

CONDUCTING USER STUDIES IN ENGINEERING EDUCATION DURING THE COVID-19 PANDEMIC

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Abstract

In this paper, we report about our experiences on adapting ongoing laboratory research of a supervised Virtual Reality (VR) study to a remotely conducted unsupervised desktop-based application. Challenges in the context of participant recruitment, pre-/post-test, and our application are illustrated in conjunction with the corresponding transformations. In addition, based on a qualitative problem analysis by an interdisciplinary team of experts, recommendations for future studies and transformations of VR lectures are derived from the findings and experiences of this project.

Introduction

In the last decades, extended reality (XR) technologies including virtual, augmented, and mixed reality (VR, AR, MR) have been a topic of interest among academic researchers as well as private industries (Makransky & Petersen 2021). These technologies play an important role in engineering education, as they enable immersive learning experiences, allow exploration of otherwise difficult to access environments, and offer augmented and enhanced knowledge transfer (Soliman et al. 2021, di Lanzo et al. 2020).

To date, learning in XR has been explored in various application domains in university teaching and schools (Albus et al. 2021). In these environments, abstract content such as chemical processes or new technologies, e.g., from robotics, can be experienced interactively to develop a deeper understanding of the topic. Besides the classic media comparison studies, which contrast VR with other media and explore potential advantages of the former to the latter (Makransky & Petersen 2021), there is also the question of how to support learners in VR in a specific use case by an adequate design (Vogt, Babel, Hock, Baumann & Seufert 2021). This can also include a closer look at specifically important learner characteristics that can additionally enhance learning, depending on the design variant offered (Vogt, Albus & Seufert 2021).

The SARS-CoV-2 pandemic has caused an abrupt disruption stretching from the professional work environment to the private lives of people globally. When the World Health Organization (WHO) announced the beginning of a global pandemic due to the virus in March 2020, a "stay at home" order forced non-essential employees around the world to move their workspaces as offices closed to manage the surging number of cases (Sohrabi et al. 2020). As a result, an unprecedented need for digitization in-

creased sharply to reconstruct operations across multiple disciplines. Like many other industries, educational and research institutes were not prepared to adapt the previously predominant workflow of on-site and in attendance teaching and learning to the new situation.

Efforts to digitize educational institutions and adapt workflows accordingly have been ongoing for many years. The new immediate demand for solutions has given digitization an unprecedented boost. As courses increasingly take place digitally, it is increasingly important to expand and enhance digital capabilities and evaluate new approaches. However, one of the biggest challenges facing ongoing research includes the shift from laboratory-based research to remote work practices and the use of remote research methods.

Despite growing accessibility of hardware in the consumer sector, testing core aspects of XR applications in the form of usability and user experience (UX) studies still heavily rely on laboratory settings with technical equipment. Through governmental restrictions such as lockdowns, travel regulations and ever evolving limitations to social gatherings in the past two years, conducting research without face-to-face meetings as often the case in UX studies meant making quick adjustments to ongoing experiments and moving from a controlled environment to uncontrolled distance testing. With the lack of guidelines and safety protocols for hygiene regulations, as well as the constantly changing requirements and circumstances, the studies pose a new and challenging situation in the research community. In this work, we present our approach to transform existing and planned VR user studies to accommodate for remote asynchronous settings and outline potential changes with regard to study protocols, research methods, and application design. For this, we first introduce our initial aims for digitalization in the scope of engineering education and showcase related work in this field. We then concentrate on the adaptations we made in terms of participant recruitment, pre- and post-tests and the developed application during the pandemic for our use case of a VR learning scenario. Finally, based on our qualitative expert problem analysis, we report about the identified challenges and results of the conducted immersive multimedia study along with recommendations for future research approaches.

Aims and initial research design

Design principles are important to make learning processes easier. However, it is still unclear whether the findings regarding design features can also be applied to VR learning

environments (Makransky & Petersen 2021). The application used in the scope of this work investigates what influence the use of color coding, signaling (Van Gog 2014), and segmentation (Mayer 2020) in a learning session has on the reception and retention of what is learned.

