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Teaching Operations Management with Virtual Reality: Bringing the Factory to the Students

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ABSTRACT

Recent developments in virtual reality (VR) technologies offer new opportunities for teaching management courses. The objective of this paper is to present one way to use VR to teach operations management. In partnership with a global manufacturer, we integrate virtual environments of the manufacturers' real factories in a course assignment. The assignment was used in two graduate operations management courses. Theoretically, we draw on the concept of immersion. To evaluate the effects of VR on students' learning experiences, we use focus groups and a survey. We find that VR can be implemented cost-efficiently in operations management courses and present one way to do it. Considering effectiveness, we find that students generally perceive that VR improves their learning experience. The presented VR assignment provides students a guided discovery learning, which is active. However, we also find several limitations with the current technology, which can be overcome in future implementations. Teachers can use the idea and findings presented here to innovate their own teaching by means of readily available and low-cost VR technologies.

Keywords: Virtual reality, Operations management, Immersion, Active learning Guided discovery learning, Virtual factory, Teaching innovation

INTRODUCTION

"If the mountain will not go to Muhammad, Muhammad must go to the mountain." While the roots of this Turkish proverb go back several centuries, recent advances in virtual reality (VR) technologies provide unprecedented opportunities for "bringing the mountain to Muhammad." In this paper, we describe how we "brought the factory into the classroom" by integrating VR in operations management courses. We did so by asking students to complete a course assignment using information gained from virtual environments of six factories of a global manufacturer.

There are repeated calls for more active learning experiences in business curricula (Brandon-Jones, Piercy, & Slack, 2012; Rollag & Billsberry, 2012). A common way to make learning more active in operations management courses is to organize field trips to factories. Such field trips help students better understand and learn concepts and remember them for significantly longer than classroom teaching (e.g., Greene, Kisida, & Bowen, 2014; Orion & Hofstein, 1994). Though field trips are common in many disciplines, they have serious limitations. For instance, it can be difficult to get access to factories, and one may not be permitted to enter all the areas relevant to the class. In general, factory visits require considerable resources to coordinate and organize—especially for class sizes exceeding around 25 students. Additional constraints are imposed by limited budgets and busy study and teaching schedules during the semester. Because field trips to factories are burdened with these administrative and logistical challenges, they are usually organized only once, if at all, per semester. Furthermore, teachers are constrained to a choice of local factories. So, given how difficult it is to bring the students to the factory, why not bring the factory to the students instead?

In partnership with the ABB Group (hereafter ABB), we integrated VR technology in a course assignment. To solve the assignment, students were encouraged to visit virtual factory environments, supplementing the other material available. The virtual factory environment was comprised of five facilities of ABB, located in Finland, Germany, and Switzerland, which the students could explore without having to physically visit them. Visiting through virtual tours can circumvent many drawbacks of traditional field trips. We aimed to provide the students an immersive experience similar to that of a field trip to a factory. In this paper, we present the design and application of the VR-enriched course assignment and evaluate its effect on students' learning experiences.

BACKGROUND

The days when "teaching used to stop at the classroom door" are gone (Rollag & Billsberry, 2012, p. 744), and the idea to learn and teach with VR has already gained traction in some disciplines. For example, virtually *simulated* environments have long been used for training in high-precision jobs, such as aircraft and sea-vessel piloting, military operations, and surgeries (Burdea & Coiffet, 2003; Zhou & Deng, 2009). The advancement of VR technology allows for a broader adoption of it in teaching. In a recent article in the *Wall Street Journal* about the use of VR for field trips in geoscience courses at Penn State University, Marty Resnick, a technology researcher at Gartner, is quoted, "60% of schools will be using virtual reality by 2021" (Belkin, 2018).

VR is an artificial environment that is presented to the user in such a way that the user experiences it as a close-to-real environment (Burdea & Coiffet, 2003; Sherman & Craig, 2002). A simple form of VR is 3-dimensional images or videos that can be explored with a computer interface or wearable VR glasses. In this form of VR, the user uses the senses of seeing and hearing to experience the digital environment. The VR environment can be an artificial creation, a digital copy of the real world, or a combination of the two. While artificial virtual environments, such as simulation games (Karriker & Aaron, 2014; North-Samardzic & de Witt, 2019) or computer games such as SecondLife or FarmVille (see for example Krom, 2012) have been used in business curricula, the integration of VR of real business operations is a new innovation.

The concept of *immersion* is central to VR (Dede, 2009; Minocha, 2015). According to Dede (2009, p.66), immersion can be defined as “the subjective impression of participating in a comprehensive, realistic experience.” Immersion through VR has some salient characteristics that assists the learning experience of students. VR enables students to step into the world of a factory and—at their own speed and following their own curiosity—explore what it looks like and how it operates. VR supports active learning, as opposed to passive learning. Immersion helps by moving the learning from simple consumption of information to an actual experience, which students must actively navigate (Mantovani, 2001). Deci and Ryan (2000) show that the intrinsic motivation of adults is encouraged when they experience autonomy and are able to make choices relating to their own learning.

Several recent studies conclude that immersion through VR enhances students’ learning experiences or improves their learning outcomes (Chavez & Bayona, 2018; Janßen, Tummel, Richert, & Isenhardt, 2016; Lee, Sergueeva, Catangui, & Kandaurova, 2017; Schmoelz, 2018). For example, research by Mahrer (2014) shows that students with access to VR resources outperform those who have access to only written material. Students who used VR in the geoscience class at Penn State obtained better test results than classmates who went on a field trip (Belkin, 2018). In another study, students reported higher retention rates when immersing in 3D environments (Chen, Yang, Shen, & Jeng, 2007). In brief, the increased immersion accessed through VR is reported in the literature to contribute positively to the learning experiences of students. These potential benefits motivated us to develop and evaluate a VR-enriched course assignment.

