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Effectiveness of three-dimensional visualisation on undergraduate nursing and midwifery students' knowledge and achievement in pharmacology: A mixed methods study

Julie Hanson[a,*], Patrea Andersen[a], Peter K. Dunn[b]

[a] School of Nursing, Midwifery and Paramedicine, University of the Sunshine Coast, Locked Bag 4, Maroochydore DC, QLD 4558, Australia
[b] School Health and Sports Science, ML 40, Locked Bag 4, Maroochydore DC 4558, Australia

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ABSTRACT

Background: Historically nursing and midwifery students have reported difficulty understanding the concept-based science underpinning the interactions between drugs and their targets. This knowledge is crucial for the administration and monitoring of the therapeutic and adverse effects of medications. Immersive three-dimensional technology is reported to enhance understanding of complex scientific concepts but the physical effects of motion sickness may limit its use.

Objectives: This project compared the effectiveness of three-dimensional immersive visualisation technology with two-dimensional visualisation technology as a teaching method to improve student understanding of a pharmacological concept, and to assess levels of student discomfort and satisfaction associated with the experience.

Design: Traditional lecture content and presentation about drug-receptor binding was followed by exposure to either a two- or three-dimensional artifact visualising β-adrenoceptor binding. Two student groups were compared by type of exposure: Group 1 watched the artifact via a three-dimensional immersive facility and Group 2 on a wide, two-dimensional screen.

Settings: School of Nursing and Midwifery in a regional university in Southeast Queensland, Australia.

Participants: Two hundred and two second year undergraduate nursing and midwifery students.

Methods: The study used mixed methods methodology. Pre- and post- testing of student knowledge was collected using five multiple-choice questions. A post-intervention survey elicited students' self-assessed perceptions of discomfort and satisfaction with the learning experience.

Results: The three-dimensional immersive learning experience was comparable to the two-dimensional experience in terms of satisfaction and comfort but resulted in statistically significant improvements in post-test scores.

Conclusions: The three-dimensional experience improved understanding when compared to two-dimensional viewing, satisfied students leaning needs, and caused minimal discomfort. The results are encouraging in terms of using three-dimensional technology to enhance student knowledge of pharmacological concepts necessary for competency in medication management.

1. Introduction

Globally, the equivalent of US$42 billion is being spent as a consequence of medication errors (WHO, 2018). Health professional competence and medication administration systems and practices are key foci in recent international medication safety initiatives (WHO, 2018). Rapid advances in drug development that includes increasing numbers of combination medications, pre-filled drug dispensing machines coupled with advanced nurse practitioner roles and nurse prescribing have given rise to concerns about the extent of nurses' knowledge of pharmacology during medication practice. Consequently, course content and methods of teaching subject matter in pharmacology curricula have come under scrutiny (Dilles et al., 2011; Lim and Honey, 2006; Lloyd et al., 2013; Lu et al., 2013; Vaismoradi et al., 2014). In Australian pharmacology curricula for nurses lectures and tutorials remain the dominant teaching modes; pharmacodynamic and, pharmacokinetic concepts, toxicology and complementary medicine are commonly taught; and non-traditional teaching methods such as

* Corresponding author.
E-mail addresses: jhanson@usc.edu.au (J. Hanson), panders1@usc.edu.au (P. Andersen), pdunn2@usc.edu.au (P.K. Dunn).

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computer simulations, workshops, project work and online course work are seldom used (Lu et al., 2013). Despite continuing reliance on traditional methods, there is mounting evidence regarding the effectiveness of three-dimensional (3D) visualisation for teaching science concepts (Allen et al., 2016; Lloyd et al., 2013; Silén et al., 2008). There is growing interest in the use of active learning techniques because they are reported to motivate and engage students (Chickering and Gamson, 2009; Schweitzer and Brown, 2009; Swords et al., 2013).