After conducting a systematic literature review on the use of XR technologies within the realm of engineering education, the curriculum of the bachelor degree in civil engineering in Germany was examined with the aim to derive learning objectives in modules. Common experiments from the field of structural mechanics were evaluated with regard to transformation suitability and subsequently implemented as learning scenarios in virtual 3D environments. The background, design principles, and the methodology for the developed learning scenario to use in structural analysis education have been described in a previously published work (Krischler et al. 2021). A VR classroom scene was implemented using Unity 2020 and deployed as an executable for PC. In this application, users are able to conduct several beam bending experiments. The overall learning objective is understanding the individual components of the underlying equation of deflection (e.g., geometry, material, Young's modulus, moment of inertia) for a beam with a rectangular cross-section which is presented in the center of the virtual room. The learning content was divided into several subchapters based on the variables of the underlying equation and introduced to the user one-by-one in order to understand the context of geometry, material, and loads independently. Measuring the forces and deformation values give valuable insights of the material characteristics and developed stresses.

An exemplary image of a student testing out the application is depicted in Figure 1. In our between-subject design study, we compared the effectiveness of one color coded version of our application to a control group with a focus on different levels of learning outcome and learners' cognitive load.

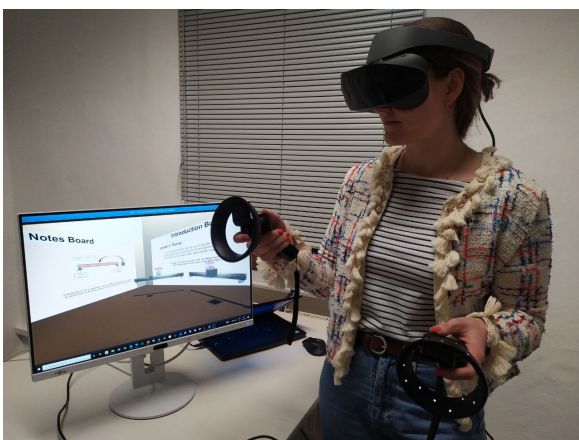


Figure 1: Student exploring the learning application in virtual reality.

Related Work

In a review, research papers in the architecture, engineering, and construction (AEC) training/education field pub-

lished from 1997 to 2018 were analyzed to observe trends in technologies and application areas (Wang et al. 2018). Almost half of all publications in recent years relate to architecture visualization and design education, while the least amount of publications investigate the use of virtual reality in structural analysis education. Although this subject is fundamental in engineering, the realization of real-time, dynamic simulations are often time-consuming and the complexity of the model affects simulation time.

XR technologies can replicate and enhance a scene in a detailed and immersive manner for learning or training in a virtual environment, and have been shown to increase knowledge and skill transfer (Adami et al. 2021). Nevertheless, running XR studies often require specialized equipment (e.g., head-mounted displays, custom input devices) to track and observe participants. With the necessity of specific hardware often bound to a location, it comes as no surprise that most studies are exclusively conducted in laboratory settings (Mottelson & Hornbæk 2017).

In search for alternatives to arduous in-lab studies, remote studies were introduced. Two of the main advantages of remote testing are the reduction of in-person support and time-flexibility (Mottelson et al. 2021). Both factors inevitably decrease cost, as remote studies need to be designed as self-explanatory as possible, and thus can be conducted at any time. One of the greatest challenges remote studies pose is the lack of control, as the studies usually take place in settings that do not match the conditions in a laboratory setting. In their work, Koo & Skinner (2005) specifically examine the challenges of online recruitment for remote studies.

Remote user studies can generally be divided into supervised and unsupervised activities. Supervised experiments are studies where participants and supervisors are locally not in the same place but are able to communicate through some medium (e.g., microphone, hand-held transceiver) and interact with each other. In cases where spatial separation is reached with separate rooms at the same location, behind-the-glass moderation is an often chosen option, where participants can be observed and audio guided through the task. A more common situation nowadays is communication via an online session such as Skype, Zoom or other online platforms. Conducting unsupervised research experiments online with human participants through an open call is referred to as crowdsourcing. The term was examined more than a decade ago in a meta-analysis of the literature at that time by Estellés-Arolas & de Guevara (2012). Advantages of crowdsourcing are noted to be cost reduction, participant maximization and diversity as well as flexibility (Goodman & Paolacci 2017). The lack of monitoring can lead to poor data quality. However, this can be counteracted through incentives, which should be calculated depending on the participant type.