COURSE ASSIGNMENT WITH VR

In cooperation with the ABB Group, we developed an operations management course assignment that integrates readily available VR technology. ABB is a Fortune 500 multinational corporation headquartered in Zurich, Switzerland. ABB operates in technology-heavy industries, namely robotics, power, heavy electrical equipment, and automation. Since 2017, ABB offers a VR app which allows users to virtually visit five of their factories, located in Switzerland, Germany, and Finland. The app was originally developed for attracting young talent during trade and job fairs, but due to the relevance of the content it can also be effectively used for our purpose.

The ABB VR app “360 VR Tours” is downloadable for free on Apple App Store and Google Play. The app encompasses 360-degree still pictures and videos, blended with additional instructions and information, such as factory layout drawings. Figure 1 shows one of our students using the app and two examples of 3D videos he could be looking at (the pre-assembly area in one of the Finnish factories or final assembly of a turbocharger in one of the Swiss factories).

Insert Figure 1 Here

The virtual factories are digital versions of the real factories (at the time the VR was recorded). In each virtual factory, a number of areas in the factories are available and can be visited in any desired order. To explore the VR environments, the students were given inexpensive Google cardboard-type VR glasses (see Figure 1), which were intended to be used with the students’ smartphones and could be kept by the students after the class. The price of simple VR viewers for smartphones ranges from 3 to 50 USD (e.g., Google Cardboard or Samsung Gear VR). High-end

VR viewers cost approximately 300 to 500 USD (e.g., Oculus Rift or HTC Vive) but are not needed for the 3D photos and videos used in the course assignment presented here.

Together with managers from the ABB corporate headquarters and one of its Swiss factories, we developed an assignment with three modules corresponding to the learning objectives of our course: configuration of production networks, factory planning and design, and coordination of production networks. In the first part of the course assignment, the students were asked to use the VR environments to collect information about the production processes and products in specific factory locations. In the second part, the students should make use of the VR environments to analyze the production layout, internal logistics, and general productivity of the sites. In the third part, the students were asked to compare the factories using VR to suggest a multi-site production-improvement program. The task assignment provides students "guided discovery learning," which has been shown to have a better effect on student learning than lectures alone (Druckman & Ebner, 2018).

The following is an example of a question the students were asked: "Describe and analyze the assembly area in factory X in country Y based on what you see in the VR app in terms of (a) layout and (b) material-handling systems." Appendix 1 includes a wider set of exemplary questions that could be asked by teachers aiming to incorporate VR in their courses.

To complement the information accessible through the app, students were asked to browse the webpage and annual reports of ABB. In addition, because we were lucky to have access to ABB staff, the course faculty and ABB provided a presentation with additional assignment-related information (e.g., key figures, supply chain structure, organizational structure, market development, and so on). This was needed due to the details of some confidential questions ABB wanted to include in our assignment but is not needed to answer the questions included in

Appendix 1. Teachers can and should use VR technology to come up with their own questions tailored to the learning objectives of their courses.

EVALUATION METHOD

To study the effectiveness of integrating VR in a course assignment on students' learning experience, we used a two-stage evaluation approach. In the first phase, we conducted a pilot run in a half-day MBA class and used observations and forms to collect immediate feedback on the students' learning experiences. In a second phase, we implemented a full 12-week course assignment in one of our graduate-level operations management classes and used randomized focus groups and an evaluation survey to collect data on learning experiences.

Phase 1: Pilot run

We first piloted the assignment in a half-day operations management block course of an MBA program. The block course was attended by 15 students. For this, we adapted and condensed the course assignment and asked that students presented and discussed their group results in class. The overall setting was ideal for receiving immediate feedback. First, this block course was unrelated to the students' course grades, and the authors were not involved in any other activity with the students or in course administration. This meant that we did not have to expect a distortion in students' feedback related to concerns of an impact on their grades. Second, a portion of the MBA students had relevant backgrounds in the manufacturing industry, which made them able to compare their impressions from the VR against prior experiences. At the same time, there were some students who were less exposed to factory environments in their previous careers, which allowed us to gain insight into how less-experienced students may benefit from VR. Third, the block course nature of the class allowed us to directly observe students experiencing the virtual environment and discussing it with their group members.

Immediately after completion of the pilot run, we asked the students to honestly share their impressions, experiences, thoughts, suggestions, and criticisms with us via feedback forms. Two reminders were sent to increase the response rate. We used this feedback to inform moderation questions for the focus groups and questions for the evaluation survey.

Phase 2: Full implementation and evaluation

The VR-enriched course assignment was then used in the course "Global Operations Strategy" offered every spring semester. In 2018, this course was attended by 54 graduate students. The course is taught over a 14-week period and offers 3 credits in the European Credit Transfer and Accumulation System (ECTS). The course assignment was launched in the third week and lasted throughout the course. Each of the three parts of the assignment was submitted three weeks apart from one another.

To evaluate the students' opinions on the use of VR in the course assignment and its implication for their learning experiences, we employed two complementary methods of evaluation: moderated focus groups and an evaluation survey.

Moderated focus groups

Moderated focus groups is a well-established method for teaching evaluation (Breen, 2006; Lederman, 1990; Stewart & Shamdasani, 2014; Watts & Ebbutt, 1987). Focus groups are particularly well suited to collect feedback on new ideas (Stewart & Shamdasani, 2014). We conducted the focus group discussions towards the end of the course. To avoid a bias introduced by the involvement of teaching authorities in the evaluation process, the focus-group discussions were conducted and moderated by personnel of our university's Department for Educational Development and Technology. This department was not involved in any other activity in the course, including teaching and assessment. To avoid a desirability bias, no compensation was offered to participating students. Participating students were guaranteed full anonymity and asked to sign consent forms. Lastly, we used a randomized draw to invite students. Random rankings were assigned to potential participants, and students were invited until a sample size of 10 students had been reached (18.5% of class size). According to the educational developer, students willingly accepted to join the focus groups as long as they were available on the day of the focus group meeting. Hence, non-response bias should not be a serious problem in the focus groups. Subsequently, the sample was split into two groups, consisting of students with diverse academic backgrounds, ages, and genders. We allocated five students to each group, following the advice of Breen (2006), who suggests groups to consist of four to six participants.

