TUM School of Management
Technical University of Munich

INSIGHTS FROM VIRTUAL REALITY-ENHANCED TEACHING IN HIGHER EDUCATION

PROF. DR. DAVID WUTTKE

EDITORIAL

WELCOME FROM THE DEAN

For years, digitalization in teaching has been a hot topic at universities, and the pandemic has given it an unexpected boost. This also applies to the TUM School of Management, which sees technology-enhanced learning as an important development in its teaching activities.

Put simply, technology-enhanced learning (TEL) seeks to maximize the student learning experience by using technology. It is transforming and enhancing education and educational institutions globally. As a school, we have committed to fostering the use of TEL in our TUM School of Management Strategy 2026 in order to improve the digital experience for our faculty and students. We plan to establish a minimum level of technology-enhanced learning in all of our programs and make TEL the standard in all modules. To foster the needs of our students and the innovative elements of our programs, we will use an intelligent mix of on-site, online, and hybrid teaching.

As a lab for developing innovative approaches to education, TUM Campus Heilbronn has been pioneering the use of virtual reality (VR) in teaching as an alternative and unique way for students and professors to interact and collaborate digitally. VR offers a highly immersive environment with a clear focus on content. This white paper furthermore depicts how students are benefiting from the VR experience, identifies areas of improvement, and provides an insightful outline of how the use of VR in higher education can succeed.

I would like to thank David Wuttke for taking advantage of the many opportunities at the TUM Campus Heilbronn to initiate new approaches in teaching and congratulate him on the successful use of Virtual Reality.

Prof. Dr. Gunther Friedl
Dean of TUM School of Management

Source: TUM School of Management

PROF. DR. GUNTHER FRIEDL
Dean of TUM School of Management

EDITORIAL

WELCOME FROM THE AUTHOR

Virtual Reality (VR) has great potential, which is still vastly untapped in management education. The COVID-19 pandemic forced us to teach remotely and search for meaningful alternatives to online video communication tools. Our team explored the use of a virtual classroom environment in two courses in the summer term of 2021. In our solution, students and faculty were represented by avatars and communicated in a digital representation of a real classroom.

Why this white paper? We want to share a modern way of online teaching. We want to publish our lessons learned and hope that the insights on technical effort, didactic approaches, and organizational aspects are valuable for others who would like to embark on our journey.

Who is the target audience? We target this report to all those who are excited about VR — be it faculty, students, or teaching support staff. We want to share our perspective on what is feasible and where technology still lacks behind.

Who are we? Prof. Dr. David Wuttke is Assistant Professor of Supply Chain Management at the Technical University of Munich, TUM School of Management and based at the TUM Campus Heilbronn. He and his team are part of the Center for Digital Transformation.

Prof. Dr. David Wuttke
Assistant Professor of Supply Chain Management

Source: TUM Campus Heilbronn

PROF. DR. DAVID WUTTKE
Assistant Professor of Supply Chain Management

EXECUTIVE SUMMARY

THE FUTURE OF TEACHING IN VIRTUAL REALITY BEGINS NOW

We transformed two entire lectures into virtual reality formats to create immersive environments and foster increased interaction during the COVID-19 pandemic.

Through the course of the COVID-19 pandemic, virtual reality (VR) tools have emerged as an alternative way in education for students and professors to interact and collaborate digitally. We have pioneered and executed a semester of lectures in Production and Logistics fully in a VR environment, utilizing cutting-edge technology and providing students with a unique approach to experience an innovative way of learning through the course of their studies.

Students identified many positive benefits of a VR approach with lectures throughout the semester. First, the clear opportunity to explore a new technology (e.g., using avatars, exploring virtual spaces) to which very few have had prior exposure. Second, the new ability to communicate in a spatial environment. Third, an immersive classroom experience in which students were once again able to engage naturally with other students through a feature known as spatial voice. This allowed students to talk with those in close physical proximity whilst eliminating the voices of other participants farther away. In addition, whiteboards and ad-hoc interactive discussions fostered a smooth flow of the lecture without any breaks in technology.

“I think VR is a really good option and real alternative to the lecture hall because it gives us back a little bit more of our university feeling.”
Student in the program Bachelor of Management and Technology, TUM Campus Heilbronn

This transformation requires a well-designed and clearly-executed strategy, allowing for flexible adjustments during the semester.

To enable and accomplish the transformational experience provided to students, our team navigated and resolved a series of organizational challenges. Consideration and close collaboration by a variety of stakeholders were involved in presenting students in two separate study programs (Bachelor of Management and Technology and Master in Management) a smooth VR experience. Early planning and long lead times for VR devices and software selection, approval, and delivery were crucial for time management in spearheading this initiative, as was designing the

FIGURE 1: LENDING OF VIRTUAL REALITY HEADSETS

Source: TUM Campus Heilbronn

appropriate support elements throughout the course of the semester, such as IT support, creation of troubleshooting materials, as well as e-scouts.

We conducted a feedback survey at the middle and end of the semester, respectively, to measure how students were benefiting from the VR experience. We received largely positive responses, with a few suggestions for improvement. We also asked for drawbacks and weaknesses of the chosen approach to improve the lecture quality.

“VR gave a twist in the monotony of lectures in a video-conferencing software and gave me something to look forward to.”
Student in the program Master in Management (MIM) TUM Campus Heilbronn

We collected feedback from students and further stakeholders systematically and share it throughout this white paper.

The lack of convenient note-taking capabilities in the VR software was a frequent source of discontent from students. Another minor drawback was the discomfort induced by wearing the VR headset. However, in post-semester interviews, we found that discomfort was mitigated via frequent short breaks during the lecture period.

Clearly, this is just the beginning of VR environments in the classroom. With many students stating their wish to continue with VR (under certain conditions) even when live-learning

VR makes online teaching more natural and interactive, but can come at the expense of increased setup times and potential physical discomfort.

A dedicated preparation including alternative learning paths becomes key.

10 KEY TAKEAWAYS

1. VR offers new opportunities for smooth online teaching and collaboration far beyond other video-conferencing software. These benefits include switching seamlessly between presentations and small group interaction, as well as developing ideas together on whiteboards.
2. Alternative learning paths become key. VR is not yet ready for everyone. Although teaching in VR is, to some extent, an experiment with benefits outweighing the costs, it is important to ensure that each student can reach the learning objectives.
3. The fun factor and its inherent excitement are important to help overcome initial struggles with technology but will wear off eventually; by then, a working solution must be established. Eventually, VR can also become monotonous.
4. VR requires a new didactic approach and a new schedule. Pure VR sessions should not be longer than 90 minutes; the optimum time might sometimes even be as short as 45 minutes.
5. Technology acceptance should not be underestimated even for open-minded students. While all of our students had a technical background, some complained about the additional effort to learn a new format and suggested using established alternatives instead.
6. Social learning is a key factor shaping the value of VR approaches. If a VR approach helps bring students together, this is associated with a benefit.
7. Students consider physical discomfort as an inhibitor to future use of VR. Hopefully though, this issue will be solved by new product development.
8. Functionality still needs improvement for effective teaching in VR. The lack of note-taking ability and augmenting an existing slide deck is perceived by some students as the number one downside. An appropriate didactic format can partially mitigate this problem while ultimate hardware and software solutions are being developed.
9. Internet connectivity is a larger concern when using VR compared to low-bandwidth alternatives, which allow switching off video feeds. This creates heterogeneity among student participation, raising the difficulty of teaching.
10. Students value in-class experience more than engagement in VR, though they see value in selected, continued use of VR even after the COVID-19 pandemic. Potential applications could focus on more interactive elements, such as production or supply chain simulations involving lectures in virtual factories, plants, or other locations. In addition, short VR sessions can be a promising complement to in-class sessions.