Radiah et al. (2021) developed a framework to conduct remote VR user studies in cases where participants own HMDs to access at home. While remote experiments can be highly cost-effective in terms of man-hours spent in

a laboratory, this type of research also has its limitations. Recent research introduced five industrial case studies with different remote and hybrid setups during the pandemic (Siltanen et al. 2021). While conducting remote studies is not a new concept, there is a lack of guidelines and protocols to follow in these special conditions.

Methodology and Implementation

Originally, the research group had planned to conduct a user study with the goal to teach various engineering tasks and to present degree relevant information utilizing VR technologies. With the target audience being university students from different engineering degree programs, the research questions aimed to discover which interaction metaphors, learning principles, and aids have the most effects on the users' reception, retention, and recollection. For comparative studies, the participants are divided into two or more subgroups: one or more treatment groups with manipulations on the study material and one control group without such modifications. For this type of studies, it is important to note that other conditions should differ as little as possible between the groups in order to examine the emerging effects of the independent variables.

Before a study begins, researchers decide on whether the study is aimed towards qualitative or quantitative research. Depending on the goal, a participant profile is defined with the needed criteria. With qualitative research, the profile needs to be distinguished in detail, as qualitative methods are aimed towards individuals or small groups. The outcomes are non-numerical data, which are further analyzed to gain profound insights of participants' subjective actions and views (Moser & Korstjens 2018). As the name suggests, quantitative research is designed to collect large data for the later analysis to be statistically significant. For this, unambiguous questions and scales are used to obtain reliable and objective data. With the minimum number of participants required being higher than with qualitative research, the recruitment of participants is more difficult as the response rate is usually more sparse (Delice 2010). Thus, the participant recruitment is advised to be adapted accordingly.

Utilizing a test before the learning game gives insights to candidates' prior knowledge, general abilities such as spatial visualization, domain specific expertise, and motivation. By comparing this data with the results in the post-test, the educational application can be evaluated in terms of the independent variables attributed to the environment, in this case especially with regard to cognitive and motivational parameters.

Real-life experiments are very time-consuming and special laboratory equipment is often needed. By transferring complex experimental setups to a digital environment, users can experience learning units in an interactive, exploratory, and self-paced manner. Furthermore, digital experiments can provide possibilities that are not realizable or feasible in real life. Inspired by a laboratory demonstration of a flexural beam test through externally applied

loads, a virtual classroom scene with a similar setup was developed for the students' self-regulated learning, shown in Figure 2.

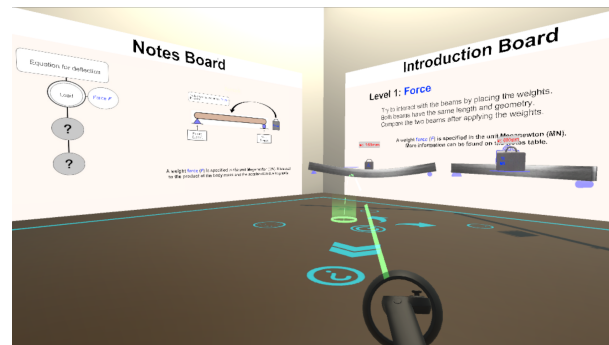


Figure 2: Exemplary VR learning scene demonstrating a flexural beam test of the original user study application.

Moving from the controlled real-life laboratory environment to the remote unsupervised testing needs adjustments not only within the application itself but within the entire workflow including participant recruitment as well as pre- and post-tests.

In this section, the original ideas and concepts for the planned user study are introduced with regard to the participant recruitment, pre- and post-test, and the application itself. Furthermore, the challenges due to the current pandemic situation are highlighted, and the conducted transformations compared to the original design are presented.

Participant Recruitment

The original plan prior to the lockdown was to both integrate the application into the civil engineering course plan as a supporting element and investigate it under controlled conditions. The teachers of the topic-related courses were to be informed about the contents of the learning environment in order to be able to instruct the students accordingly in class. The target group of the study is civil engineering students who have not yet become acquainted with the contents of the learning environment during their studies. In addition, a platform was to be used to publicize the location, time, as well as the content of the study, and students were to be approached directly for the purpose of potential candidate acquisition. Participants were planned to be recruited in person in order to be able to respond promptly to any questions that may arise.

