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Research Note

Virtual reality and simulation for the teaching of sterile pharmaceutical manufacturing in pharmacy education: A cross-sectional evaluation of student opinions

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ABSTRACT

Introduction: Use of virtual reality (VR) is increasing in education. A VR and simulation field trip was developed, allowing students to experience a walkthrough of a sterile pharmaceutical manufacture site using three modalities: a VR headset with 3D static tour, 2D static desktop tour and a 360° dynamic video tour. This study aims to understand student opinions, assess usability of the modalities used and investigate potential for a simulation to replace physical site visits. **Methods:** Data from undergraduate pharmacy and postgraduate pharmaceutical science students was gathered through an online survey. A system usability scale (SUS) score was calculated for each modality. Responses were coded and analysed using descriptive and inferential statistics and open-text responses were analysed using conventional content analysis.

Results: Data was collected from 82.3% ($n = 79$) of students who participated in the virtual field trip. Most students (97.4%, $n = 76$) across both courses were either extremely satisfied or satisfied with the session. Almost two thirds of students (64.9%, $n = 50$) ranked VR walkthrough highest, followed by 360° video walkthrough (19.5%, $n = 15$) and desktop walkthrough (15.6%, $n = 12$). Two out of three students (66.7%, $n = 12$) with previous on-site experience agreed the virtual field trip could replace a physical site visit. Open-text responses revealed advantages and drawbacks versus physical visits. All modalities displayed acceptable usability. Most students (91.0%, $n = 71$) would welcome wider use of VR and simulation in their course.

Conclusion: Positive results obtained highlight potential for greater implementation of VR and simulation to support teaching of sterile manufacturing and increase student accessibility to manufacturing sites.

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Introduction

Educators constantly strive to develop innovative approaches for students to attain real-world learning experiences. They are increasingly faced with the challenge of matching learning styles of modern students who enjoy task-based, independent and active-learning strategies.¹ Virtual Reality (VR) and simulation provide a platform which has proven successful to meet such challenges, integrate technology within curricula, and improve student engagement.² Here, a user can become immersed and navigate a seemingly physical multisensory computer-generated environment.³ Within healthcare education, nursing, medicine and dentistry students have all benefited from its implementation in their curricula.^{4–9} Equally, in pharmacy education, numerous successful applications have been demonstrated that bridge the gap between theory and practice and aid visual understanding of complex processes.¹ Published applications within pharmacy education include but are not limited to teaching drug-receptor interactions, dispensing tasks and patient counselling and appear well received by students.^{2,10–16}

Recent research has highlighted the important role work experience plays in pharmacy student career decisions.¹⁷ Besides dedicated periods of work placement embedded within the course, pharmacy programmes can also introduce students to employment settings via physical on-site visits. These can include visits to community pharmacies, hospitals or pharmaceutical manufacturing sites. While these on-site visits are beneficial to both student learning and career decision making, they require extensive planning and resource allocation. In addition, they may be constrained in scope due to contamination concerns in Good Manufacturing Practice (GMP) and aseptic compounding facilities. Thus, VR and simulation may provide an opportunity to support student exposure to such sites without logistical or administrative burdens.

Accordingly, the aim of this research is to investigate student perspectives of a virtual field trip to a GMP clean room environment to support understanding of sterile manufacturing. The usability of three simulation modalities is assessed. Using an online survey, this study aims to understand student opinions of the virtual field trip, their comfort using VR and simulation for education, and potential for VR and simulation to replace a physical on-site walkthrough of a GMP sterile manufacturing site. This research will inform future implementation of VR and simulation in teaching of pharmaceutical manufacturing within pharmacy curricula.

Methods

Study context

School of Pharmacy, University College Cork (UCC), delivers a range of undergraduate and postgraduate courses. Second year Master of Pharmacy (MPharm) students undertake module PF2017 (Sterile Pharmaceutical Preparations) during which the virtual field trip is delivered. During this module students should develop an understanding of manufacturing of sterile drug products that meet GMP requirements.