Teaching in VR is still in its infancy and has a vast potential for being a strong alternative to standard online teaching.

Our application touches the surface of what VR can offer. Future applications will be even more interactive and likely complement classroom experience.

formats are possible again, the appetite for involving innovative and immersive technology in teaching environments is certainly present. Specifically, future focus and use of VR may be on creating flexibility whilst ensuring immersive classroom experiences for distance learning as well as enabling methods to expand interaction beyond the constraints of a physical classroom. As such, our team is in the process of programming VR lectures set in factories and other unique locations such that students may experience new technologies and truly encapsulate the essence of the forward-thinking, innovation-focused Technical University of Munich.

BACKGROUND

After one year since the onset of the COVID-19 pandemic in 2020, the digital transformation impressed upon educators and students alike became the new normal. Taking this opportunity one step further and in the hopes of creating an innovative experience for students, our team led by Prof. Dr. David Wuttke at the TUM School of Management at the Heilbronn Campus conceptualized and executed two full courses in virtual reality during summer term 2021. As with all new initiatives, many challenges and learnings were acquired throughout the process. This report seeks to share and inform, as well as provide a perspective on future developments.

Initially, we wanted to find an alternative to teaching during the COVID-19 pandemic but found a format with future potential.

TUM CAMPUS HEILBRONN

The TUM Campus Heilbronn is located in Baden-Württemberg and started in Winter Semester 2018/2019 led by the TUM School of Management. Hosting two centers specializing in digital transformation and family enterprises in the Heilbronn-Franken region, the campus is characterized by an entrepreneurial and innovative culture. Students and faculty interested in digital transformation and innovative technologies hail from a variety of cultural and professional backgrounds. A highly international student body, small class sizes, and an exploration mindset provide the backdrop for which students engage daily with their professors and colleagues. Nonetheless, like with many other educational institutions, challenges arose during the COVID-19 pandemic. Many students were unable to arrive in Germany due to travel restrictions, thus, rendering a large portion of students geographically absent. Additionally, virtual lectures conducted on video conferencing platforms became the status quo, which gradually eliminated the interaction and engagement provided by small class sizes. While there are many improvement opportunities in the scope of digital teaching, our team chose a radical innovative approach leveraging VR.

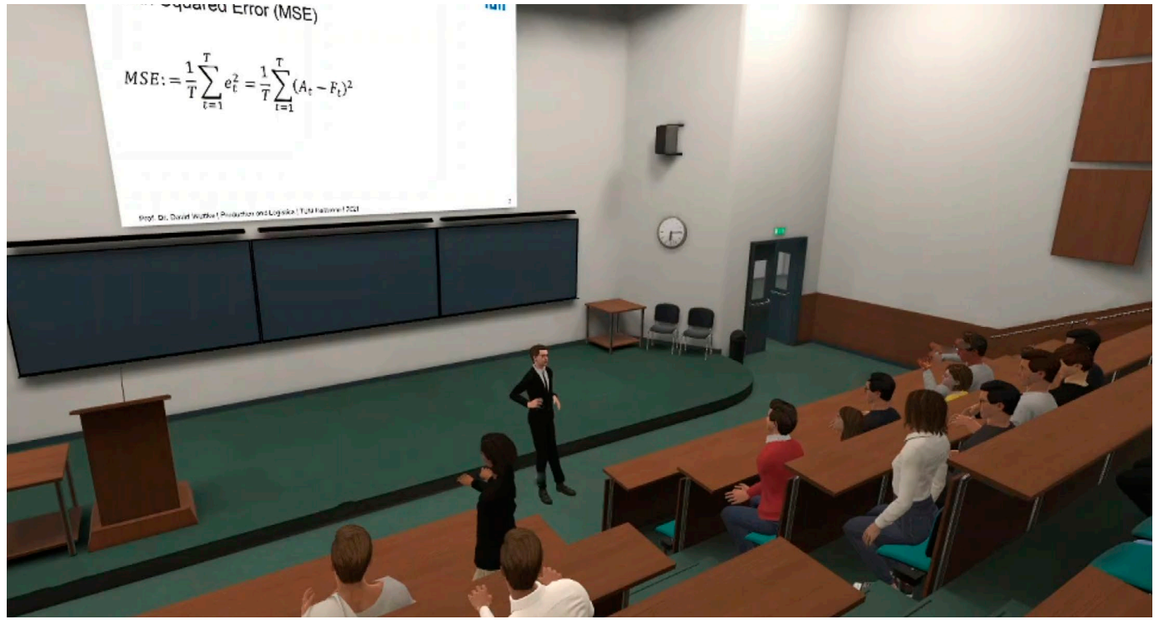
The TUM Campus Heilbronn offers various opportunities for testing innovative teaching formats like ours with the vision of spreading new formats to other TUM Campuses.

FIGURE 2: OUR TEAM

From left to right: Begimai Marlenova, Prof. Dr. David Wuttke, Mrunal Mohadikar, and Sairam Sriraman

Source: TUM Center for Digital Transformation

FIGURE 3: VR SCENE IN A LECTURE THEATER



Source: TUM Center for Digital Transformation, Screenshot of VR environment

The VR project and its ongoing follow-up projects are true team work, comprising a professor, three research assistants (PhD students), two e-scouts, and two student assistants.

TEAM OF THE PROFESSORSHIP IN SUPPLY CHAIN MANAGEMENT

Our team is anchored at the Center for Digital Transformation. While we conduct research on digital transformation in industry (e.g., on the use of augmented reality in production ramp-ups), we are also curious as to how those technologies will shape our way of teaching and how they can be used to increase the quality of online teaching. Our team consists of Prof. Dr. David Wuttke, Assistant Professor of Supply Chain Management, and research assistants Begimai Marlenova, Sairam Sriraman, and Mrunal Mohadikar. In addition, three e-scouts (student assistants) supported our lectures and two student assistants helped us in testing and crafting our approach.

APPROACH TO VIRTUAL REALITY

In summer term 2021, we used a virtual reality environment to substitute online sessions in video conferencing software. Students were equipped with VR headsets or PCs and joined those online sessions at fixed times. Students and the professor alike were then represented by avatars, potentially mimicking their appearance. We explored different virtual rooms, such as a lecture hall, a large executive meeting room, an exhibit hall and various event locations. Each of these had specific features. For instance, the lecture hall resembled a real university lecture hall; however, this also made working in small groups more difficult. The exhibit hall was large and provided multiple spaces for group work interaction. At the same time, teaching from center stage was more difficult as not all students would have a convenient location in the room. Event locations finally turned out to combine the best of both worlds, having great opportunities to present from center stage and enough space for dynamic group work. The platform further allowed some degree of customization, such as placing whiteboards at specific locations, replicating the main screen content, or adding diverse items (e.g., chairs, logo). In addition, it has a feature called “3D voice” which is essentially spatial audio. By turning this feature on, the loudness of voices drops in the distance, as in the real world. This feature turned out to be key for seemingly starting group work in different areas of a room. Another convenient feature of this solution is centralized control. Administrators or session organizers can seat all students automatically, mute them, and switch between spatial audio and a flat audio signal. The latter is helpful for presentations.