Challenges

As with many institutions, educational organizations such as universities in Germany were closed overnight in March 2020 due to the SARS-CoV-2 pandemic. One of the initial challenges was to convert the traditional lecture and study halls to online learning environments. Although establishing virtual classrooms lead to an enormous gain in terms of communication, the access to the students decreased with each passing week. Remote learning often led to unilateral conversations with little to no response coming from the students. A new phenomenon called "Zoom fatigue" became well known in remote work arrangements, which

describes the exhaustion that arises due to frequent video conferences (Nesher Shoshan & Wehrt 2021). This led to exploration of alternative information channels as the need to reach new participants and attract attention grew.

Transformation

Potential participants are contacted via e-mail and, when possible, asked directly to participate in the user study. In the recruitment mail, the candidates are informed on the structure of the study, the average completion time, the compensation incentive, and the technical (e.g., operating system, web browser) and personal (e.g., age, medical limitations such as color vision deficiency) requirements. In addition, they are provided with a link leading to the web page through which the pre-test, application, and post-test can be accessed. With the expectations set, if the candidate chooses to partake in the study, the presented website can be opened with the link at any chosen time over the course of the set study duration. After opening the survey, a randomized ID is generated for the specific user. In this step, each user is also randomly divided either into the "treatment" or the "control" group. The group association as well as the user ID is then logged on the server side.

Pre- and post-test

In addition to the direct interactions and questions in the VR learning environment, it was originally planned to ask students questions outside the learning environment. In this way, their initial understanding and knowledge of the topic could be assessed and learners' interest and motivation for the topic could be examined in detail. By answering the questions after the learning unit, deeper insights could be gained into whether they had only memorized terms or also developed a deeper understanding of the topic. The pre- and post-test were to be conducted in a controlled setting, which would have allowed any comprehension problems or other questions to be addressed by the investigator. Since it was planned to ask these questions outside of VR, no conceptual change was required at this point. Nevertheless, the online survey had to be transformed accordingly.

Challenges

In general, an online questionnaire should be as self-explanatory as possible. In this case, the wording had to be critically checked for general comprehensibility and texts had to be structured briefly and clearly. If instructions are ambiguous, it is possible that learners can complete tasks incorrectly, incompletely or become frustrated by the unclear task. In a worst-case scenario, they may abandon the learning unit prematurely. Due to the new setting of the learning environment, the instructions for the learners also had to be adapted accordingly.

Transformation

Since additional requirements were placed on the online survey, three experts from media design, psychology and civil engineering critically reviewed the questions and in-

structions. Particular care was taken to ensure that the instructions and explanations for the tasks and questions were appropriately transformed from VR to the desktop environment in order to make appropriate references to the learning unit.

The pre-test begins as soon as the participant clicks the provided link. The post-test was conducted directly after using the learning application in the same questionnaire. The given answers are recorded directly on the website.

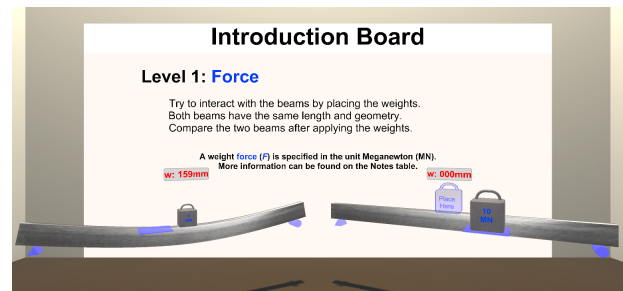


Figure 3: A learning unit in the virtual environment as desktop-based application.

Application

The developed virtual environment in Unity depicted in Figure 2 was designed to mimic a classroom setting consisting of a room with three panels. At the front, the introduction board informs the user on the current task in the experiment (Figure 5). While the notes board on the left-hand side gives supplementary information on the task as well as a summary of past learning materials (Figure 4), the question board on the right-hand side displays the in-application questions to verify the content learned (Figure 6).

In a laboratory setting, the participants would have been equipped with an HMD and a handheld controller to use in VR. Before participants start working with the application, a supervisor would have given an introduction on the structure of the experiment, instructions on the VR hardware, and a prior warning on cybersickness often caused through the HMDs (Palmisano et al. 2020). Furthermore, the software and hardware setup would be prepared for the participants beforehand to secure a smooth workflow. One of the greatest advantages of a controlled laboratory setup is guidance and aid through a supervisor at all times during the application run. Due to the exciting nature of VR technologies, particularly among inexperienced users, misuse of the equipment as well as errors on user side caused by out-of-scope behavior during the study can be minimized through communication.

