CAREER FEATURE

Immersive virtual reality as a competitive training strategy for the biopharma industry

Immersive virtual reality simulations tailored to aspiring industry operators in biopharma manufacturing could become a cost-effective alternative to real-life training for teaching practical skills.

A highly trained workforce is the productive engine of every successful biopharma company. However, the biopharma sector generally has not adopted rapid technological advancements in training methods and instead relies largely on older approaches[1]. A traditional training approach is to let employees read standard operating procedures (SOPs) described in lengthy documents, of which the average biopharma company has around 1,250 (ref. [2]). Employees often perceive this form of training as unnecessary and of little value, and therefore fail to comply with regulations, which may lead to increased occurrences of costly errors[3]. Not surprisingly, 25% of quality defects in the industry can be attributed to human error, rendering it the main cause of product recalls[4].

To avoid these issues, biopharma companies resort to real-life, on-the-job training. However, this approach is resource-intensive and time-consuming, as it requires test facilities and experienced trainers. Overall, an estimated $7 billion is spent by biopharma companies on employee training each year[5,6]. Accordingly, the industry needs new, cost-effective and engaging training methods for developing and maintaining key skills in its workforce.

A promising avenue for cutting costs and increasing training efficiency is replacing traditional training methods with electronic learning (e-learning), educational games or virtual reality (VR) simulations[7]. An emerging body of evidence suggests that simulator training improves learning outcomes in related fields such as medicine and science education[8–10], supporting exploring these technologies for training procedures in the biopharma industry.

In medicine, a major focus of simulator training has been teaching practical skills to prepare for performing surgical procedures. Studies show that skills acquired in surgery simulators are transferable to a clinical setting[11–13]. However, the simulators are not intended to replace real-life training but to complement it, so randomized controlled trials typically use non-simulator-trained professionals as the control group. Thus, these studies assess only the benefits of adding simulator training on top of real-life training, instead of comparing different training approaches[10,14].

In science education, gamified laboratory simulators are used to teach high school and university students in natural sciences. For this user group, studies show that desktop-based simulations lead to learning outcomes that are better than or equal to those of traditional teaching methods[15,16]. Some studies also investigated safety training, including laboratory safety, suggesting that simulation-based training can lead to positive behavioral changes in emergency situations[17–19].

However, none of the reviewed science education studies investigated the use of laboratory simulators as a replacement for real-life laboratory training or systematically assessed skills performance after training, as is done for surgery training. A possible explanation is that these educational games have been perceived as supplements to theoretical teaching methods because they originated as e-learning versions of presentations and textbooks[20].

E-learning has progressed to more immersive VR technologies with head-mounted displays that may boost training effectiveness. Instructional designers propose that the increased realism and immersion experienced in VR environments may positively affect learning outcomes[21]. Some evidence indicates that VR is particularly suited for teaching psychomotor skills[22,23]. Also, acting out steps from a VR simulation improves knowledge of the procedure — the key to passing a compliance test[24]. However, the positive effects of the technology on training are still unclear, with randomized trials conducted using educational games in VR only starting to emerge[21,25].

Here, we adapted VR training to teach procedures in biopharma manufacturing. To correctly execute tasks in this line of work, employees must be able to integrate theoretical knowledge about specific regulations with practical laboratory skills. On the basis of these requirements, in collaboration with the biopharma industry, we created a state-of-the-art, immersive VR simulation that merges the capabilities of surgery training with educational games. Like established simulators in medicine, this new genre of simulator training focused on conveying practical skills. However, the simulation also integrated underlying theoretical concepts into the narrative. It also included gaming elements such as scorekeeping and interactions with fictional characters similarly to educational games[15].

We investigated the extent to which this type of VR simulation can replace traditional professional training methods in the biopharma industry by measuring practical skills performance and theoretical knowledge of study participants after training (Supplementary Methods).

Results

Study overview. To ensure the most direct relevance to the biopharma industry, we designed the study to be conducted with industry operator trainees, as opposed to previous studies that have been biased toward university student populations[26,27]. Before entering the workforce in pharmaceutical manufacturing, aspiring industry operators are trained in measuring techniques (metrology) at production schools for vocational education[28]. The specific training content for the study was developed in collaboration with a large multinational biopharma company according to its operating procedures. The training focused on conducting and documenting a pH calibration and adjustment. This topic was chosen for its relevance to a large number of employees in biopharma manufacturing.