We used state-of-the art VR headsets and a VR platform of a leading VR event platform provider.

Various choices and flexibility are key in a VR environment to adjust the process over the course and continuously improve the approach.

FIGURE 4: VR SOCIAL INTERACTION

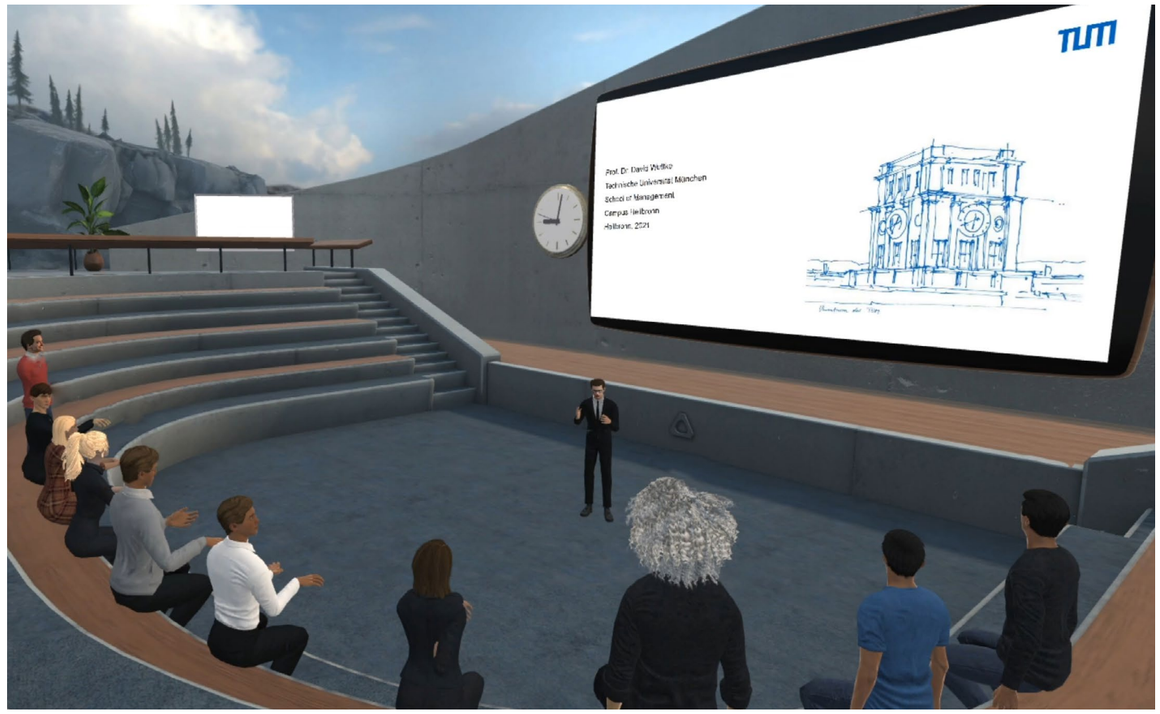
Source: TUM Center for Digital Transformation, Screenshot of VR environment

The planning process started 5 months prior to the first session in VR.

PLANNING THE USE OF VIRTUAL REALITY

To conceptualize a virtual classroom, both hardware and software solutions were carefully identified, evaluated using cost, quality, user experience, applicability, among other criteria, and ultimately elected for use by the university. Lending of the headsets was centralized at the Heilbronn Campus and facilitated by the IT organizational lead for VR activities at TUM Campus Heilbronn. Students were given the opportunity to schedule a pick-up time slot during the first week of the semester where strict hygiene rules were observed. Alternative times were made available to students who were unable to do so, either due to COVID-19 complications (e.g., quarantine, geographical distance) or other conflicts upon request. All VR headsets were then returned after the semester. Customized FAQ and tutorial guides for both VR headsets and the VR platform were created and published on our online learning platform to field any questions in advance. They included topics, such as compatibility with other VR devices, alternative hardware options like personal VR headsets, computers, smartphones, and tablets, which were available to all students, particularly serving the minority of students who either could not schedule a pick-up (e.g., out of country) or found the use of a VR headset inaccessible (e.g., dizziness, headaches, extreme discomfort).

FIGURE 5: VR SCENE AT AN EVENT LOCATION



Source: TUM Center for Digital Transformation, Screenshot of VR environment

Student assistants were recruited to help in the back-end during lectures to record the lecture, create various classroom visual elements (e.g., place virtual chairs, whiteboards, backgrounds), and display any visual media (e.g., presentations). Specifically, each lecture was attended by the professor and two student assistants: one to display and control visual media and one to record the entirety of the lecture uninterrupted. This enabled a set-up such that the primary focus of the professor would be on teaching the material and any logistical/technological issues were handled in tandem by the student assistants.

Besides the professor, we required two student assistants in each lecture.

“A strategic approach towards digital transformation is key. That also pertains to tapping into new territory when teaching with the aid of VR.”

Prof. Dr. David Wuttke, Center for Digital Transformation, TUM Campus Heilbronn

Given the recency of the solution, regularity of updates, and new features of the online environment, it seems recommendable to distribute those tasks. Recorded lectures were then made available to students on our online learning platform to watch/rewatch as needed.

INVOLVED PARTIES

Due to the lack of standardized processes and routines, various parties needed to be considered in the planning and execution process.

STUDENTS

Student participants had the unique opportunity to experience and use a new technology through the course of one semester. While a select few students initially struggled with technical difficulties, the break from continuous video conferencing classes and the variety provided by virtual environments were greatly appreciated and welcomed by students. This encouraged participation and willingness to engage with the new devices and platforms.

PROFESSOR

The main task for the professor was to redesign the didactic concept of the lecture. Two design thinking workshops were conducted with PhD, graduate, and undergraduate students to tailor the new format to the needs of the students. Key learnings included different learning paths to meet individual needs, splitting long sessions (previously, all 180 minutes taught on one day of the week) into shorter ones (45, 45, and 90 minutes), and to spend considerable resources on the smooth onboarding of students. This upfront planning was accompanied by continuous improvement circles throughout the lecture, for instance, by constantly adjusting the format. Whereas initially the course was taught akin to a physical classroom approach with a majority focus on presenting theory through slide decks, we continuously replaced those elements with more interactive discussions to leverage the key advantages of VR. The second major task for the lecturer is teaching in VR. Once the technical setup is completed, a strong team of student assistants trained and experienced enough in supporting VR, the actual teaching is akin to a physical classroom, with the added benefit of always having sufficient (clean) whiteboards available and sufficient space for dynamic student interaction.