2. Background

Competent pharmacological decision-making is an essential attribute for practicing nurses to ensure safe medication administration (Lim and Honey, 2006). Skilled graduates have a positive impact on health care costs (Choo et al., 2010); patient safety, especially with regard to reducing drug administration errors (Lu et al., 2013); and patient outcomes (Lim and Honey, 2006). Several authors have emphasised that the decision-making capabilities of nurses and their clinical judgment is dependent on a combination of pharmacological knowledge and competence, and that academics and clinical mentors share responsibility for the development of these skills (Bullock and Manias, 2002; Holdforth and Leufer, 2013; Lim and Honey, 2014; Sherwood, 2011; Vaismoradi et al., 2014). A significant factor in drug administration errors by nurses is a lack of pharmacological knowledge and conceptual understanding of pharmacokinetics and pharmacodynamics (Bartley, 2011; Choo et al., 2010; Lim, 2012; Lu et al., 2013). For example, the function of the autonomic nervous system is pre-requisite knowledge for conceptual understanding of drug-receptor binding (Bryant et al., 2018). While nurses' poor calculation skill and lack of proficiency in mathematics is commonly associated with medication error, it is also evident that insufficient knowledge of how drugs work and interact with the body, particularly during the administration of high-alert medications, result in serious consequences for patients (Lu et al., 2013). The translation of science theory and concepts into practice can pose a barrier to student learning and understanding. While there is a growing body of literature describing the use of 3D visualisation for teaching science concepts, there is little evidence regarding its efficacy in teaching and its impact on learning (Richardson et al., 2013). Key factors to consider when using virtual technologies to teach pharmacologic concepts include overcoming existing barriers, such as established conservative methods of tuition, and evidencing the capacity of 3D to enhance conceptual understanding and academic achievement.

2.1. Barriers to science learning and understanding

Research in the area of human information processing has identified that visualisation methods employing animation can remove barriers to understanding by simplifying complex cognitive processes associated with learning (Low, 2001). Using animation as a visual aid has advantages over static pictures and diagrams as it mitigates the initial cognitive effort of mentally working out the processes involved (Low, 2001). This reduction in cognitive load allows the mind to concentrate on the content, address visual abstractions and often results in a quicker grasp of concepts. Consequently, animation and visualisation technology is able to deliver more information than that available in a static diagram and increases understanding by providing a visual and conceptual perspective of processes that are not demonstrated in other methods (Andersen et al., 2012; Yeung et al., 2007). Hoffler and Leutner (2007) suggest these factors are responsible for enhancing motivation and engagement with difficult concepts and accelerating learning

Despite the reputed advantages of using visualisation in teaching, concerns about what is known as cybersickness negatively impact its use (Polcar and Horejsi, 2015; Pölönen et al., 2013; Wa et al., 2011). Cybersickness is defined as an adverse physiological response to virtual exposure, and symptoms similar to motion sickness are reported including nausea, disorientation and oculomotor disturbance (Hale and Stanney, 2006). Several authors have reported that stereoscopic projection, used in 3D devices such as CAVE™ and Oculus Rift™, cause motion sickness (Lui and Uang, 2011; Rebenitsch and Owen, 2016; Polcar and Horejsi, 2015; Pölönen et al., 2013). Stereoscopic projection refers to the illusion of depth created within an image giving viewers the feeling that they can reach inside the images (Polcar and Horejsi, 2015). Hale and Stanney (2006) claimed that at least 12% of the population has difficulty in maintaining visual focus on an object with both eyes (binocular vision) and in depth perception. These focal changes may be compounded by stereoscopic projection. Additionally, 80–95% of people experience a degree of visual disturbance in a virtual environment (Hale and Stanney, 2006) and this is reputed to be more prevalent with age (Lui and Uang, 2011). However, in an investigation into the effects of cybersickness on learning, Taylor and Layland (2018) found that although virtual environments may trigger cybersickness, 360-degree virtual reality experiences were no more likely to cause cybersickness symptoms than other virtual reality learning environments when they compared manikins, standardised patient video case study and 360-degree virtual reality video.

2.2. Evidencing 3D impact on conceptual understanding

3D models incorporated into teaching and learning materials have facilitated understanding of complex educational problems (Silén et al., 2008; Swords et al., 2013). In medical education, Silén et al. (2008) used visualisation that incorporated high-resolution Computerised Tomography (CT) and Medical Resonance Imaging (MRI) to enable students to understand anatomy and physiology, topics that were difficult to teach using traditional classroom approaches. Silén et al. (2008) found that using 3D images stimulated student interest and desire to learn and gave students a clearer illustration of anatomical structures, their size and spatial relationships as well as improving their understanding of complex physiological processes. Typically, these visualisations employ materials embedded on a web page and accompanied by explanatory text. The layout is similar to traditional online learning platforms except that 3D images with activities allow students to interact with applications using a keyboard or mouse. While a student-centered approach to learning using visualisation pedagogies is not a new concept (Low, 2001), virtual environments using 3D technology are advancing (Jang et al., 2017) and have the potential to profoundly impact science education (Merchant et al., 2014).