The two focus groups were led by the same professional educational developer. A focus group moderation guide was developed and used, following recommendations in the literature (e.g., Breen, 2006; Morrison-Beedy, Côté-Arsenault, & Feinstein, 2001; Stewart & Shamdasani, 2014). The review of the literature and the results from the pilot run informed the set of open moderation questions, which inquired into three main points: (1) students' first impression and general opinion on the use of VR in the classroom; (2) perceived benefits and drawbacks of using VR in class; and, (3) potential for future improvement of the technology and integration of VR into teaching. The focus group moderation guide is included in Appendix 2. The moderator used the guide to ensure these three topics were covered on time and that all participants were involved. Other than that, the discussions evolved as naturally possible.

Each focus group interview lasted 45 minutes, the typical class duration. They were organized in a meeting room at the university campus at a convenient time for the students, for example the class before the course class with a 15 minute break in-between and outside of exam periods. All the participants received a pre-prepared invitation letter with information about format, recording, and confidentiality. As instructed by the moderator, the students devoted their full attention to the moderated discussion.

The focus group interviews were recorded, fully transcribed, and anonymized before the teaching team gained access to the data. The anonymized transcriptions contained a total of 20,526 words (approximately 10,000 words each). As recommended in the focus group literature, the data analysis followed a structured data reduction approach (Breen, 2006; Morrison-Beedy et al., 2001). First, one researcher coded all the transcripts with first-order constructs ("topics") and second-order constructs ("themes"). After that, two other researchers independently re-coded all the transcriptions by the suggested themes. We calculated a satisfactory inter-rater reliability score of 87%.

Evaluation survey

After students had accumulated experience with VR for all the three parts of the course assignment, the Department for Educational Development and Technology administered an anonymous survey to all students of the class. The goal was to collect additional data regarding students' thoughts and feelings about the use of VR in teaching. The content of the survey questions had been determined by literature research and by observations from the pilot run in the MBA block course. We measured six aspects of our students' learning experience: enjoying the course assignment work; the general increase in curiosity for the topic; the ability to explain to others what was learned (a proxy for retainment); VR's effectiveness in solving the course assignment; stimulation of team discussions; and, immersion in the course assignment. We also included three control variables: prior experience with VR, industrial experience, and time spent in the VR environment. The answers were on a five-point Likert scale (1 – “strongly disagree”, 2 – “disagree”, 3 – “neutral”, 4 – “agree”, 5 – “strongly agree”). We sent three reminders to increase response rates.

Of the 54 students, 34 participated in the survey. This corresponds to a response rate of 65%. We tested for non-response bias by t-testing whether the mean differences in our learning-experience variables were significantly different among the groups of early and late respondents. In untabualted results we found no significant differences among these two groups, suggesting that non-response bias is not a major concern.

RESULTS

In this section, we present the results from the pilot run, the focus group interviews, the survey, and other evidence.

Feedback from pilot run

Twelve of the fifteen MBA students who participated in our pilot run submitted feedback about their experiences. In general, the students expressed enjoyment, reflecting on various positive aspects of the teaching innovation. However, we also received constructive criticism suggesting potential areas for improvement. This initial feedback allowed us to refine the course assignment implementation and drew our attention to important aspects of how our teaching innovation affected students’ learning experiences.

One student wrote, “I personally love[d] it, it’s an easy way to bring the factory to the class.” This enthusiasm was shared in various degrees. Another student summarized, “In my opinion [it] is an outstanding way of combining theory and practical application and offers the possibility of analysis based on real cases." More neutral assessments spoke of an "interesting experience" and the use of VR glasses as "motivating." A student with limited experience in the manufacturing industry expressed, "Seeing plants and production in motion through virtual reality meant I didn't have to work on the assignment solely based on imagination and words."

One of our immediate observations in our pilot run was that once we handed out the VR glasses, the students instantly became excited. We heard remarks like "Oh, this is cool!" and "Ok, that's interesting!" Students expressed their curiosity in various ways. In one feedback, a student noted, "[the approach was] unusual and therefore interesting [..]." We learned that, for many students, it was their first experience with VR. After the initial excitement leveled out, students retreated into their groups and immersed into the VR factory environments. Figure 2 shows a photo from one of the groups using the VR app to solve the course assignment.

Insert Figure 2 Here

We observed that some students immersed more into the VR than others. For instance, in one group, the VR environment sparked a passionate discussion about possible task solutions. One especially enthusiastic student in another group could be seen wearing the VR glasses with a head-strap, eagerly commenting on his experience, turning to maneuver through the app, while occasionally jotting down notes on a flip chart. In another group, students remained less immersed. For example, they used the VR app on their phones without the VR glasses while having a professional discussion about the visible manufacturing equipment.

After our initial pilot run, we implemented the full VR-enriched course assignment in the operations management course. On the organizational side, we implemented several changes based on the initial feedback from the MBA students. For instance, MBA students had criticized that one is unable to ask questions in VR, which is why we subsequently organized a guest lecture at the start of our full assignment implementation. In that class, students received important background information and had the opportunity to ask questions of ABB managers. Later, students had the chance to send us questions, which we collected and passed on to ABB to be answered by two managers.

Focus group interviews

The coding of the moderated focus group interviews resulted in five broad themes: "Motivational effects," "Immersion experience," "Learning implications," "Improvement potential," and "Physiological side-effects" (examples of the coding structure are included in Appendix 3).

Motivational effects

The focus group discussions confirmed the results from the pilot run that introducing VR technology has an immediate motivational effect. Students discussed their positive first impressions on 13 occasions during the focus groups. The following comment from a student captures the general feeling in both focus groups: "It's something new. I mean, personally I didn't have previous experience of that. So, it's always interesting when you have something new." It was clear there was some kind of "*wow-effect"* tied to the introduction of VR in an operations management class. On seven occasions, students explicitly reported their excitement. For instance, one student found it exciting to see a 5-axis milling machine in VR. Others found simply working with VR already to be exciting.