IT AND ADMINISTRATION

The support from IT and various administration departments enabled the procurement and distribution of the VR devices and software licenses to the VR platform. After testing and selecting the hardware and software options, the university began the tendering process. Student borrowing contracts were additionally drafted and signed by the appropriate TUM representatives, after which the devices were distributed by the IT-VR representative. At the end of the course, the return of the VR headsets was also centrally managed and facilitated by IT. While these processes worked very well, it is noteworthy that a comprehensive planning and dedication to the project are crucial.

E-SCOUTS

Student assistants, also called e-scouts in this context, were involved during the lectures, responsible for ensuring that the lecture content was displayed, the lecture “room” was appropriately selected, and managing the controls (e.g., seating, muting or unmuting participants, and enabling 3D voice). E-scouts also recorded each lecture via desktop or phones and uploaded the recordings on a video streaming platform. For these purposes, two e-scouts attended each lecture session. Additionally, one e-scout attended each exercise session (conducted with video conferencing software by PhD students). While it is technically feasible to run online lectures in the VR platform without e-scouts, doing so adds substantial stress on the lecturer. In the first session, the lecturer tried to run the presentation from his PC but regularly struggled with switching between the real world (i.e., PC and Power Point) and the virtual world (i.e., the classroom on the VR platform). Only by delegating those tasks to an e-scout, were we able to create a smooth flow.

The TUM e-scout approach has proven to be extremely helpful during this class. They ensured a smooth flow and enabled the professor to focus on teaching rather then technology.

Support by others is key to maintain the focus on content and students. The professor should not be distracted by advancing power point slides, which requires more attention in VR than in a physical classroom.

We created over 80 videos and 200 quizzes on our online learning platform to accommodate students without the ability to participate in VR sessions due to various reasons.

ALTERNATIVE LEARNING PATHS

To accommodate for different learning styles and individual needs of the students, more than 80 complementary prerecorded lectures were also available on our online learning platform for students to watch in conjunction with the VR lectures. In addition, over 200 multiple choice questions on our online learning platform as well as a completely new designed exercise sessions in video conferencing software were made available to allow for different learning paths and mitigate possible risks inherent to VR-based lectures.

CONSTANTLY IMPROVING

Our key objective was to start right from the beginning of the modules to offer an advanced online experience compared to teaching the same modules with video-conferencing software in 2020. Still, we were also aware of the experimental nature of our lectures. And so, we decided to be constantly open for student feedback. For instance, changes related to technical issues, such as replacing a microphone or adjusting settings were made to provide a better experience. We also started using relatively small virtual screens akin to those of real rooms and soon learned that those should be larger. Since placing multiple screens with identical content can be done seamlessly in the VR environment we had chosen, we added multiple screens. We further constantly explored various locations until we identified certain event locations to be the most useful. Besides these technical changes, we also made a series of teaching related changes. While we started teaching as we would in a physical room, with presenting content as usual, we soon moved away to more interaction. Specifically, students regularly had to work on specific tasks in small teams. In addition, we found the whiteboard feature of our chosen VR platform quite helpful. And so, we decided to derive theory and equations rather on those whiteboards than conveying them through PowerPoint presentations. Overall, being prepared to constantly change the format based on students' feedback was very important in our context.

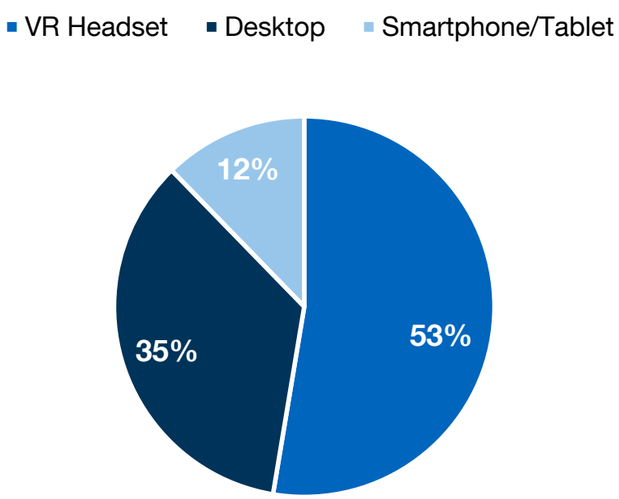
QUANTITATIVE STUDY

SURVEY AND ANALYSIS

Combining a mid-term and end-of-semester survey, we obtained early feedback to constantly improve our approach.

We conducted two surveys, one during the semester (mid-term survey), and one afterwards (end-of-semester survey). We used feedback from the first survey to adjust our didactic approach during the semester. We then used the follow-up survey to explore the effectiveness of our measures. In addition, both surveys serve as a baseline for this report. The target respondents of the survey were master students in management (MiM) and bachelor students in management and technology (BMT) at the TUM Campus Heilbronn, who attended the lecture "Production and Logistics" in a virtual reality interface. The survey was emailed to them once at the middle of the semester and once at the end of the semester. The students were mainly asked about their opinions and behaviors as the users towards virtual reality. The questions were mostly multiple-choice questions with follow up why-questions and Likert scales, and it ended with an open question about their further comments on the topic. The mid-term survey had a response rate of 64% (N=45) and the end-of-semester-survey had a response rate of 40% (N=28). This drop can be explained as arguably (1) the former survey was early enough to use results for improving the lecture, (2) some students likely perceived that giving feedback once might be sufficient (given the large overlap in questions), and (3) the latter survey coincided with the study period for exams.

FIGURE 6: DEVICES USED BY STUDENTS



RESULTS

In presenting the results, we note that all interpretations are purely exploratory in nature. Neither the study design, nor the size of the courses with a total of 70 students, nor the number of courses is sufficient to draw statistically valid conclusions. Yet, they are indicative of some tendencies which may be examined in other contexts.

The majority of students used VR headsets to join the lecturer on the VR platform (Figure 6). At the same time, we note that almost as many chose a desktop solution (e.g., laptop) or smart phone/tablet. In part, this relatively large number of non-VR-headset users can be explained with the fact that some students were not able to visit the Heilbronn campus to borrow a device (e.g., due to travel restrictions from foreign countries). Some students later reported on feelings of dizziness and so they switched to less immersive alternatives.

Despite the intentional focus on VR devices, still a relatively large fraction (47%) of students eventually opted for less immersive devices.

SCHEDULE PREFERENCES

Before turning to the perception of VR devices, we asked students about the time schedule of the module. As per module description, Production and Logistics, in which the VR teaching took place, comprises 4 academic hours per week (i.e., 4 x 45

STUDENTS' THOUGHTS

IN FAVOR OF SHORTER SESSIONS

"Shorter sessions feel more productive. Also, continuous sitting sessions are reduced."

"For now, 45 minutes is better, since in the case of the 'many' technical difficulties, I will only miss a 45 minute session rather than the full 90. For example, today I missed a 90 minutes lecture because [an update took too long with my Internet connection and system]."

"In a VR environment, 90 minutes can be tedious on the eyes."