2.3. Impact of 3D visualisation on student achievement

The success of visualisation as a tool to teach complex ideas was evidenced in one study by students achieving higher grades when compared to those in previous years (Swords et al., 2013). Swords et al. (2013) reported that students' perceived visualisation as more engaging and more effective for critically analysing complex data sets than conventional teaching and learning methods (Swords et al., 2013). Silén et al. (2008) reported similar findings arguing that the use of 3D technology in teaching enables students to draw rational conclusions that facilitate greater understanding. Recent developments to support serious gaming has seen the advent of newer technology and software. This has extended learning opportunities and student engagement by using visualisation and immersive experiences. An example of this new form of visualisation is the Automatic Virtual Environment (CAVE2™) developed by the Electronic Visualisation Laboratory (EVL) at the University of Illinois, Chicago. The potential value of this cutting-edge technology for teaching and learning in pharmacology is unexplored in nursing and midwifery. Consequently, research is needed to substantiate 3D immersive visualisation as a means to engage students in their learning and to improve measurable learning outcomes. In addition, it is essential to provide guidance on pedagogical issues for staff

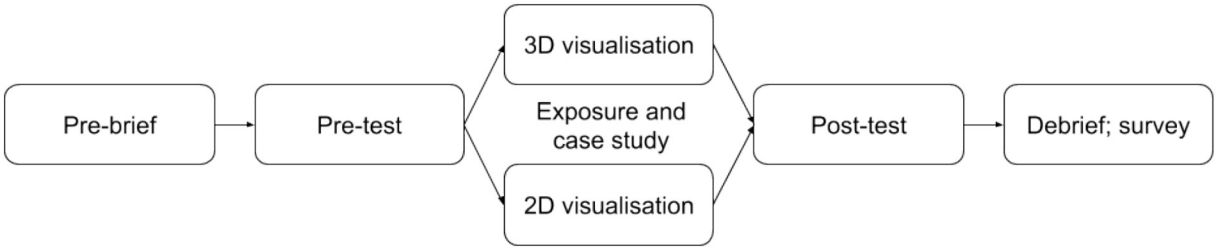

Fig. 1. Five stages of the visualisation artifact project.

seeking to redefine curricula when employing 3D technology (Polcar and Horejsi, 2015).

3. Methods

3.1. The technology

This project involved creating a 3D artifact using stereoscopic visualisation technology in an attempt to enhance student pharmacodynamic understanding of drug-receptor binding of a β-adrenoceptor. Images were created to visualise the role of the autonomic nervous system in controlling resting heart rate and the action of a beta blocker medication at work to reduce sympathetic innervation of the heart. This involved creating 3D imagery of a neuron; the neurotransmitter acetylcholine (Ach) attaching to muscarinic M_2 receptors in the sinoatrial (SA) and atrioventricular (AV) nodes of the parasympathetic branch of the nervous system; the neurotransmitter norepinephrine attaching to adrenoceptors in the SA node, atria and ventricles of the sympathetic division of the nervous system to increase heart rate, automaticity, conduction velocity and force of contraction and, a beta blocker medication competitively binding to β_1 receptor sites and displacing norepinephrine.

Two different rooms were used to expose students to this artifact: (i) CAVE2™ 3D visualisation studio consisting of 80 LCD panels (floor to ceiling), placed in an arc of 320° measuring 7 m in diameter; and (ii) a two-dimensional (2D) standard PowerPoint projected onto 16:9 standard LCD computer screens merged together to form a wall panel in a standard teaching space.

3.2. Aims and objectives

The aim of the project was to assess the quality of the student experience through academic performance on tests, physiologic response to stereoscopic projection, and satisfaction ratings. Hence, the objectives for the project were to: (a) measure the effectiveness of using a 3D artifact in CAVE2 ™ on undergraduate nursing and midwifery students' pharmacodynamic knowledge of drug-receptor binding compared to exposure using a two-dimensional (2D) wide screen; (b) self-assessed levels of discomfort, such as headache, dizziness or motion sickness, associated with stereoscopic projection in the CAVE2™ environment; and (c) elicit student perceptions of satisfaction with their learning using visualisation technologies.