Study participants were randomly assigned to one of three training conditions. In the first condition, participants read a 20-page SOP on pH calibration and adjustment — an established method for compliance training in the biopharma industry (Fig. 1a). The second condition consisted of a first-generation VR simulation for compliance training (Fig. 1b) based on the SOP and a set of predefined knowledge

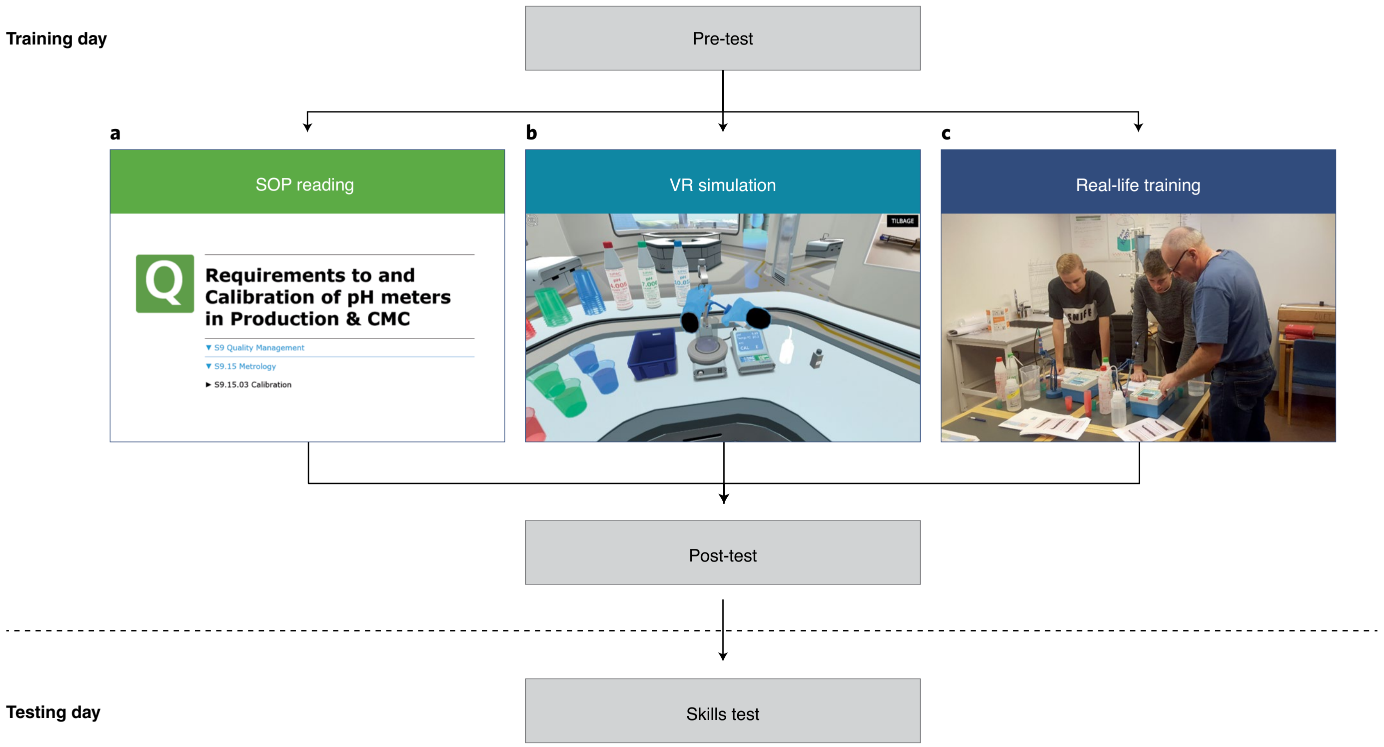

Fig. 1 | Flow chart of study setup. On training days, study participants filled out a pre-test questionnaire before being randomly assigned to one of three training groups: **a**, standard operating procedure (SOP) reading, **b**, virtual reality (VR) simulation or **c**, real-life training. Immediately after the training, participants were assessed with a post-test questionnaire, followed by a practical skills test on the next day (testing day).

questions used for evaluating employees after training (compliance test). The final condition followed the protocol of the VR simulation, but with real-life training in an on-the-job laboratory setting. In this training, two participants at a time were trained simultaneously by an experienced industry operator (Fig. 1c).