IN FAVOR OF LONGER SESSIONS

"The break in the middle of the 90 min lecture is helpful enough. Plus, if we had two 90 min lectures, the schedule would have been a little more stable, I feel. I do not like changing schedules. It makes me miss on some lectures sometimes (but that's on me, I guess)"

"Time efficiency, [...] technical issues happen mainly at the start of the lecture, so dividing the lecture of 90 mins in two of 45 mins means to have two times the initial technical issues."

"The 45 minutes lectures make it seem like we have too many meetups in one week even though the actual class is short, but mentally it may still register as 'too much', especially in comparison to the fact that it means we now meet up 4 out of 5 days a week whilst for other courses we meet up only 1 day a week. With the 90 minute lectures, it's a nice session, we may just need a short break in between for those that wear a headset."

The discussion on the optimal length of sessions - 45 minutes versus 90 minutes - is still ongoing with strong arguments for either preference.

minutes = 180 minutes). In former on-campus lectures, those were taught on one day, e.g., from 9 AM to 12:15 PM (including a 15-minutes break). Here, we decided to split it into 45 minutes, 45 minutes, and 90 minutes per week. Around 89% of students believed that this course has more lectures per week than other courses. Some of those students justify their perception with relatively high setup times for each class (being online, having the device switched on, and being logged-in consumes about 5-10 minutes). Yet, if allowed to choose between attending 45-minutes and 90-minutes lectures, 53.3% of students would rather attend the shorter lectures, while only 24.4% of students preferred to attend the longer one. The reasons that students provided for their preferences of shorter lectures were mainly about consequences of using VR headsets like dizziness, discomfort, tiredness, and technical difficulties of VR software like unexpected updates before the lectures, or poor Internet connection (see box: *Students' Thoughts*).

The session-length trade-off is ultimately between physical discomfort and setup times for each session.

CLASS ATTENDANCE

When asked about the frequency of their attendance in VR lectures, around 36% of students said they are attending all the sessions, while 55% of students were attending 1 to 2 sessions per week and 9% of students had not attended any sessions. In 71% of the cases, students further reported to have changed their attendance pattern. The reason behind the change of their attendance behavior varied from technical difficulties that showed up during the semester, distraction with or without VR headsets, their busy schedule throughout the semester with other courses, and different personal learning methods. For instance, one student reports on experimenting with different alternatives: *"To be honest, at first I was a little bit skeptical, whether the VR sessions have some advantages; but when I once joined via PC, I recognized that I get more distracted not using VR than while using it."*

Regarding a comparison between students' attendance in their different lectures throughout the semester, 40% of them mentioned that there is no difference, while 31% mentioned they attend this course's lecture more frequently, and 29% mentioned they attend this course's lectures less frequently. The most frequent stated reasons for an elevated attendance revolve around the technical innovation, content, and interaction.

Course attendance, on an aggregated level, did not change during the semester. However, individual students changed their attendance decision.

"As the semester advances my schedule gets more and more messy, and when I already know that I will miss one of the three sessions/week, I rather go with the videos [on our online learning platform]."
Student in the program Master in Management (MIM) TUM Campus Heilbronn

The top reasons that prevented students from participation are grounded in the offered alternative learning paths. Being able to study (linear) online videos with a comprehensive amount of automatically corrected quizzes online in combination with comprehensive exercise sessions in video conferencing software better meets the learning style of some students. This emphasizes the importance of providing alternative learning paths in VR-based online lecturers.

PERCEIVED BENEFITS

Besides the direct link between the use of VR and the attendance rate, we also surveyed the perceived VR benefits by students (Figure 7). Throughout the semester, the feature to chit-chat with classmates gained importance. This reflects the importance of social learning. Rather than being left alone at home, VR enables at least some form of informal interaction with others. The immersive classroom experience was equally valued but stayed constant over time.

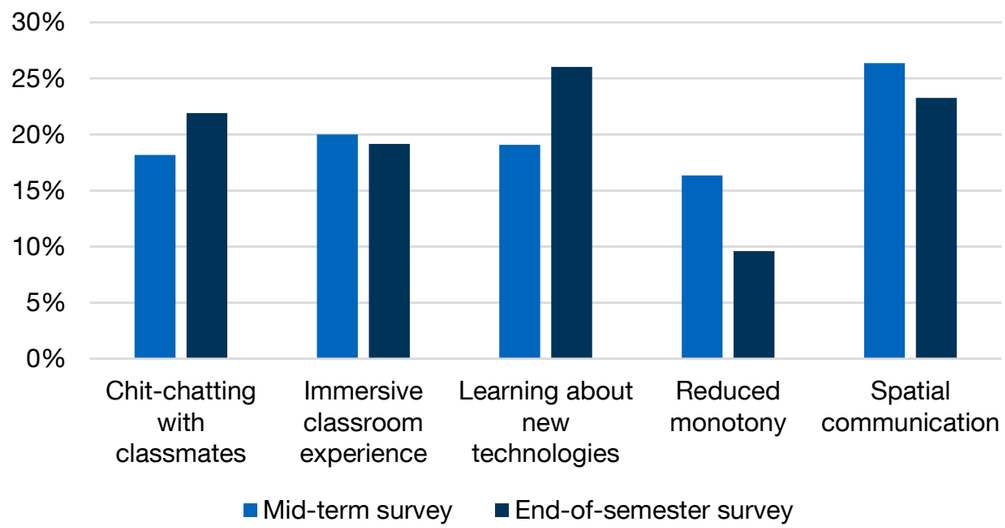
Social learning is among the most important features and perspectives of VR-supported online teaching.

"Just 'doing something cool in VR' is beneficial at the beginning but not sustainable."
Prof. Dr. David Wuttke, Center for Digital Transformation, TUM Campus Heilbronn

The aspect of learning about new technologies increased in importance and became the top benefit at the end of the semester. In contrast, reduced monotony as a benefit became less relevant. This captures the fact that the aspect of novelty and the initial excitement wear off rapidly. When the initial excitement ends, it is important to have established long-term benefits of VR. Extrapolating this trend, however, the initial excitement may be enough to overcome some technical struggles that occur particularly at the beginning of such a teaching project.

When the initial excitement ends, it is important to have established long-term benefits of VR.

FIGURE 7: PERCEIVED BENEFITS OF VR BY STUDENTS



The benefits notwithstanding, VR still has several drawbacks that need to be mastered. If it is not possible to address them entirely, hybrid approaches of limited use of VR might be a feasible approach.

PERCEIVED DRAWBACKS

Turning to the perceived drawbacks of VR by students, we clearly note that dependence on Internet connectivity is a key struggle (Figure 8). Other than video conferencing software where one might turn off videos or video feeds are automatically compressed to reduce bandwidth requirements, the VR platform is quite demanding when streaming a virtual scene with spatial audio in real-time. In contrast to adaptive compression in streaming videos, the stream in the chosen VR platform is static and so students with lower bandwidth sometimes had difficulties in accessing a session or lost connection during the lecture.

“When standing far away from the blackboard (in the virtual space), it gets very blurry and over time that causes dizziness. Furthermore, you should be able to select an eye care program to eliminate problems with the eye.”