The Master of Science (MSc) in Industrial Pharmaceutical Sciences, Operations & Management is a 12-month fulltime MSc programme designed for students seeking to work in pharmaceutical manufacturing environments. In module PF6045 (Pharmaceutical Operations & Management), students undertake both physical and virtual field trips to enhance their knowledge of GMP working environments prior to embarking on an 8-month placement within a pharmaceutical manufacturing environment.

Virtual field trip session overview

Information regarding development and funding of session modalities and visual examples of such can be found in Supplementary Materials 1 and 2. The virtual field trip was performed in a computer-aided laboratory. Groups of between 10 and 15 students attended a given field trip session lasting approximately one hour. Students were assigned a designated station that consisted of a desktop-PC, a VR headset (Meta Quest 2 (Meta Platforms Inc., US)) and a chair. Each station had a cross mark on the floor adjacent to a PC and chair, this served as a centre point for the associated boundary when using the VR headset. Prior to each session, training was provided on how to use VR headset and associated controllers. A safety message was also conveyed.

Students were directed to their digital learning environment on the PC desktop and to an embedded link to the 2D static digital twin. Upon opening the link students were prompted to take a pre-defined virtual facility tour, lasting approximately five minutes. After this, students were instructed to manually tour the facility by clicking on scans. Students were instructed to click and read any tags and labels available in a room or walkway; this lasted approximately 12–15 min.

Next, students were instructed to tour the facility manually through controllers. The 3D version of a digital twin did not have the capability of the pre-defined virtual tour. Students experienced the 3D digital twin for approximately 15 min.

A final element was the 360° video, demonstrating the same facility, rooms and equipment as per the digital twins except in a dynamic video format. The video was approximately seven minutes long with a narration provided. The same lecturer delivered all sessions.

Study design and participants

The population eligible for inclusion were students of all genders (self-reported), undertaking modules PF2017 and PF6045 in the academic year 2024/2025 ($n = 96$). In this manuscript PF2017 students will be referred to as “undergraduate” and PF6045 students as “postgraduate”. All participants were required to be over the age of 18 years. An online survey study was adopted to facilitate widespread data collection for the eligible student population. Ethics approval was granted by University College Cork, School of

Pharmacy Social Research Ethics Committee. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement was used to guide study reporting.¹⁸

Data collection

Survey design

The survey (Supplementary Material 3) was developed by the research team, comprising pharmacist academics from UCC and current MPharm students. It was informed by previous literature to ensure relevance. The survey used a combination of multiple-choice questions, yes/no questions, Likert-scale ratings and open-text questions.

Sections of the survey included questions on demographics, prior level of VR and simulation experience or GMP clean room environments, potential of the session to replace a physical visit and user satisfaction. To assess usability of each session element the System Usability Scale (SUS) instrument was included, as described previously.^{19–21} Further information regarding calculation and Interpretation of SUS scores can be found in Supplementary Material 4. An information sheet preceding the survey highlighted the study purpose and its anonymous nature, followed by a compulsory consent form. The survey was developed on Microsoft® Forms (Microsoft Office, 2016).

Survey distribution

The link to the survey, information sheet and consent form were added to the Canvas virtual learning environment (Instructure, US) on the morning of the sessions. At the end of the session the research team verbally informed students about the study. In addition to the canvas link, a link was provided via a QR code as the researchers left the room. Students were given time to make an informed decision to participate or not. Participation was voluntary and participants could withdraw up until the point of data submission. Data was extracted from the survey platform.

Data analysis

A valid survey response was achieved when a participant clicked 'submit'. Data remediation was performed both manually and using Microsoft® Excel (Microsoft Office 2016). Data was analysed using descriptive and inferential statistics in Statistical Package for Social Sciences (SPSS), Version 27. Chi-squared (χ^2) tests were conducted to compare groups on categorical data, examining the association between student demographics and their responses. Post-hoc analysis was conducted using the z-test to compare column proportions; adjustment for multiple testing using the Bonferroni method was performed. Effect size was reported using either the phi

Table 1
Student characteristics.