The initial excitement seemed to be associated with their own expectations of how VR would work in a course assignment. Our focus group participants discussed their expectations 14 times. One student spoke of "curiosity […] to see how it works." In contrast, a student stated that he "was not expecting anything." Still, some students expressed that their initial excitement quickly tapered off. For instance, one student described a moment of disillusion upon finding out that it is "just an app you can download in the app store." Generally, it seems as though some students have unrealistically high expectations for VR. One student summarizes it well: "VR is kind of a buzz word. It automatically excites you a little bit."

From the transcripts of the focus group discussions, we discovered that the introduction of VR boosted the students' motivation by sparking their excitement and providing positive first impressions. This is in line with our feedback and observations from our pilot run in the MBA class. We suspect that the early-phase motivational effects were more pronounced in the MBA class. Because of the shortened assignment design, motivational effects could be sustained throughout the 3-hour class. The focus group discussions also showed how some students may have been exposed to more "hype" around VR. Different students may be differently exposed to the hype or have different previous experiences with VR, and therefore may carry different expectations of what to expect from VR technologies. To prevent unrealistic expectations from having adverse effects on, for instance, enjoyment, active expectation management may be needed.

Immersive experience

Another dominant theme in the focus group discussions was how VR allowed the students to immerse into the factory environment. One student summarized his positive experience, stating, "One picture is like 1000 words, so by looking at this app, the information you're getting is much more than someone could explain in 45 minutes."

Even though the immersive capabilities of VR were generally regarded positively by the students, they would prefer an actual factory visit if there is a choice. However, students appear to see VR as a good substitute for factory visits. As one student puts it, “VR is definitely better than having no idea of what is going on.” On 21 occasions during the focus groups, students discussed how VR provided them a realistic insight into the factories. For instance, discussing the details of the safety gear that is visible in the app’s VR environment, a student reported, “From small things to very important things, you can definitely see it, and you can understand how it works [...].”

Related to this, some students discussed that their VR experiences engaged them and provided for an active rather than a passive learning experience. One student described his experience as an “active discovery.” Another student added the interesting aspect that, in contrast to a conventional factory tour, there is nobody to tell the student what to look at and what is relevant. As the student described, he himself had to answer the question, “Okay, what should I be looking at?”

A recurring topic has also been the level of depth of understanding that VR provides (discussed 24 times). One student assesses, “VR itself, it helps. It gives you a certain in-depth perspective.” Another student commented that the virtual environment allowed for a better understanding of spatial depth. The limited amount of information directly obtainable from the app was also discussed and sometimes criticized. Interestingly, one participant mentioned that this makes “some detective work” necessary, which the participant implied was helpful to their understanding. One student made the assessment that “looking for something with seemingly limited information, is a very good exercise for us to take.”

Learning implications

The focus group discussions also shed light on the learning effects of using VR as a teaching resource. Even though a conventional factory tour may still be preferable for several reasons, VR was also reported to be superior to field trips in some aspects. Interpreting the statements of our students, VR has the capability of providing for a convenient and available learning experience or discovery at the students' own pace. "It was good that you could discover the factory on your own speed" was a typical statement. The possibility for immersing in the factory environment independent of time and place appears as a strong advantage that VR brings to teaching operations management. In the words of one participant, "You can just put on your VR headset and take a look [...] it's convenient." Someone else noted, "You can use it everywhere."

An important topic was also how VR was embedded in the learning task (i.e., the course assignment). It is clear that students perceived VR differently as a resource in relation to the assignment. One student reported, "[VR] was definitely useful to answer the questions." However, some students seemed to have expected an app that included everything needed to solve the assignment. Some also appear to have perceived VR as the center of the assignment, whereas it was more intended to be an additional resource. This was understood rightly by the participant who reflected, "It was more of a support on the side and we tried to align our work to make use of VR."

Improvement potential

In addition to the aforementioned topics, the focus group participants also discussed the limitations of using VR. Many arguments concerned the limitations of the ABB app itself. Other related points touched upon issues like mediocre user friendliness. Students also reflected on whether the use of VR glasses is advantageous over using web versions of the app. The detailed discussion of the limitations allowed us to better understand the potential for improvement and may provide ideas for the design of future implementations.

Several different limitations of the used app were mentioned. One student remembers, "The app crashed three times during the research." Another participant said, "I would like to have a little bit more information [included in the app].” The wish for the ability to “walk around” in the factory, similar to how one navigates on Google Maps’ street view function, was a recurring topic. Another idea from a participant was to allow for a zoom function in the app (a function that has been implemented in the app subsequent to our use). One student concluded that “in an ideal world,” the observer should even be able to “look behind stuff” (i.e., going into machines). We also noted the criticism that not all visuals in the VR were of importance for the given assignment. However, this may not necessarily be a limitation because separating the relevant from the irrelevant may be considered an important skill in operations management. Another recurrent discussion topic was the resolution of the app, which some participants did not find ideal and others did not mind. Some students also reported that, because of their eyeglasses, they could not take full advantage of the VR glasses. For these vision-impaired students, web-based alternatives may be especially relevant.

The discussants also reflected on the user friendliness of the VR in general as well as the VR glasses we handed out to them. One participant recounted the following: “I don’t carry them [VR glasses] with me, because I don’t have that much space. So, I ended up mostly just using the app and not really the glasses.” Through the discussions, it also became clear that students wished for more professional goggles instead of inexpensive give-away Google Cardboard viewers. We also noted the statement of a participant who reported that the use of VR glasses in public may be intimidating: “A lot of times we’re in the middle of the study room or whatever and [if using the VR glasses] we feel awkward.” An additional point raised was that taking notes while using the VR glasses is not so easy.

Physiological side-effects

Though they are not severe, it is necessary to mention that the use of VR can cause several side effects. These are generally of light physiological nature—e.g., motion sickness—and related to the state of the VR technology we used (cardboard headsets and the ABB app). Also, as we learned, not everyone is affected, and those who are may not be affected equally. This drawback also appeared in other studies using cardboard VR glasses (Lee et al., 2017). A potential way to mitigate the drawbacks due to physiological side-effects appears to be the use of higher quality VR glasses, which among other features can be adjusted to the user (e.g. optimal distance between the lenses).