Student in the program Bachelor of Technology (BMT)
TUM Campus Heilbronn

Noteworthy, this problem became less relevant over time which can be related to newer versions of the VR platform, the fact that some students switched to computer access instead of VR use and that more and more students during the semester were able to move to Germany where they sometimes had a better Internet connection. The difficulty of use was, interestingly, rated as a minor issue. We believe this is due to comprehensive training sessions at the very beginning of our courses, where we dedicated 90 extra minutes as training sessions. Discomfort was clearly present continuously. Students accordingly felt wearing a VR device for 45 or 90 minutes to be a major struggle and we concur with the perception. In part, VR devices can create dizziness (but this can be dealt with by moving slower and making use of teleportation features instead of walking around). Dizziness can eventually be further reduced by better VR headsets with an increased resolution and frequency. In part, however, this relates to the still heavy VR devices. Our VR headsets weigh about 700g, which becomes quite heavy over time. The heavier a device, the stronger the mounting must be to carry it, which can add further strain. We expect that new product development will be necessary to provide lighter VR headsets. But eventually, the feeling of dizziness is very subjective and potentially will persist for some students.

The weight and physical comfort should not be underestimated.

So, there is hope that physical discomfort as one of the top downsides of VR will eventually disappear. The main issue that became even more severe around the time of exams (i.e., end-of-semester survey) is taking notes during the lectures. Being in a completely virtual, immersive environment, students cannot see their desk in front of them and cannot annotate slides. This makes it difficult for students to have access to handwritten notes while preparing for the exams. One way to deal with that is through built-in functions by the VR platform; though currently the capability of writing in VR is quite limited and yet insufficient to deal with this issue. Voice recognition algorithms are being improved and might become a feasible solution so that students can dictate their notes. Yet, this creates some overlap between hearing content and dictating notes, which appears to be only a partial solution to the problem. A, perhaps, more promising vision is the development of keyboards recognizable by VR

Technological advancements will solve some, but not all drawbacks of VR. Technical issues, such as taking notes seem more solvable than overcoming social distance.

FIGURE 8: PERCEIVED DRAWBACKS OF VR BY STUDENTS

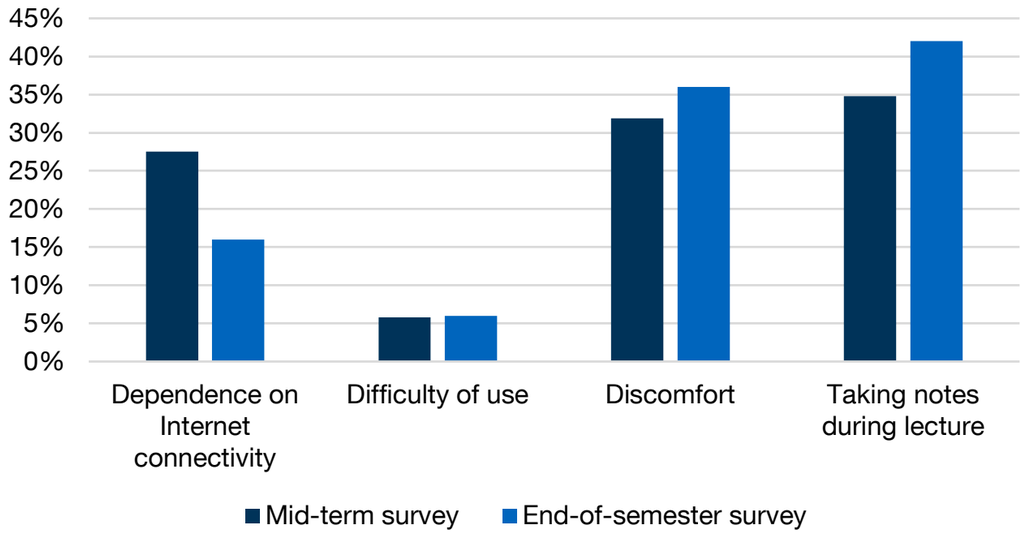
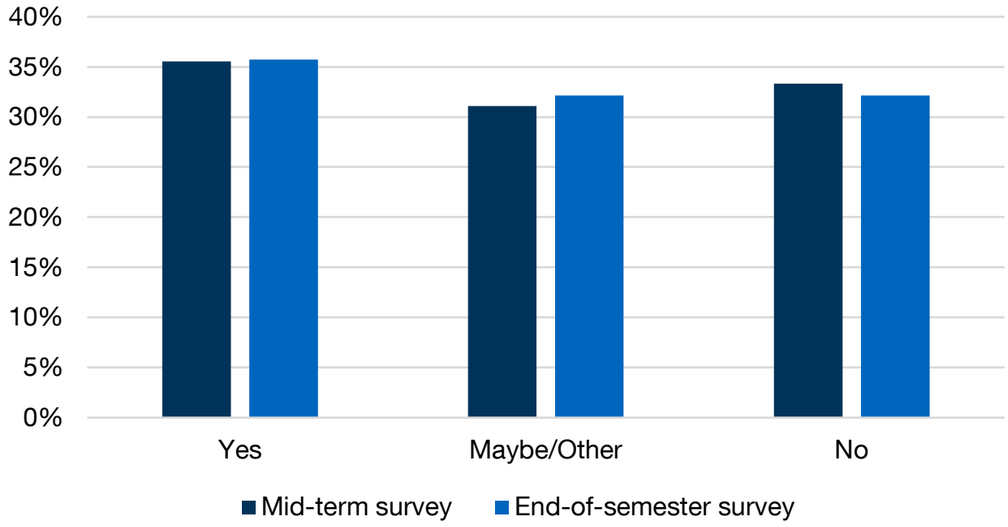


FIGURE 9: PREFERENCE TO USE VR AFTER PANDEMIC



Offering alternative learning paths (e.g., with online video units) eventually increases heterogeneity among students making teaching more difficult.

VR AS A COMPLEMENT TO VIDEOS

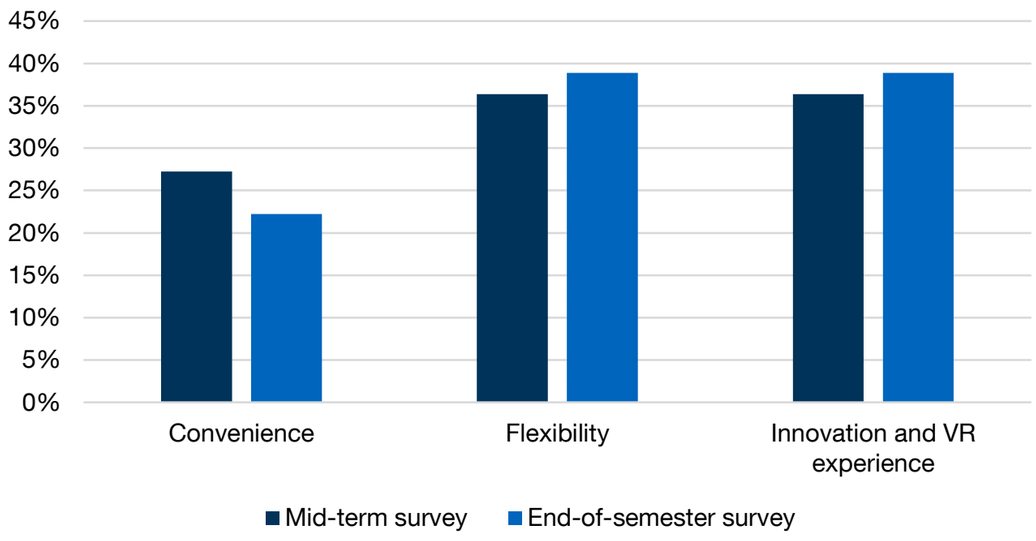
When it comes to improvement recommendation, an interesting trade-off arises between repeating contents from online videos and purely offering complementary content. From a teaching point of view, these additional videos give rise to heterogeneity. Without having any online videos, all students are likely unprepared. However, this also increases the importance of covering all facets in the VR lecture (which can cause stress at times). Having online videos available reduces this stress as students can study them in depth. Yet, expecting students to be prepared leads to the aforementioned heterogeneity as some, but not all, will watch them. When assuming students are prepared, some will be lost. On the other hand, when assuming students are unprepared, those who studied the video units might become demotivated. Some students prefer to consider online videos as complements to VR interaction, as expressed in the following quotes.