3.3. Setting and participants

The study was conducted in the School of Nursing and Midwifery at a regional university in Southeast Queensland, Australia. Of the 226 s-year students enrolled in the Bachelor of Nursing Science degree or Bachelor of Nursing Science and Midwifery dual degree at the research study site, 202 consented to participate.

3.4. Ethical considerations

The University Human Research Ethics Committee approved the study. A Research Participant Information Sheet was provided to students two weeks in advance of the learning activity in the online course materials. The role of the course coordinator as a researcher in the study was disclosed to participants via the research information sheet, class attendance was not mandatory, study participation was voluntary, and all the data were anonymous. A convenience sample was used and participants gave consent in class prior the activity. The study design provided autonomy, giving nursing students the freedom to decide whether to participate and release information for research purposes. There was no identifying information on tests or questionnaires. Anonymous data is reported in this paper.

3.5. Research design

The study is positioned within a co-constructivist epistemology where a structured process of review and reflection is paramount to achieving optimal learning (Stewart, 2012). The intervention was conducted in five stages that included pre-brief and debrief (Fig. 1).

3.6. Data collection

Stages 2–4 addressed research Objective (a) and Stage 5 addressed Objectives (b) and (c). Stage 1 involved a pre-brief where all students were given information regarding the session and the research component, informed consent was sought, and the learning outcomes were discussed. Students were advised how to respond in the event of feeling any discomfort during the visualisation. In Stage 2, consenting participants completed a pre-test. In Stage 3, all students viewed either a 2D wide screen viewing of the artifact in a standard teaching space or a 3D immersive learning experience in CAVE2™ visualisation studio. Students experienced a 2D or 3D visualisation learning environment depending on the availability of the facility and the class size. Both visualisations were followed by working through a case study with their tutor. In Stage 4, after exposure to the artifact and completion of the case study, consenting participants undertook a post-test. Stage 5 involved a structured debrief for all participants, and the completion of a survey for consenting participants.

3.7. Instruments

The three objectives (Section 3.2) were met using three instruments. The effectiveness of the artifact on knowledge acquisition (Objective a) was assessed using a five-question multiple-choice test (Table 1). The same questions appeared in both the pre- and post- test and were presented online (using SurveyMonkey; https://www.surveymonkey.com) and in random order. Students were told which questions they answered incorrectly only after the posttest. Both pre- and post-tests were scored as the number of questions correct out of 5. The tests were password protected so that access to the tests was only possible during the learning activity. Discomfort ratings related to the visualisation (Objective b) were obtained using a 10-point ordinal scale ranging from 1 (no discomfort) to 10 (incapacitating). Student satisfaction (Objective c) was rated using the Modified Satisfaction with Simulation Experience Scale (SSES) (Levett-Jones et al., 2011) designed as a five-point Likert

Table 1
The five multiple-choice questions used in the pre- and post-tests:

1 What is the term most commonly used to describe neurotransmitters?
a. electrical signals; b. nerve impulses; c. action potentials; d. chemical messengers
2 Which neurotransmitter is responsible for parasympathetic effects on the heart?
a. adrenaline; b. noradrenaline; c. acetylcholine; d. dopamine
3 Name one effect of the sympathetic nervous system on the heart.
a. decreased conductivity; b. increased force of contraction; c. decreased automaticity; d. decreased heart rate
4 Which receptor sub-type is blocked by a beta-blocker to decrease heart rate?
a. β1 – adrenoceptors; b. β2 – adrenoceptors; c. – Muscarinic M2 receptors; d. Muscarinic M3 receptors
5 Identify a drug that is classed as a beta-adrenoceptor antagonist.
a. adrenaline; b. atropine; c. bisoprolol; d. losartan

scale. An expert panel established content validity of the original satisfaction scale that showed internal consistency (using Cronbach's alpha) of 0.77. Exploratory factor analysis yielded a three-component structure termed Debriefing and Reflection (Questions 1 to 7), Critical Thinking & Clinical Reasoning (Questions 8 to 11), and Clinical Learning (Questions 12 to 24); each subscale demonstrated high internal consistency: 0.94; 0.86; 0.85, respectively. For this project, minor wording changes were made to 10 of 24 questions. Question 25 ("I believe that the visualisation will enhance my understanding of patients conditions and treatment taught in other courses") was added to evaluate the context of the learning experience from a simulation experience to a 3D immersion (Fig. 2).