Characteristic	% (n)
Gender	
Man	26.6% (21)
Woman	73.4% (58)
Age	
18–20	53.2% (42)
21–23	38.0% (30)
24–26	3.8% (3)
27–29	5.1% (4)
Prior Experience with VR Technology	
None	59.5% (47)
Used Once	26.6% (21)
Used Several Times	13.9% (11)
Used A lot	0% (0)
Comfort Using VR and Simulation Technology for Educational Purposes	
Very Comfortable	48.1% (38)
Somewhat Comfortable	43.0% (34)
Not Comfortable	8.9% (7)
Previous On-Site Experience in GMP Clean Room	
No	76.9% (60)
Yes	23.1% (18)
Module Session Completed Under	
PF2017 (Undergraduate)	74.7% (59)
PF6045 (Postgraduate)	25.3% (20)

coefficient (ϕ) or Cramer's V (V), depending on crosstab table size.

Responses from open ended questions were imported into NVivo® (Version 15) to facilitate analysis. Conventional content analysis was conducted as per the steps outlined by Hseish and Shannon.²² Initial steps included reading and re-reading responses to ensure familiarisation, followed by open coding to create initial non-hierarchical codes. Similar codes were grouped to form generic categories. Generic categories were collated under main categories. Example quotes for each code and category were identified by all authors (Supplementary Material 5). Qualitative data analysis was conducted by one author and cross-checked by a second author to improve data credibility and confirmability.

Results

All valid survey responses were collated ($n = 79$). The response rate was 82.3% (79/96 students). Student characteristics are shown in Table 1. Approximately three quarters ($n = 59$, 74.7%) of respondents were undergraduate, owing to the larger class size, compared to the postgraduate class, ($n = 20$, 25.3%). Approximately 60% (59.5%) of students had no prior experience with VR technology, and approximately half (48.1%) stated they were very comfortable using VR and simulation technology for educational purposes.

Student perceptions of session and modalities utilised

Overall, the session was well received, and student satisfaction was high. In total, 97.4% ($n = 76/78$) were either extremely satisfied or satisfied with the session overall (Table 2), with similar ratings observed across both reported genders ($\chi^2 = 0.56$, $df = 2$, $p > 0.05$, $V = 0.08$).

Students with different levels of prior experience with VR technology reported similar overall satisfaction rates ($\chi^2 = 1.78$, $df = 4$, $p > 0.05$, $V = 0.11$). Conversely, more students who rated themselves as very comfortable using VR and simulation for educational purposes (71.1% $n = 27$) were extremely satisfied with the overall session (30.3%, $n = 10$) somewhat comfortable, (14.3%, $n = 1$) not comfortable ($\chi^2 = 17.14$, $df = 4$, $p < 0.05$, $V = 0.33$). Most students 96.1% ($n = 74$) experienced no technical issues. When asked to rate their technical experience of the session, 56.8% ($n = 42$) stated excellent, 37.8% ($n = 28$) good, 4.1% ($n = 3$) fair, and 1.4% ($n = 1$) poor.

Students were also asked to rate their satisfaction with the three modalities used. The highest number of students were extremely satisfied with the VR walkthrough (55.1%), followed by the 360° video walkthrough (52.6%) and the desktop walkthrough (44.9%). When prompted to rank the three modalities, almost two thirds of students ranked the VR walkthrough as their favourite (64.9%), followed by 360° video walkthrough (19.5%) and desktop walkthrough (15.6%).

Participants were welcomed to share any reasons behind their ranking of the modalities. The main categories, generic categories, and codes obtained from conventional content analysis are presented in Table 3, highlighting perceived positives and drawbacks of each modality.