In terms of navigation, users are given two options to move around the virtual room: On the one hand, the user could walk physically in the real world. The movement is mapped one-to-one to the virtual displacement. To avoid any collisions while moving in the real environment, the borders of the actual room are marked on the virtual floor prior to starting the application. On the other hand, the user

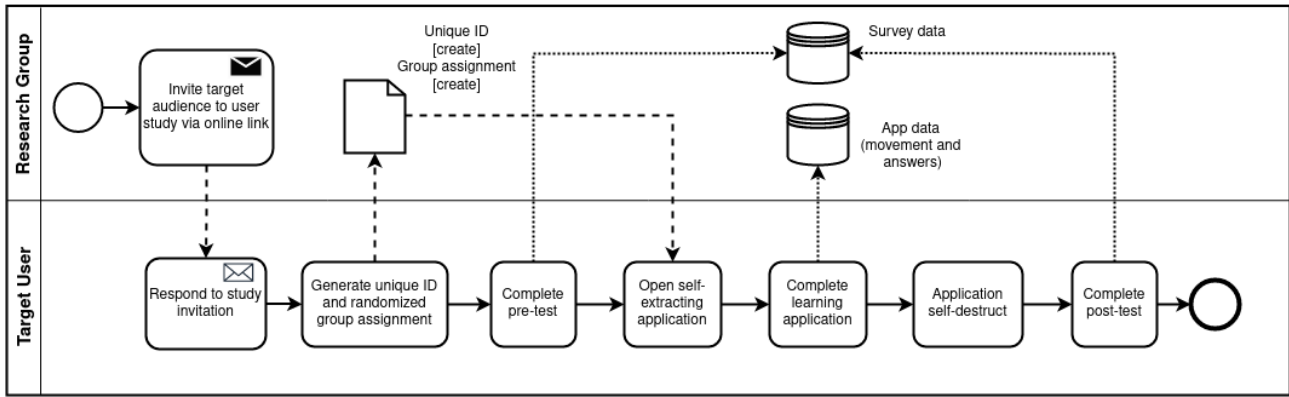


Figure 7: Adapted workflow during the pandemic for a robust data flow.

in the former part, we divided this section into the same subsections: participant recruitment, pre- and post-test, and application. Additionally, we report our preliminary results from our quantitative evaluation.

Participant Recruitment

Recruitment for the desktop-based user study was carried out through various channels. It was found that personal contact with lecturers or direct contact with other learners had the highest success rate for participation. In comparison, only a fraction of participants contacted via mail finished the survey without involving the lecturers. Compensation for participation poses an important issue in the context of recruitment. Lower cash incentives were less valued by the participating user group compared to vouchers (e.g., for coffee or bookshops) of the same amount. In addition, the portfolio of possible compensation could have been expanded to make participation more attractive overall. However, it is important for the evaluation of the results to keep the incentives as constant as possible across all participants. Therefore, this important topic should already be considered during the planning phase for the trial study with consideration of the participant occupation, task complexity, length, and location of the study. In addition to pricing of monetary compensations, non-monetary incentives can pose an alternative lever, depending on the target participants. Additional circumstances such as the political or ideological positions of the audience should also be considered nowadays, as vouchers for certain online marketplaces (e.g., Amazon, Zalando) do not find a positive standing in some groups.

In addition, more resources could be spent on advertising for the study. For example, short promotional videos have proven to be a useful tool to create a more positive attitude towards the study, which in turn could lead to a higher probability of complete participation. Such promotional videos could also be well shared via social media platforms. A personalized request or component would be beneficial to increase commitment to participation and during user participation itself. It has also proven efficient to give participants a specific time for participation.

This is also in line with expectations from social psychology (Gollwitzer & Brandstätter 1997). This shows that the framework (e.g., "when do I participate", "from which remote location do I participate") can also be decisive for success in online applications. Encouraging a certain group of participants to take part all at the same time also seemed to be particularly promising and to be associated with a high participation rate and also a high completion rate.

