying supporting content within the user's field of vision. The software should be optimized for ease of use, particularly during time-sensitive or physically demanding tasks. It must integrate seamlessly with the different available hardware and network infrastructure in educational institutions.

Overall, HMDs enable immersive, interactive support across distances when the above points are observed for successful use. They enable participation from a first-person perspective, which was particularly valued in the laboratory. Students could be supported and supervised in their activities in a context-sensitive manner, and the synchronous, spontaneous opportunity to communicate facilitated their work. There is also potential for HMDs in other contexts, especially for joint practical work across greater distances. The findings suggest that HMD remote supervision is particularly effective in smaller settings where individualized support, clear communication, and a shared visual context are important. The close interaction between supervisor and student enables tailored guidance to be provided and misunderstandings to be minimized, which is especially valuable in hands-on or experimental scenarios (eq 1).

Adopting an exploratory approach, this study opens the promising, yet previously under-explored area of remote supervision in an educational context. It has provided initial insight into possible application scenarios for HMD-supported remote support and highlighted the potential for inclusion-oriented applications (case 3) and cross-university applications in 1-to-1 settings (case 2), which can be transferred to other use cases.

Future research should examine the long-term integration of HMD-supported remote supervision with different software options into teaching and supervision practices, especially in laboratory settings, and explore its use in larger, more diverse settings. In addition, the possibility of displaying information in the field of vision using AR should be investigated in more detail, as this function was only usable to a limited extent due to the circumstances described. Investigating how different group settings, e.g., with more students at the same time, and task types, e.g., more authentic chemistry settings like in cases 2 and 3, affect the suitability and design of HMD-supported supervision would also be beneficial, as would examining the role of supervisor training and digital literacy in successful implementation.

■ ASSOCIATED CONTENT

● Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.5c01094.

Notes for Instructors (PDF, DOCX)

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Notes

Institutional Review Board Statement: All participants were students at the University of Konstanz and the University of Education Weingarten. All participants were adults and participated voluntarily. No particularly vulnerable groups participated (e.g., minors or individuals with limited capacity to provide informed consent). All participants were transparently informed in advance about the purpose, procedure, duration, and use of the data and provided their informed consent. Participation was entirely voluntary, without coercion or undue incentives. The study did not collect any sensitive personal data (e.g., health-related data, political views, or religious beliefs). Data were collected within the context of regular teaching, learning, or professional development activities and did not go beyond these activities. Due to all these measures in the conduct of the study, an audit by an ethics committee was waived.

The authors declare no competing financial interest.

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