Usability of the VR and simulation modalities

The SUS grade of each VR and simulation modality used during the VR field trip are shown in Table 4. The desktop walk through scored highest with a mean SUS of 79.96 and a grade of A-, where an A grade indicates 'superior performance'. This was followed by the 360° video walkthrough and the VR walkthrough which was designated an 'average performance', with a calculated grade of C+.

Potential for VR and simulation field trip to replace a physical onsite walkthrough of a GMP sterile manufacturing site

Approximately three quarters of students, 76.9% ($n = 60$) did not have any previous on-site experience in a GMP clean room environment. Similar ratings of the session overall were obtained for students with or without previous on-site experience in a GMP clean room environment. ($\chi^2 = 0.91$, $df = 2$, $p > 0.05$, $V = 0.11$). As expected, more postgraduate students had on-site experience. Where 63.2% of postgraduate students had experience ($n = 12$), versus 10.2% ($n = 6$) of undergraduate students ($\chi^2 = 22.73$, $df = 1$, $p < 0.05$, $\phi = -0.54$). Of the 18 students (23.1%) with onsite experience, two thirds, 66.7% ($n = 12$), agreed the virtual walkthrough could replace a physical onsite walkthrough. Students with previous experience in a GMP clean room environment were asked to provide an additional comment in an open-text question. The main categories, generic categories, and codes obtained from conventional content analysis of these responses are presented in Table 5.

When asked if the use of VR and simulation enhanced their understanding of sterile pharmaceutical manufacturing, 37.2% ($n = 29$) felt it was substantially enhanced, 53.8% ($n = 42$) felt it was moderately enhanced, while only 9.0% ($n = 7$) felt it was minimally

Table 2
Student perceptions of session elements.

Session element	Extremely satisfied	Satisfied	Neutral	Dissatisfied	Extremely dissatisfied
Session Overall	48.7% (38)	48.7% (38)	2.6% (2)	0% (0)	0% (0)
VR Walkthrough	55.1% (43)	33.3% (26)	9.0% (7)	1.3% (1)	1.3% (1)
Desktop Walkthrough	44.9% (35)	43.6% (34)	11.5% (9)	0% (0)	0% (0)
360° Video Walkthrough	52.6% (41)	43.6% (34)	3.8% (3)	0% (0)	0% (0)

Table 3

Main categories, generic categories, and codes identified for justification of session elements rankings.

Main categories	Generic categories	Codes
Positives of VR Simulation	Realistic experience of environment	Immersive, felt like you were there. Easy to envision the environment. Greater understanding provided.
	Interactive and enjoyable nature of simulation	Hands on, Ability to interact with environment. Ability for self-controlled navigation Best visuals Fun and entertaining activity Ability to hold attention and engage audience.
	Novelty of the technology	New experience. Different to anything done before. Alternative form of education, learning enhancement.
Drawbacks of VR Simulation	Getting used to navigating the VR environment	Difficulty getting around simulation.
	Technological and hardware challenges	Challenge to find written information about areas. Blurry Visuals Discomfort with VR headset, headache, flashing lights. Disorientating. Challenges clicking to different environment.
Positives of Desktop Walkthrough	Ease of user experience	Easy to Navigate Improved user control Lack of Time Pressure High quality images Clear icons with explanations.
	Information presentation quality	Well established technology, nothing new. Usual way of learning. Previous experience with technology.
Drawbacks of Desktop Walkthrough	Lack of novelty of presentation	Repetitive Less entertaining, enjoyable. Not immersive Hard to visualise. Did not maintain attention.
	Not as interactive or engaging	Easy to follow instructions. Easy to consume Practical Improved guidance provided. Felt rushed Couldn't move at own speed, lack of autonomy
Positives of 360° Video	Consumer-friendly format	Unvaried Lack of interactive learning element, watching versus doing Not as interesting.
Drawbacks of 360° Video	Lack of user control	
	Difficult to maintain attention	

Table 4

System usability scores of the VR and simulation modalities used.