In the focus group discussions, students discussed dizziness and headache from the use of VR. One student felt "a little bit dizzy" and proposed that this would not be the case with more sophisticated, expensive models, such as Oculus Rift. The same student hypothesized that dizziness might be dependent on use time. Not everyone had this problem however; for instance, one student reported that the more-static design of the app did not cause the dizziness experienced from apps with more dynamic movement. One further source of discomfort for one of the focus group participants was heat radiation from the smartphone, which is placed in the VR glasses a few centimeters in front of the eyes.

To avoid these side-effects, some students reported that they stopped using the cardboard viewers, instead looking directly at the smartphone screen from a distance or using a computer. The use of 2-dimensional VR on websites allows many of the advantages discussed in this paper, yet with a lower level of immersion. Conversely, it allows a more stable picture that can readily be discussed in a group. There are other advantages of using computer screens, such as the opportunity to tour the factory as a team or a class, or take notes during the tour. On the downside, the use of two-dimensional screens reduced the level of immersion.

Survey results

Finally, the evaluation survey helped us understand the bigger picture and to test our previous insights from the MBA pilot and focus group interviews. Because we naturally have a small n, our analysis is limited to descriptive statistics and correlation tables. Figure 3 shows histograms for the six core variables of learning experience. The descriptive statistics for all variables are given in Table 1.

Insert Figure 3 Here

Insert Table 1 Here

Looking at the statistics in Figure 3 and Table 1, it becomes clear that the data are skewed toward the right with a relatively long tail on the left. Therefore, mean and mode values of our responses lay systematically below their median values. For instance, the mean response to the question regarding how helpful the embedding of VR in the course assignment was is 3.26. However, the median tells us that half of the students found the embedding of VR so helpful that they answered with 4.00 or higher. Here, 4.00 was also the most common answer. Taking the stance that education should give the best possible experience to the greatest number of people, we will discuss our results below in terms of the median responses.

We obtained "non-neutral" median values of more than 3.00 for our variables "retainment," "helpfulness," "stimulation of discussion," and "immersion." Moreover, we found that the median time spent in VR was 30–60 minutes. According to these results, the main strengths of the VR-enriched course assignment could be that the virtual content (1) is memorable, (2) helped to solve the course assignment, (3) stimulated group discussion, and (4) allowed for an immersive experience. Overall, this is in line with the findings from the pilot run and focus group discussions.

Somewhat unexpected against the background of our generally enthusiastic feedback from the MBA students is the fairly neutral level of responses obtained from the question, "Overall, [have you] thoroughly enjoyed the way virtual reality has been embedded in the course assignment?" One potential reason for this may be that in our second implementation of the course assignment, students had significantly longer exposure and more time to explore the VR environment. Hence, they had longer exposure to the limitations of the VR technology and the virtual environment. Supporting this explanation, anecdotal evidence from the focus group interviews suggests that excitement was highest in the beginning. The dizziness experiences by some students were of course also contributing negatively to their enjoyment.

Table 2 shows the correlations among the variables in the survey.

Insert Table 2 Here

We find a range of significant positive correlations between the variables. *Enjoyment*, *Curiosity gain*, *Retainment*, *Helpfulness,* and *Immersion* are positively correlated pairwise with statistical significance. This suggests that those students who enjoyed VR the most were also those who found it most helpful in solving the course assignment, those who immersed relatively more often in the VR app, and those who felt most confident with explaining the course material to outsiders (our retainment proxy). These findings are by and large as expected. For example, the level of curiosity is a determining factor of the depth with which students explore the course material (e.g., Skinner & Belmont, 1993), and the "time-on-task" is a known predictor of learning retainment (Stallings, 1980).

The three control variables—prior VR experience, industrial experience, and VR use time—were not significantly correlated with other variables in the overall results.

Other evidence

We note that the students' grades in the same course improved from a mean of 4.96 in 2017 (std. dev. 0.32, 57 students, no VR) to a mean of 5.38 in 2018 (std. dev. 0.23, 54 students, with VR) (4.00 = pass, 6.00 = best grade). The courses were taught by the same faculty, contained the same teaching material, had similar types of course assignments (but one with and one without VR), and were attended by the same type of students. The improvement in course grades provides an additional indication that the students enjoyed the class and that it was contributing positively to their learning experience and learning outcome.

DISCUSSION

In an editorial for this journal, Rollag and Billsberry (2012, p. 743) pointed out, "Education has always been slow on the uptake of new technology. (…) The last thing an instructor wants to be doing is fumbling around trying to make something work in front of an audience of 200 undergraduates." One of the greatest advantages of the presented VR-enhanced course assignment is that it is cheap and simple. Anyone can do it. We found that VR can efficiently be integrated in an operations management course. We also found that the VR assignment was an active learning experience, which is known to be more effective than passive classroom teaching.

The evaluation results show that VR was perceived somewhat positively by the students, but with reservations. The observations and feedback from the pilot run clearly suggest that VR can provide students with an improved learning experience. The results from the full implementation were more mixed. For several of our learning experience measures in the survey the mean is close to neutral, but their median and mode were consistently higher. The students reported that they enjoyed the immersion enabled by VR, and that it increased their motivation—at least in the short run. However, the students also reported some disappointment with the current state of technology and some challenges with physiological side-effects.

We now discuss the generalization of our findings. We also offer implications and advice for teachers who want to experiment with or integrate VR in their courses.

Guided discovery learning enabled by VR immersion

The impression of having immersed into a virtual factory environment dominates the students' learning experiences. On this point, all our data sources agree. This supports prior studies that argue for a central role of immersion in VR-aided learning (Chavez & Bayona, 2018; Gamlin, Breedon, & Medjdoub, 2014; Janßen et al., 2016). We observed how students from various backgrounds zoomed out of reality and into the VR app (see Figure 2 for a good example). This was mirrored in the MBA students' feedback forms. Through its immersive aspect, VR helped the students relate to the course assignment and reduce its abstraction level. In the words of Dede (2009, p. 66), "the ability to change one's perspective or frame of reference is a powerful means of understanding a complex phenomenon."