Before the training, participants filled out a pre-test questionnaire to determine their demographics and evaluate their backgrounds including expertise in pH calibration. Immediately after the training, participants took a post-test questionnaire of the compliance test plus items about perceived learning, self-efficacy, enjoyment and invested mental effort, to measure the learning experience (Supplementary Table 1). On the next day, participants' practical skills were individually assessed (Fig. 1). In this assessment, participants performed a pH calibration and adjustment with real equipment using skills learned in their training while a metrology expert assigned scores indicating which tasks participants performed correctly according to regulations.

Improving compliance and practical lab performance. The primary objective of the study was to investigate the extent to which VR simulations can replace the traditional biopharma industry training methods of SOP reading and real-life training (Fig. 2a,b).

Currently our company collaborator assesses compliance of operators after traditional training using a post-test questionnaire with 15 multiple choice questions. The questions we used were developed by the company to test their employees' theoretical knowledge about the regulations and procedures. We investigated how the different training methods affected the trainees' ability to pass this standardized test.

The post-test knowledge scores differed significantly between conditions ($F_{2,62} = 17.84$, $P < 0.001$). Higher scores were achieved in the VR condition than in the SOP condition ($t_{41} = 5.28$, $P < 0.001$), and VR training did not differ significantly from real-life training ($t_{41} = 0.76$, $P = 0.45$). The theoretical knowledge gained from VR training was 39% higher than from reading the SOP and equal to knowledge gained from real-life training. Thus, we conclude that the VR simulation was equally capable of preparing operators for the standardized compliance test compared to working with a real trainer and significantly better than reading the SOP.

In addition to passing a theoretical test, employees must be able to apply learnings from their training to an on-the-job setting. This skill is particularly relevant with the US Food and Drug Administration's announcement to "shift their inspection focus to [practical] performance and away from compliance"[29]. Hence, we developed an additional test assessing participants' practical skills on the basis of the steps presented in the training material. The test consisted of 21 tasks that participants individually and independently performed with real equipment on the testing day. The number of correctly executed tasks in the skills test, as assessed by a metrology expert, differed significantly among conditions ($F_{2,57} = 15.80$, $P < 0.001$). Higher scores were achieved with the VR condition compared to reading the SOP ($t_{38} = 3.14$, $P = 0.003$), while lower scores were achieved with the VR condition compared to real-life training ($t_{39} = -2.32$, $P = 0.026$). Participants trained in VR performed 41% better on the skills test than participants who read the SOP and 21% worse than participants who received real-life training. Thus, for preparing operators to perform practical tasks on the job, VR training was substantially more effective than reading the SOP albeit not on par with real-life training.