"Content should be taught via online videos and interaction should take place in VR without repeating all of the content again. This could save a lot of time."

"Pre-recorded videos with live lectures for discussion and interaction for knowledge consolidation and clearing any doubts/questions. Last but not the least a live yet recorded exercise session to apply the newly learned theory."

headsets. When this becomes available, students may likely add notes. However, even this will not solve all issues since notes would need to be mapped to PDFs or PowerPoint files and not just recorded as a pure text file. Nonetheless, we see note-taking as a technical limitation that will eventually be solved. As such, we observe that currently, the drawbacks are quite limiting, but can be expected to be overcome, and thus, pave the way for more VR use in classrooms.

FIGURE 10: REASONS IN FAVOR OF USING VR IN THE FUTURE



VR AS A SUBSTITUTE TO VIDEOS

Other students feel that pre-recorded videos should be a substitute to VR sessions, capturing indirectly the idea of alternative learning paths and preferences.

"I think it's a nice twist on the regular lectures and I am positive that many people who prefer group work enjoy this type of lecture format, however people (like me) who can focus better with videos or on their own may find it a bit distracting. In that case however, I think it's nice that we have an option to choose either the VR lectures or the pre-recorded videos."

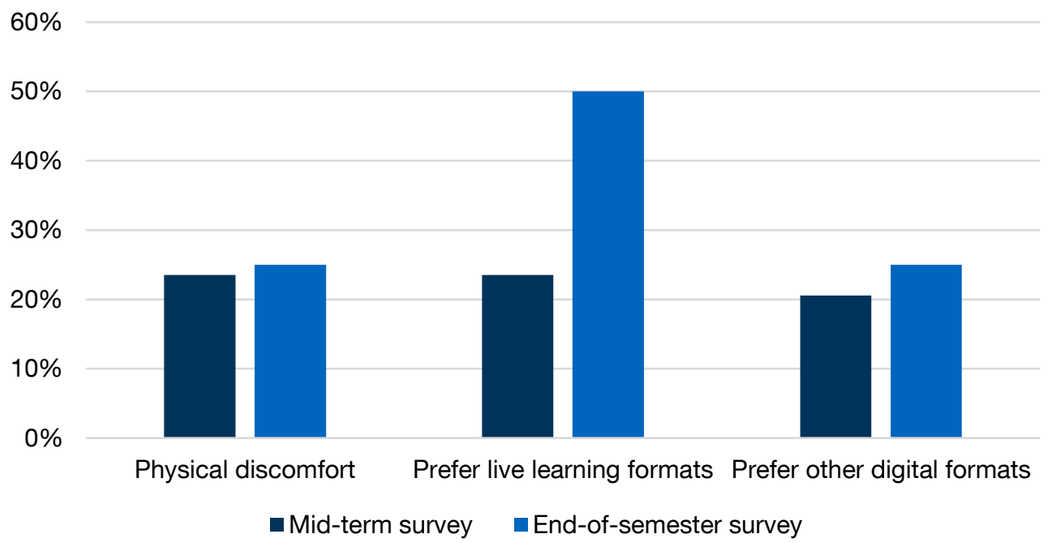
"I think it is a really great way of finding an actual alternative to being in university studying as it gives us back more of that university feeling. The possibility to chat with classmates and actually feel like we are studying together is a lot more motivating as well as the possibility to raise your hand gives it a more comfortable feeling. Additionally, when comparing this format to [video conferencing software], I have the feeling people do not have as much of a barrier to speak if they are talking with an avatar then when they have to turn on their camera in [the video conferencing software] and then their picture is focused on when they say something."

USING VR AFTER THE COVID-19 PANDEMIC

We then explicitly asked students about their expectations on the use of VR in the future, and whether there they see a future use even when teaching in a physical classroom becomes available again. This answer was, in aggregate, quite consistent across the semester with a third wishing to continue using VR, a third undecided (that is, they would appreciate it under certain conditions) and a third opposed to VR use (see Figure 9). The reasons

About a third of all students would strongly appreciate to use VR even after the COVID-19 pandemic, another third is undecided.

FIGURE 11: REASONS AGAINST USING VR IN THE FUTURE



The reasons in favor of or against the use of VR in the future resonate with the perceived advantages and disadvantages.

in favor of VR are convenience, flexibility, and the innovative VR experience (see Figure 10). The latter of which increased over time. The reasons in opposition to using VR are physical discomfort, preference for live sessions, and preference for other digital formats, such as video clips or video conferencing software (see Figure 11). Throughout the semester, the preference for live sessions increased substantially. This likely reflects the increasing need to physically interact socially with others.

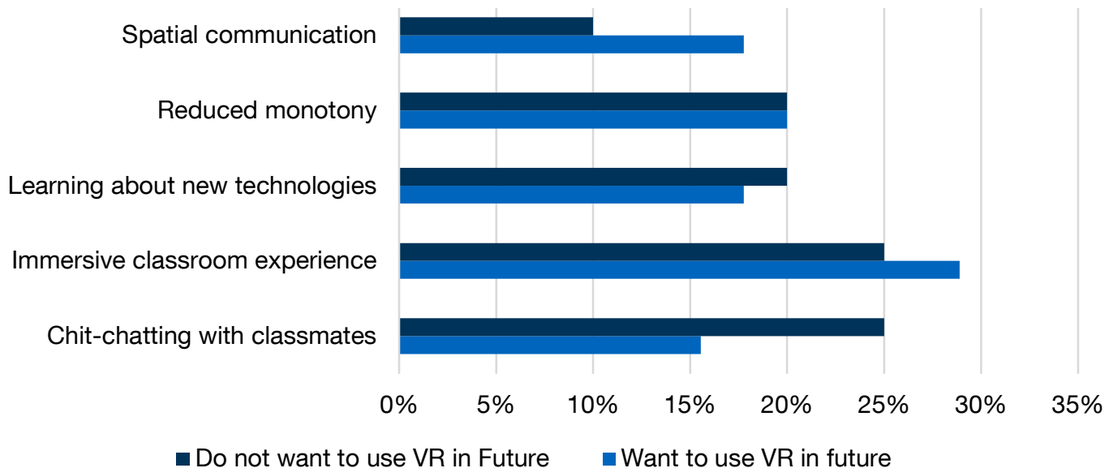
CONNECTION BETWEEN PERCEIVED VALUE AND EXPECTATIONS

To examine whether the replies suggest some differences in our sample between students who would like to use VR in the future and those who are opposed or would do so only under certain conditions, we can further split the perceived benefits and perceived drawbacks by the two groups. Since we departed from a small sample size, such analysis should be viewed with caution and deemed exploratory in nature. For the sake of brevity, we focus on the mid-term survey here.