Reported advantages of VR over conventional factory visits included the possibility to immerse at the user's own speed and to rediscover the virtual factory environment whenever they wish. This way, VR can contribute to increased levels of active learning in operations management courses, which is generally seen as beneficial (Brandon-Jones et al., 2012). Some students reported that they liked to do "detective work" in the virtual environment, finding helpful hints and insights in the information available. The information-rich VR environment forces students to actively and critically investigate what information is helpful and what is not. This active learning experience is akin to "guided discovery learning" (Druckman & Ebner, 2018). We conclude that the use of VR in operations management classes allows for flexible and somewhat immersive learning experiences, which is shown in extant literature to improve learning outcomes (Dede, 2009).

However, virtual factory visits have limitations concerning immersion too. Although the current technology offers some level of immersion, it is still not the same as being present in an actual factory. Students reported limited opportunity to "walk around", no background noise, no smell, no opportunity to ask questions to factory workers, and difficulty in taking notes. All this reduces the level of immersion. Some visually impaired students, or students who feel dizziness, must use screens instead of VR headsets, which also reduced the level of immersion (Lee et al., 2017). A very limited number of students reported that their older smartphones were incompatible with the app we used. We conclude that VR is no full substitute for factory visits, but a complement enabling a form of immersion that is independent of time and place.

Implications for teachers

From our experiences of integrating VR in a course assignment, we summarize six main recommendations for teachers.

First, VR offers a great possibility in situations where field visits are not an option or only rarely organized. If presented with a choice, the students stated they preferred the field visit. However, VR can go beyond what a field trip offers and provide access to multiple sites, far-flung places (in our case a factory in Finland) and areas that might be unsafe for humans (such as close-up view of a milling machine). Synergetic approaches and blended learning combining field visits and the use of VR can also be designed (e.g., on the last day of our course, we brought the students to one of the factories featured in the ABB app). For instance, VR can complement a field trip by serving as a refresher and enabling the students to revisit particular areas to help refresh their memories.

Second, when using VR as a resource, teachers need to be aware of their audience and manage their expectations to avoid disappointments. Especially at engineering universities, such as the one at which this study has taken place, students may have unrealistic expectations based on their own assumptions and (lack of) experience with VR. Accurate descriptions and, potentially, short in-class demonstrations may be helpful. Awareness should be raised about the potential side-effects of prolonged use of VR, regardless of which VR viewers are used. Teachers (and app developers) should also ensure that the VR content can be viewed using a range of different devices, including VR viewers, or web browsers. This ensures that students can choose to view the content in a way that best suits their needs.

Third, the choice of which type of VR viewers should be used boils down to a trade-off between availability and sophistication. Having used an inexpensive Google Cardboard option to allow students to keep their viewers, we can confirm that it is possible to implement VR in operations management courses for less than 5 USD per viewer (i.e., student). Providing more advanced VR viewers can reduce frustration stemming from limitations and physiological side effects related to low-quality viewers. VR viewers made from plastic are reusable, but they need to be kept hygienic, for instance, by using disposable covers. Inexpensive give-away VR viewers appear to be well-suited for short course assignments and smaller budgets.

Fourth, the teaching staff needs to ensure that the VR content is relevant to the assignments students are asked to complete. There should be a clear link between what is being asked of them in the assignment and the VR content. The ultimate way to ensure this would be to work with a company and develop the virtual environment from scratch, which would require a cooperative partner and sufficient funding. Technologically, however, it is not difficult. Amateurs can make their own VR apps if they have a smart phone, a 3D camera (for example, Insta 360 One, which costs about $400), and a (free) VR-app software (e.g. Google Tour Creator or Uptale). However, creating one's own VR app is subject to a range of limitations, especially when engaging with multinational companies. For instance, creating an app that shows company operations is likely to have a range of legal implications regarding confidentiality. These limitations can be circumvented by drawing on already available VR apps, as we did. A number of companies have recently developed VR apps of selected factories and operations for marketing and talent-hiring purposes. We believe that we will continue to see an increase in the number of apps like the ones ABB developed and a greater variety between them. Currently, only a few of these apps are openly accessible, but agreements can be made with companies directly to allow their use in class. With a growing variety of apps, teachers would have more opportunities to find an app that fits well with the learning objectives of their courses.

Fifth, in our experience, positive emotions are especially concentrated in the first half hour of exploring the VR factory environment. Hence, in shorter course assignments, enjoyment is likely to prevail over technology-related drawbacks and limitations of the app. Perhaps the phase of effective enjoyment could be extended by using more sophisticated VR glasses, which decrease physical side effects and allow for a more user-friendly experience. We recommend integrating VR in shorter assignments rather than assignments spanning over many weeks and months.

Sixth, as the use of VR in operations management courses is still new and remains largely unexplored, we suggest that the teachers document and evaluate their use of VR. Sharing experiences, ideas, and best practices ensures that students have the best possible learning experiences. This is not about pushing a new technology into the classroom, but to understand when, why, where, and how VR can help improve students' learning experience and learning outcomes. A systematic exchange of experiences also allows to improve teaching efficiency.

CONCLUSIONS

We integrated VR in our teaching of production and operations management, and systematically analyzed the effect of it on students' learning experiences. Together with ABB, we developed a VR-enriched course assignment and used it in two of our graduate-level classes in 2018. In one class, we used VR as a resource for a half-day break-out assignment; in another, we used it as part of a course assignment that extended over the full semester. Using data collected through feedback forms, focus group discussions and an evaluation survey, we have analyzed the effect of VR use on students' learning experiences. Theoretically, the concept of immersion was useful to explain some of the underlying mechanisms.

We conclude that the current state of VR technology offers good opportunities for enriching operations management courses and can provide students with immersive learning experiences—yet, not without drawbacks. Virtual access to factories that may be otherwise logistically impractical for field visits is now possible. Students can explore these virtual factory environments at their own pace, whenever they wish, and can learn to actively distinguish between relevant and irrelevant details. Teachers can enable students to conduct "detective" work in a factory environment, viewing and reviewing factory areas in any order they wish, to answer a given question. To this extent, this would not be possible in the setting of a conventional field visit. With VR, we can bring a factory to the classroom, or students can conduct a virtual factory visit in the convenience of their homes. As a new teaching technology, VR shows the potential to provide a short- to midterm boost of students' motivation.