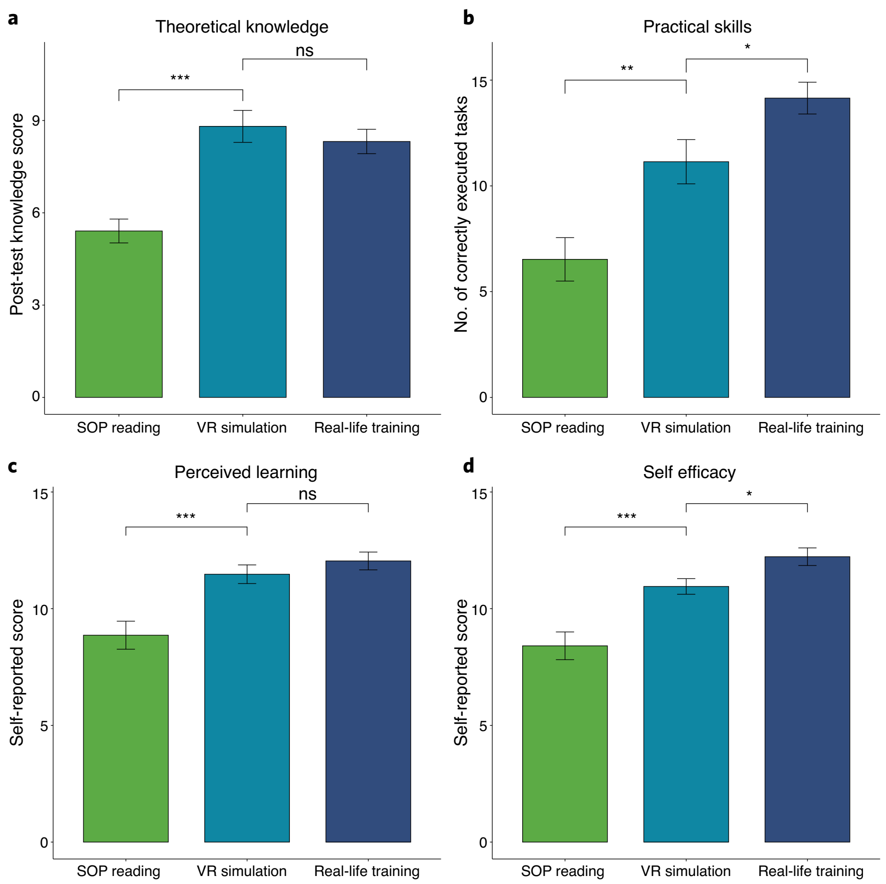

Fig. 2 | Direct and indirect performance metrics comparing VR with SOP reading and real-life training. a, Theoretical knowledge was measured by a multiple-choice test used for compliance assessment in the biopharma industry. **b**, Practical skills were evaluated by metrology experts as participants performed laboratory tasks. The correct execution of tasks according to regulation was scored. **c**, Participants' self-reported perception of how much they learned was measured with psychometric questions on a five-point Likert scale. **d**, Participants' self-reported ability to perform a pH calibration, use the logbook and remember the steps in the protocol (self-efficacy) was measured with psychometric questions on a five-point Likert scale. Statistical analyses were performed using ANOVA, followed by independent samples *t*-tests between VR and SOP reading and between VR and real-life training; $***P < 0.001$, $**P < 0.01$, $*P < 0.05$; ns, $P > 0.05$. Error bars depict s.e.m.

Self-reported indicators of training efficiency. A large body of evidence suggests that learning is influenced by factors such as motivation, engagement, self-efficacy and previous experience[30]. Hence, in addition to directly measuring learning outcomes, we included self-reported, indirect measures of performance and subjective experience in the pre- and post-tests. We observed significant differences in perceived learning ($F_{2,62} = 13.01$, $P < 0.001$), self-efficacy ($F_{2,62} = 18.64$, $P < 0.001$), mental effort ($F_{2,62} = 9.74$, $P < 0.001$) and enjoyment ($F_{2,62} = 51.11$, $P < 0.001$) between conditions (Figs. 2 and 3).

In line with the theoretical knowledge score, participants in the VR condition had the same perception of how much they learned as participants who received real-life training ($t_{41} = -1.03$, $P = 0.308$). Similarly, participants in the VR condition reported higher perceived learning compared to those who read the SOP ($t_{41} = 3.59$, $P < 0.001$). Also in line with the practical skills test, when asked about self-efficacy, participants trained in VR were less confident about their ability to perform a pH calibration in the lab, use the logbook correctly and remember the protocol step by step compared to participants with real-life training ($t_{41} = -2.52$, $P = 0.016$). Again, compared to the SOP condition, participants who were trained in VR reported higher self-efficacy ($t_{41} = 3.68$, $P < 0.001$). Thus, these indirect performance metrics supported the findings of the direct performance metrics, with perceived learning as a proxy for theoretical knowledge and self-efficacy for practical skills (Fig. 2c,d).

Enjoyment and mental effort. To determine participants' engagement with the training material, we asked four questions about how much they enjoyed their training experience[31]. Participants in the VR condition enjoyed their training as much as participants who received real-life training ($t_{41} = -0.39$, $P = 0.695$) and more than participants who read the SOP ($t_{41} = 7.84$, $P < 0.001$). This result confirmed anecdotal evidence that employees perceive reading an SOP as unnecessary and of little value (Fig. 3a)[3].