Pre- and post-test

For the online questionnaire to be used effectively, it was crucial that it was thoroughly checked by various experts to ensure that the instructions and explanations are comprehensible. In addition to experts from the respective subject area, learning processes from a psychological perspective should also be taken into account. Here, many critical trade-off decisions must be made between precise description and simplicity of presentation, so that learners are not overly strained. Especially in the pandemic situation, learners spend a lot of time online or in online learning environments. The more appealing and efficient these are, the more likely learners are to extract important information and work through the learning content to the end. In a more appealing learning environment, students can become more enthusiastic about the curriculum topics and have a more positive learning experience. At this point, it is worthwhile to interview some sample learners in order to better assess the overall impression of the learning environment or the learning questions and, based on this, to make minor adjustments and thus further improve the learning experience.

Application

Various learning aids and support measures (e.g., annotations and signaling) are integrated into the learning environments and their effectiveness is examined specifically for mixed reality applications. In the 3D environment, the user is able to walk around freely within the range of the room. The person is equipped with the HMD as well as the handheld controllers. The interactions are ray-based.

Preliminary results from quantitative evaluation

In a first learning psychological analysis with a subgroup of 54 learners, preliminary results were documented and published (Vogt, Albus, Montag, Drey, Hartwig, Tasliarmut & Wolf 2021). The study focuses on the comparison of two design variants. In the experimental group, corresponding elements were marked with color coding, whilst in the control group, the learning content was presented without color coding. In this first analysis, the focus was on the question of which variant is better for the use in the curriculum. Different concepts of learning psychology were taken into account: on the one hand, the learning outcomes (knowledge, comprehension, application), which should be as high as possible after the learning unit. On the other hand, it concerned the cognitive load during learning, which could be influenced by the design of the learning environment. Here, the additional cognitive load should be avoided and learners should be stimulated to provide cognitive resources for processing the learning content (Van Gog 2014). In order to analyze the effects of the design more precisely, additional consideration was given to learner characteristics. In the group under examination, there was a positive effect of color coding on the application level, which is important for the transfer of what has been learned to new fields of application. Color coding had no effect on cognitive load during learning. Further analyses and their publication are currently in progress.

Conclusions and Future Work

At the beginning of the SARS-CoV-2 pandemic, researchers had trouble estimating the prolonged period of time that countries would be going into lockdown. With this in mind, we wanted to assess the possibilities of conducting a remote study originating from an on-site study by retaining our research questions, study design, and measurements as much as possible while also accommodating to the new pandemic-specific challenges.

While remote user studies offer benefits such as the flexibility in terms of time and location of the study, they also come with some limitations. These include the recruitment process, special requirements to the application, and the pre- and post-test. For example, participants who are mostly university students in our case are more easily reached when asked directly if they can partake in a user study. Face-to-face study environments overcome the simple needs of the users while utilizing the provided technology. On many occasions, remote user studies have been shown to be a worthy alternative to on-site user tests. For future studies investigating VR applications, a promising option during the pandemic would also be to use certain online platforms and stores such as SideQuest from Oculus that harness the participant owned equipment. On the one hand, this could demonstrate advantages because the technical obstacles and the user hurdle are lowered. In addition, this offers advantages because users are not only trained, but are also accustomed to these circumstances. On the

other hand, with such platforms the personal approach is limited, and it is also difficult to narrow the desired target group. Nevertheless, there could be a lot of potential for future research.

The beginning of the user study was conducted in-lab using HTC Vive and Asus Mixed Reality hardware. For future XR user studies, we recommend to use tools such as Unity which enable to reuse the environment with multiple input devices, interaction techniques, and design layouts and to operate utilizing multiple channels. Additionally, other operating systems such as Linux and Apple's iOS should be considered. Since adaptations still have to be made for different implementations, especially with regard to different technical devices (e.g., control with mouse and keyboard, controllers, other HMDs), the cost-benefit ratio should be considered with regard to the flexibility of the application.

Due to the possibility of conducting studies independent of location, a fundamentally greater accessibility of the study can be assumed. In addition, the necessary personnel resources and thus also the financial resources are lower than in face-to-face studies, since no researcher is needed to accompany the studies. A major disadvantage of distance studies is the lack of control over the experimental conditions. This can affect the data quality in particular and thus lead to a lower validity of the results. In addition to the benefits of remote studies for restricted situations such as the SARS-CoV-2 pandemic, they should also be seen as an overall opportunity for alternative methodological approaches that are more accessible and easier to adapt to new circumstances. It must always be considered whether implementation as a remote study is suitable for the particular research project, and the advantages and disadvantages should be carefully evaluated in each case.

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