However, we also conclude that further developments in VR technology will be beneficial for overcoming some current challenges and limitations. A recurring limitation was that a number of students felt dizzy after short-term use of VR. Another was technological limitations like low resolution, incompatibility with certain phones, and possibilities to take notes or to discuss while being immersed in VR. Furthermore, it is important that the VR resource is well integrated in the assignment and/or course, suiting the learning assignments and learning objectives. In this regard, expectation management appears to be crucial. Teachers should clarify the role of the VR content in the course material and explain if it is a sole source of information or supplementary. Such clarification will perhaps help students avoid high expectations and disappointment.

In conclusion, we have shown that readily available VR technology can cost-efficiently and partly effectively be integrated in operations management courses. With the ongoing improvements in VR technology and increasing availability of apps with content relevant to operations management, we believe many teachers across different disciplines will integrate VR in their teaching in the years to come.

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APPENDIX 1: EXAMPLES OF ASSIGNNMENT QUESTIONS

Table A1-1: Examples of possible assignment questions*.

Explore factories	• Describe and analyze the assembly area in the Baden factory (CH) based on what you see in VR in terms of (a) layout and (b) material-handling systems. • Visit the assembly lines in the ABB factories in Baden (CH), Heidelberg (DE), and Protection and Connection in Vaasa (FIN), comment on the ergonomics of the work stations and suggest improvements. • Visit the machining area and assembly lines in the ABB factory in Baden (CH), what are the most striking visual differences between machining and assembly operations in this factory? What do these differences mean for managing the different areas and the link between them? • For each ABB factory, search for locations where you can see the following lean methods: (a) andon, (b) shadow board, (c) kaizen board, (d) kanban, (e) two-bin system, (f) poka yoke, and (g) one-point-lesson. Briefly explain each method as it is used in the location you see it. • Did you notice any lean methods, tools or techniques not covered in the list above? Where?
Compare factories	• Use the VR app to have a close look around in all the five ABB factories. Compare the factories in terms of operational characteristics. Would you recommend ABB to deploy the same improvement program across sites and divisions? If yes, sketch the main principles of a common program. If not, explain the key points how you would differentiate improvement activities across these sites or in ABB. • Use the VR app to have a close look around in the ABB factories in Heidelberg (DE), Lenzburg (CH), and Vaasa (FIN). Compare the factories in terms of their levels of automation. How and why do the levels and types of automation differ between these locations?

	• Do a virtual "Gemba walk" in ABB Protection and Connection in Vaasa (FIN) and ABB Turbochargers in Baden (CH). How would you assess these factories in terms of lean production implementation? As information is very limited, list your five most significant reasons for your assessment. What are the limitations of virtual tours in terms of assessing lean implementation? • If you were the COO of ABB, what level of integration and coordination would you aim for across the five factories in the VR app? Briefly explain your position.

*This table lists examples of questions that can be asked when using the ABB VR app. Teachers can use these questions if they correspond to the learning objectives of their course. Alternatively, teachers can use them as inspiration to come up with own questions that are better aligned with their courses' learning objectives.

APPENDIX 2: FOCUS GROUP MODERATION GUIDE

Preparations

- Arrange the chairs in a circle
- Double check the recorder works properly
- Have copies of the informed consent form and pencils handy
- Put a sign outside the room

Welcome script

Welcome. Thank you for taking part. Please note that the purpose of these focus groups is solely the evaluation of the use of virtual reality in the course assignment. Your overall satisfaction with the course, other factors related to the assignment, or the lecturers should not influence your answers. Your honest opinions will help us to further improve our course assignments in the future. Your answers are completely anonymous. Thank you for volunteering to be here! Some guidelines before we start:

- There are no right or wrong answers, only differing points of view.
- We're tape recording, so please one person speaking at a time.
- Let's be on a first name basis.
- You don't need to agree with others, but you must listen respectfully to others.
- Please have phones off, or on silent.
- My role as moderator will be to guide the discussion but you will essentially be talking to each other. I will be taking notes to help me remember important parts of the conversation.
- Have you all read the informed consent form? Do you have questions? Please sign and hand them to me.
- Do you have any questions before we begin?

Moderation questions

- What did you think of the idea to use VR in your classroom?
    - What did you think when it was first introduced?
    - What was your first impression?
    - What was exciting?
    - What was disappointing?

- How did you feel while using VR?
- What do you think are the biggest benefits of using VR in class?
- What was the worst part about the VR tool?
- Are there any ways the VR experience could be improved?
- Describe the ways the teaching team implemented VR in the teaching.

Closure questions

- Of all the things we discussed, what would you say is the most important part?
- [Moderator summarizes the key points]. Is this an accurate summary? What have I missed?

APPENDIX 3: QUALITATIVE ANALYSIS OF FOCUS GROUPS

Table A3-1: Coding table for focus group interviews.

Example of typical quote	**1st-order construct (Topic)**	**Mentions in percentage (occurrences)**	**2nd-order construct (Theme)**
"It sounded quite cool like, 'Oh cool. We're doing something using VR'. You know it's kind of a buzz word. It automatically excites you a little bit."	First reaction	5.4% (8)	Motivational effects
"Expectations are high up at the beginning because, 'Oh, there's a cool app. Maybe we can walk around.[…]' but no, you couldn't"	Expectations	4.7% (7)	
"So, it sounded super interesting and that made me quite excited to work [with] it"	Excitement	2.7% (4)	
"Great idea, and the content itself was also useful for solving the cases, but I personally was disappointed, because I understand that these Google Cardboard gadgets don't cost much and it was the only way of doing that for the class, but I personally was a bit disappointed because I know how professional equipment feels like and it's just an implementation detail."	Disappointment	4.7% (7)	