Finally, we were interested in how mentally draining the different interventions were. We expected many trainees would be new to VR and thus have to make an extra effort to learn in this environment. As per our hypothesis, participants in the VR condition reported that they invested more mental effort than participants who received real-life training ($t_{41} = 2.09$, $P = 0.043$). However, participants in the VR condition invested lower mental effort than those who read the SOP ($t_{41} = -2.27$, $P = 0.03$). This result suggests that the real-life training was the most effortless learning method for the pharmaceutical manufacturing tasks, followed by VR and then SOP reading (Fig. 3b).

Discussion

We created a VR environment for biopharma employee training that combines elements of surgery simulator training with educational games. In contrast to common practice in medicine and science education, our intent was not to supplement traditional training, including real-life training, but completely replace it with a VR option. Instead of conducting this study with populations with higher education, such as university students, surgeons and executives, our study was also innovative in developing VR training for biopharma manufacturing jobs that typically employ people with vocational or technical school degrees.

An accepted training practice in many biopharma companies is giving new employees an SOP to read and expecting them to pass a theoretical compliance test[29]. For this study, we collaborated with a biopharma company to use one of their SOPs and corresponding post-tests to closely mimic actual employee training and testing. Our study found that, of three training conditions, reading an SOP was the least efficient, least enjoyable and most mentally draining method for acquiring theoretical knowledge. Hence, for passing a standardized compliance test, VR was the most competitive training method because it was as efficient and engaging as real-life training.

However, this system of training and assessment does not guarantee a highly

Fig. 3 | Enjoyment and mental effort comparing VR with SOP reading and real-life training. **a**, Participants' self-reported enjoyment of their training was measured with psychometric questions on a five-point Likert scale. **b**, Participants' self-reported overall invested mental effort was measured with a psychometric question on a nine-grade symmetrical category scale. The metric indicates how mentally demanding training in the respective medium was. Statistical analyses were performed using ANOVA, followed by independent samples *t*-tests between VR and SOP reading and between VR and real-life training; $^{***}P < 0.001$, $^{*}P < 0.05$; ns, $P > 0.05$. Error bars depict s.e.m.

qualified workforce. Trainees gain only the knowledge needed to pass the test and not other competencies required for their job. In addition to knowing regulations on a theoretical level, biopharma employees must have on-the-job practical skills that are difficult to learn from reading an SOP. We found that our VR simulation was 79% as effective as real-life training for transferring practical skills to trainees. We propose that the VR simulation is therefore a cost-effective alternative to real-life training because it does not require highly experienced trainers or test facilities that are not always readily available. Compared to real-life training, the VR simulation is more standardized, with all trainees exposed to exactly the same, thoroughly evaluated content. This approach fits the highly regulated biopharma sector, where a focus on consistent quality helps prevent costly errors.

In initial implementations, VR training could be supplemented with real-life training on specific equipment and procedures, depending on the trainee's individual needs. However, further research in this area will enable instructional designers to better tailor training content to this medium. Accordingly, the next generation of VR simulations is expected to be much more effective than the prototype presented in this study. In our study, 83% of trainees in the VR condition had never tried VR before, which explains their higher invested mental effort. Once trainees become used to training in VR environments, performance is likely to improve. Finally, with haptic feedback and hand-tracking devices becoming commercially available, the boundaries between VR and real life continue to dissolve. Accordingly, it is conceivable that VR training will eventually be able to fully replace real-life training in the biopharma industry. ❐

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Author contributions

P.W. designed the study, managed the project and analyzed the data. F.C.-K. designed the VR simulation and coordinated the content collaboration. P.W., S.B, A.L.C. and F.C.-K executed the study. P.W., S.B., A.L.C. and M.O.A.S. wrote the manuscript.

Competing interests

A.L.C. and F.C.-K. are employees of Labster ApS. P.W. and S.B. received funding from a joint grant between the University of Copenhagen, the Technical University of Denmark and Labster ApS, where they were formerly employed. P.W, A.L.C. and F.C.-K. hold warrants in Labster ApS according to the length of their employment.

Additional information

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