Element	Mean SUS (SD)	Median (IQR)	Percentile	Grade
VR Walkthrough	71.12 (14.26)	72.5 (20)	60–64	C+
Desktop Walkthrough	79.96 (13.75)	82.5 (17.5)	85–89	A-
360° Video Walkthrough	77.5 (16.36)	75 (23.75)	80–84	B+

enhanced. It is important to note that a higher proportion of those with no previous onsite experience 43.3% ($n = 26$) reported that the use of VR and simulation substantially enhanced their understanding of sterile pharmaceutical manufacturing versus those with previous on-site experience (16.7% $n = 3$) ($\chi^2 = 5.44$, $df = 2$, $p < 0.05$, $V = 0.26$).

Relevance to module/career and wider adoption of VR and simulation in education

Students were asked about the relevance of this session to the module content. 79.5% ($n = 62$) found the session very relevant, 19.2% ($n = 15$) found the session somewhat relevant and 1.3% ($n = 1$) found the session not relevant. There were similar results observed across responses for the two modules ($\chi^2 = 0.55$, $df = 2$, $p > 0.05$, $V = 0.08$). Just under half of students, 46.2% ($n = 36$), reported that they are very likely to apply the knowledge and skills gained from this lesson in their future studies or work, while a further 50.0% ($n = 39$) said they are somewhat likely to apply the knowledge and skills.

Over 90% (91.0%, $n = 71$) of students would welcome wider use of VR and simulation technology for educational purposes in their course. Of note, all of students very comfortable with using VR and simulation for educational purposes want more VR and simulation in their course (100% $n = 38$).

Table 5

Main categories, generic categories, and codes identified regarding ability for virtual walkthrough to replace a physical on-site visit to GMP manufacturing site.

Main categories	Generic categories	Codes
Benefits of Virtual Walkthrough to Replace Physical On-Site Visit	Convenience	More efficient No transport organisation required. Lack of logistical planning requirement.
	Improved communication of information	Ability to navigate back and forth Information presented visually and in written format
	Benefits for manufacturing staff	Less on-site resources required No unwarranted human intervention in restricted areas. Lack of contamination risk.
Challenges of Virtual Walkthrough to Replace Physical On-Site Visit	Lack of human interaction	No opportunity for questions. Cannot watch people and processes in real time.
	Missing experience of rules and protocols	Unable to obtain first-hand experience of regulated nature of area.
		Lack of gowning up procedure experience.

Discussion

This study provides a unique insight into student perspectives of a virtual field trip of a GMP sterile manufacturing site. Results will be of interest to pharmacy educators who teach pharmaceutical manufacturing, co-ordinators of on-site practice setting visits and educators who wish to implement technology in their teaching. To date, most applications of VR and simulation within pharmacy education have focused on clinical and pharmacy practice components of the degree. However, exposure to pharmaceutical manufacturing and development are crucial components of modern pharmacy programmes and can be closely linked with aseptic compounding in hospital settings. It also encompasses an essential component of postgraduate pharmaceutical science programmes. In line with previous findings,^{2,10,12,13} study results reveal a positive reception from students surveyed, regardless of gender or module. Perceived relevance of the session highlights wider potential for similar initiatives to be implemented across undergraduate and postgraduate programmes alike.

A major finding was that two out of three students surveyed with previous on-site experience believed the field trip could successfully replace a physical walkthrough of a GMP sterile manufacturing site. During the COVID-19 pandemic, challenges emerged for educators to deliver content when onsite visits were restricted. VR and simulation became one method to overcome these challenges.^{3,4} In the pharmacy context, previous literature has examined potential for a 360° video to introduce students to sterile compounding prior to course activity.²³ While other novel methods used in the teaching of pharmaceuticals related content have surrounded model-based instruction and videos.^{24,25} Furthermore, this present study highlights how student learning of pharmaceutical manufacturing can be facilitated on campus using an immersive virtual walkthrough.