There is a slight tendency such that students opposed to using VR place more emphasis on chit-chatting with classmates.

In terms of perceived benefits, both groups see similar advantages (see Figure 12). Though those who would like to use VR in the future seem to value spatial communication more, that is, they like the features of group work and communication with the professor. The remaining students found chit-chatting to be relatively more important. One could conjecture that they prefer physical classroom formats as this gives them even more chances for social interaction. So, perhaps those students value breaks between physical classroom sessions more and feel that VR will never replace them.

FIGURE 12: PERCEIVED BENEFITS SPLIT BY WISH FOR FUTURE USE



In terms of drawbacks (Figure 13), those who would like to use VR in the future criticized the lack of a note-taking ability the strongest; one out of two answers captured this. For them, envisioned future uses could be on a case-by-case basis where this issue is less salient. Those who are opposed to using VR in the future seem to be more concerned about difficulty of use and the dependence on Internet connectivity. A possible conclusion is that students who suffered from either of the two experiences are more opposed to VR. In contrast, physical discomfort seems to be less related to the wish of using VR in the near future. If this pattern holds true in a larger population, this would imply that technical issues and connectivity issues are not only a threat to active class participation and learning in the present, but also cause students to take a more negative perspective on novel technologies, such as VR.

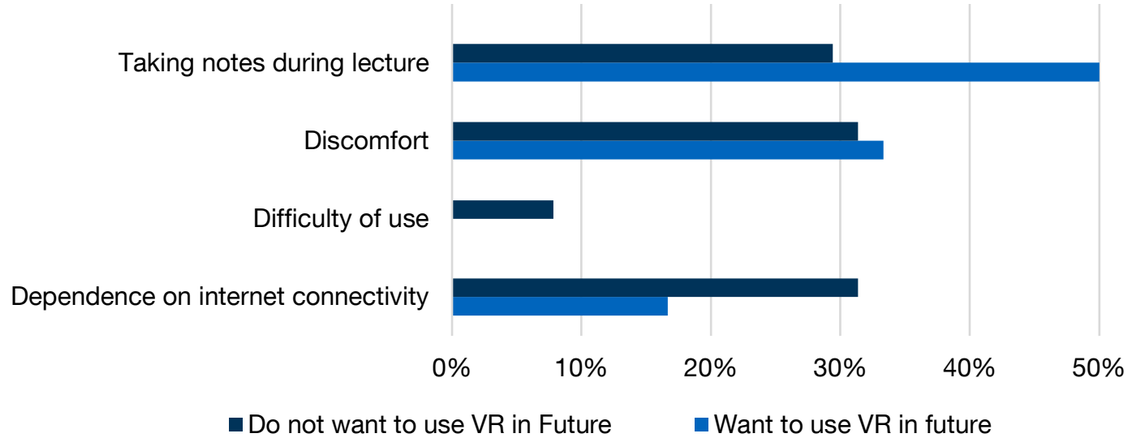
Students who do not prefer to use VR in the future often criticize their dependence on Internet connectivity and ease of use.

CONCLUSION

Overall, our inquiry demonstrates that VR has the potential to improve online teaching. Students generally state multiple strengths and advantages. On a spectrum between pure online teaching via video conferencing software and teaching in a physical classroom, it appears that our approach is seen, on average, more interactive and beneficial than video conferencing software but clearly not on the same level as teaching in a physical classroom. In addition, students stated several current drawbacks that inhibit further use of VR. While some limitations will be resolved, there is also the potential to adjust the didactic approach further to deal with some issues even before the technical solution is available.

Before technical solutions for all problems are found, adjusting the didactic approach can go a long way in improving VR lectures.

FIGURE 13: PERCEIVED DRAWBACKS SPLIT BY WISH FOR FUTURE USE



THE ROAD AHEAD

VR IS THE FUTURE

OUTLOOK

Based on our survey, informal feedback talks and interviews with students, our own observations, and discussions with others, we identify several conjectures about the use of VR in the future. Summarized in the box "The Road Ahead", those should be considered subjective and, in part, speculative.

We expect tailored approaches to VR-based online teaching to combine the best of both worlds.

We expect to see VR simulations complementing our approach.

We expect VR to be highly relevant in executive education.

THE ROAD AHEAD

1. We envision that VR will rarely be used as the sole format for online teaching. Certain sessions are more naturally taught in video conferencing software, for instance, question and answer sessions. Likewise, standard lectures are better suited for online video clips. VR environments like the chosen one are strongest when interaction is central, as in teaching cases, workshops, or group work. We expect to see more tailored approaches in the future.
2. We expect that VR simulations will be developed that go beyond our chosen approach. Universities have already started to create and use case studies in VR and we expect to see more of this.
3. Even students who are opposed to using VR in the future, to a large extent, appreciate the chance of experiencing new technologies; thus, we expect to see the use of VR as a beneficial element as a complement to many courses.
4. We expect new product development to solve several current technological and study-related challenges. Specifically, the integration of keyboards to VR headsets with a seamless option to efficiently take notes during online lectures will mitigate an important shortcoming in our approach.
5. We expect the use of VR in education to differ by program. For degrees that require students to be on campus all semester, we expect to see an increase of VR use for simulations or as isolated complements to showcase this technology. For programs with dedicated on campus phases (e.g., executive education, certificate programs), we expect VR to be used more widely as a complement to on-campus sessions.
6. Finally, we expect more people - and perhaps also you - to become excited about the new opportunities and use VR in the educational context.

CLOSING REMARKS

Since early 2020, our team has been working on exploring VR solutions to improve teaching in the area of operations and supply chain management. The COVID-19 pandemic then forced us to accelerate our plans and so we taught the summer semester of 2021 in virtual reality.

While this was not the way we first envisioned the use of VR, this project enabled us to obtain valuable insight and provide novel value to our students. Building on systematic feedback presented in this white paper and our own observations and ideas, we identified several key take-aways as stated at the beginning of this report.

Even just a few classes in VR make a difference.

“Despite a lot of fun and great feedback, our project only scratched the surface of what will be possible with VR in management education.”

Prof. Dr. David Wuttke, Center for Digital Transformation, TUM Campus Heilbronn

Based on our own experiences in this project, discussions with students, and feedback from further faculty, we are convinced that VR is the future of interactive teaching in the age of digital transformation. While predicting the future is always difficult, we would not be surprised to eventually see virtual reality (and augmented reality) elements as frequently as PowerPoint presentations today.

We expect VR and AR to become increasingly relevant for all lectures.

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