"If [a factory visit is] not an option, then VR is definitely better [than] having no idea of what is going on."	Realistic insights	9.4% (14)	Immersive experience
"The VR itself, it helps. It gives you a certain in depth perspective."	In-depth understanding	10.1% (15)	
"I think it's […] more like an active discovery than […] a passive [experience]."	Active learning	4.7% (7)	
"[One] should also keep [VR] just for I guess the excitement? At least you remember it slightly different."	Memorability	6.7% (10)	Learning implications
"You can always use the VR from home when you want to recall something."	Flexibility of using VR glasses	2.7% (4)	
"It was actually useful for certain parts [of the course assignment]. […] I enjoyed the idea that I could relate what I was working on actually with the reality."	VR integration in task	12.1% (18)	
"[The app could be improved] if you had the ability to read and walk around and, to walk around the shop floor, around this assembly line, and not the static perspective, and also, more people."	App improvement	22.1% (33)	Improvement potential
"You have the VR app and you could use it with a split screen and the goggles or you could use the webpage on your phone."	Web version	3.4% (5)	

"You really have to turn your head a lot of the time where you have to hold the thing. […] It's a bit hard to focus plus take notes and whatever."	User friendliness	6.0% (9)	
"[You do] not [get a] headache, but a little bit dizzy if you keep watching."	Dizziness	3.4% (5)	Physiological side-effects
"It gives me a headache."	Headache	1.3% (2)	
"I can feel the heat coming off the screen"	Heat from screen	0.7% (1)	

Figure 1: A student using the VR app (top left), and two snapshots from 3D videos in the VR app (top right and bottom).

Figure 2: A group of MBA students solving the course assignment using VR.

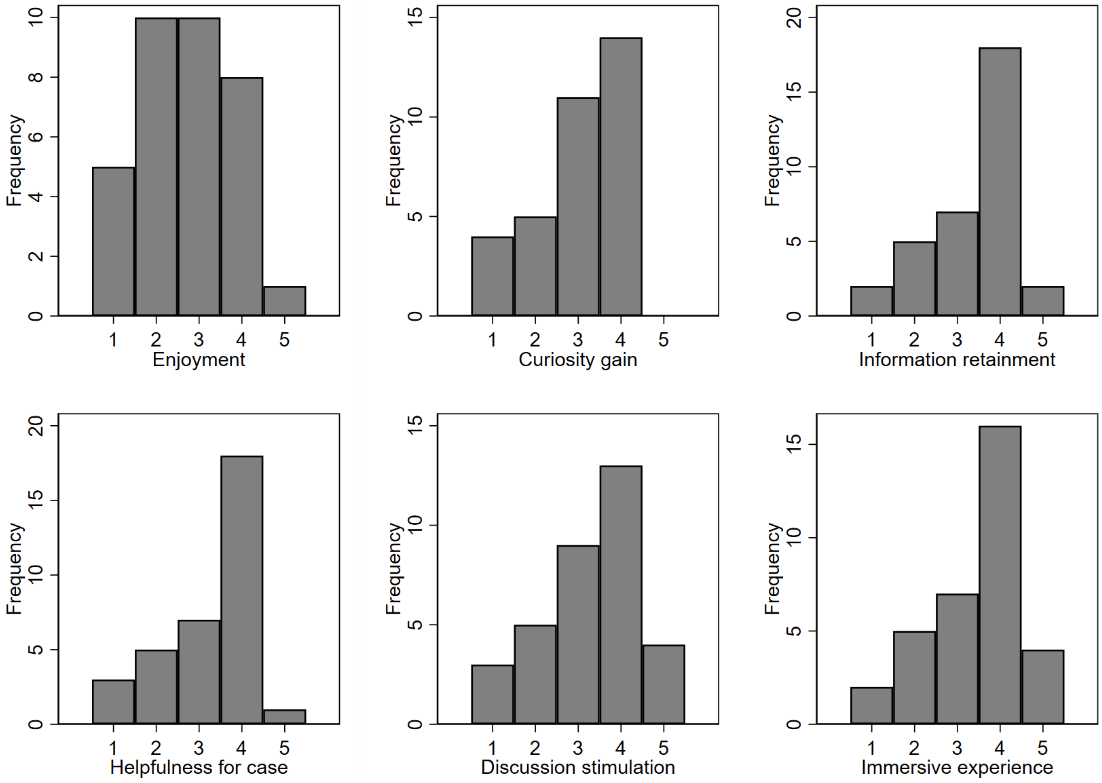

Figure 3: Survey result histograms for learning experience variables.

Table 1: Descriptive statistics for survey results (n = 34)

Variable	Median	Mean	Mode	Standard Dev.
1 Enjoyment	3.00	2.70	2.00, 3.00	1.09
2 Curiosity gain	3.00	3.03	4.00	1.03
3 Retainment	4.00	3.38	4.00	1.02
4 Helpfulness	4.00	3.26	4.00	1.05
5 Stimulation of discussion	3.50	3.29	4.00	1.14
6 Immersion	4.00	3.44	4.00	1.08
7 Prior VR experience	3.00	2.77	1.00	1.51
8 Industrial experience	3.00	2.94	4.00	1.32
9 VR use time	2.00	2.32	2.00	1.17

Table 2: Correlations of survey variables

Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1 Enjoyment	1.00								
2 Curiosity gain	0.50**	1.00							
3 Retainment	0.71***	0.63**	1.00						
4 Helpfulness	0.65***	0.47*	0.64***	1.00					
5 Stimulation of discussion	0.10	0.28	0.14	0.26	1.00				
6 Immersion	0.68***	0.53**	0.56***	0.75***	0.31*	1.00			
7 Prior VR experience	0.07	0.18	0.04	-0.13	-0.27	-0.47	1.00		
8 Industrial experience	0.11	0.11	0.31	-0.16	0.17	0.00	0.02	1.00	
9 VR use time	-0.11	0.12	-0.11	-0.10	0.15	-0.07	-0.01	0.01	1.00

*** = $p<0.01$, ** = $p<0.05$, and * = $p<0.10$, two-tailed tests of statistical significance.