For educators, challenges exist to successfully implement site visits to pharmaceutical manufacturing sites. As a result, many students lack easy access to these facilities to support learning. In addition, physical site visits for sterile manufacturing facilities will be restricted to low-criticality manufacturing areas where ancillary tasks are being conducted, resulting in students not observing key unit operations. Lack of accessibility was highlighted in this study where over three quarters of respondents did not have any previous on-site experience in a GMP clean room environment. Noteworthy, it was this student cohort who benefited most from the session, as it enhanced their understanding. In tandem, it must be acknowledged that responses to open text questions did reveal enduring advantages of physical onsite experience, including human interactions and possibilities for questions. Therefore, it is the role of the educator to strike the correct balance between using simulation and organising physical visits, with guest lecturing perhaps providing part of a potential solution. However, when resources are restricted, the benefit of virtual visits is clear.

While this manuscript focused on use of virtual field trips for GMP manufacturing, this approach can also be applied to closely related areas such as compounding pharmacies and hospital aseptic compounding units. Additionally, pharmaceutical companies can also benefit from this approach. Previous literature has highlighted the benefits of VR and simulation to facilitate student learning in a safe, low risk and non-threatening environment.^{9,26,27} It has been emphasised that by using such immersive technologies students can make mistakes and learn without putting patients at risk. Risk reduction also plays a role here. However, risk reduction in this context concerns decreased contamination risk and reduced human intervention associated with a virtual versus physical visit.

Another important aim of this study was to analyse usability, as each modality displayed different functionalities. All three modalities achieved acceptable usability grades, while the highest number of respondents were satisfied with the VR walkthrough. It should also be noted that approximately 60% of students had no prior experience with VR technology prior to the session. Given that nine out ten respondents would welcome wider use in their course, substantial scope remains to further implement this technology. Improvements can be made to the current technology as identified in the open-text responses, which future research can address. However, present study results present an optimistic insight into use of VR and simulation.

Regarding strengths and limitations, the high response rate of this study is a clear strength along with analysis of data from two student cohorts. This study only analysed students from one university, therefore lacks generalisability, and is limited by providing *p*-values above or below the 0.05 level, rather than specific values. Additionally, the study involved student perceptions and self-reported opinions and no assessment of course learning objectives or intended learning outcomes attainment was undertaken. Future research could address this gap and involve a comparative analysis between knowledge improvement from traditional teaching versus the VR

field trip.

Conclusion

This study has successfully analysed student perceptions of a virtual field trip of a GMP sterile manufacturing site. Respondent opinions were overall very positive. Impacts of this research include the revelation that two out of three respondents with previous on-site experience believed the virtual walkthrough could replace a physical on-site walkthrough. Consequentially, scope exists to develop similar initiatives and increase accessibility of sites to students with commercially available equipment and software that requires little input once developed. While it must be acknowledged that data was only collected from students of one university, this study adds to the growing evidence base that students, including those surveyed here, react positively to VR and simulation but highlights how many students have little experience with the technology for educational purposes.

Contribution to literature

This research identifies that virtual reality and simulation can play a role in modern immersive pharmacy and pharmaceutical science teaching without a loss in quality associated with immersive physical field trips. It identifies the benefits and disadvantages associated with different virtual reality and simulation modalities in a pharmacy context. This work will allow the field to develop similar virtual field trips and further optimise the learning experience for students.

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CRediT authorship contribution statement

Harriet Bennett-Lenane: Conceptualization, Methodology, Writing – original draft, Formal analysis, Writing – review & editing. **Minh Trang Dam:** Formal analysis, Writing – review & editing. **Aimee Coady:** Formal analysis, Writing – review & editing. **Lynn O'Keeffe:** Methodology, Writing – review & editing. **Evin A. Allen:** Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.cptl.2026.102683>.

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