3.8. Data analysis

All data were analysed using R Version 4.4 (R Core Team, 2018). Marks out of 5 were to summarised using changes in the percentage of

SATISFACTION WITH SIMULATION EXPERIENCE SCALE (SSES) – MODIFIED	
Debrief and reflection (using a 5-point ordinal scale)	
01	The facilitator assisted me to determine if I had met the learning outcomes
02	The facilitator summarised key points during the debriefing
03	I had the opportunity to reflect on and discuss my learning during the debriefing
04	The debriefing provided an opportunity to ask questions
05	The facilitator provided feedback that helped me to advance my understanding of pharmacodynamics
06	Reflecting on and discussing the visualisation enhanced my learning
07	The facilitator made me feel comfortable and at ease during the debrief
Case Study – Critical thinking and clinical reasoning (using a 5-point ordinal scale)	
08	The visualisation and case study developed my critical thinking skills
09	The visualisation and case study developed my clinical reasoning and decision-making ability in relation to drug therapy
10	The visualisation helped me to understand how drugs bind to receptors
11	The visualisation helped my understanding of age-related changes on pharmacokinetics
Clinical learning (using a 5-point ordinal scale)	
12	The visualisation tested my ability to apply theory to practice situations
13	The visualisation reinforced content taught in the course
14	The visualisation improved my understanding of the relevance of pharmacodynamics to medication therapy
15	The visualisation helped me to see the relevance of what I learned in the course to patient care
16	The visualisation helped me to recognise my theory strengths and weaknesses
17	The visualisation tested my capacity to set goals and plan care for adverse drug events
18	As a result of the visualisation I felt more prepared for educating patients about how beta blocker medications work
19	The visualisation has built confidence in my ability to apply drug knowledge in practice
20	The visualisation was effective in enhancing my understanding of pharmacologic concepts
21	The visualisation enhanced my understanding of the autonomic nervous system and how this system controls resting heart rate
22	The visualisation increased my understanding of how beta blockers work
23	The visualisation assisted me to identify safety points in relation to patients self-administration of beta blockers
24	This was a valuable learning experience
Additional question (using a 5-point ordinal scale)	
25	I believe that the visualisation will enhance my understanding of patients conditions and treatment taught in other courses
The additional discomfort rating question (using a 10-point ordinal scale)	
26	The visualisation caused feelings of discomfort that adversely impacted my ability to engage and learn content

Fig. 2. The Modified Satisfaction with Simulation Experience Scale (SSES).

students getting the questions correct overall, changes in the percentage of students correctly answering the questions type of exposure (using McNemar's test), and rankings average and standard deviation of scores. Paired *t*-tests were conducted to compare the means of the two samples before and after data on the same participant. *P*-values < 0.05 were used to identify notional statistical significance. Rankings from Likert Scale results in the 25 item SSES plus the addition Question 25 were analysed using SPSS to generate descriptive statistics.

4. Results

The 3D immersion technology (CAVE2™) was evaluated with 184 students, and the 2D immersion technology (Collaboration Studio) with 18 students. All students studied at the same university campus. Fewer students used the 2D wide screen options due to facility availability and the size of the cohort. The unequal sample sizes do not prevent the use of standard statistical tests, but do increase the chance of Type II errors (the chance of failing to reject a false null hypothesis).

4.1. Performance on each question in concept test

Table 1 shows the five pre-test and post-test knowledge-acquisition questions. The baseline concept test scores for the 2D and 3D immersion groups showed no significant differences for each individual question (Table 2). The 3D immersion statistically improved the percentage of correct answers on each question with the exception of Q3 (though the percentage correct still increased). In contrast, the percentage of correct answers using 2D immersion only improved statistically for Q5 (and declined slightly for Q1 and Q4). The biggest discrepancy in percentage improvement between the 3D (+25.3%) and 2D (−9.5%) visualisations was for Q1 ($P = 0.008$).

The total scores for each student was compared for the pre- and post-concept tests (Table 3). The baseline (pre-intervention) scores for both immersion techniques were similar ($P = 0.868$). Student scores out of 5 significantly improved for students in both the 2D and the 3D immersion groups but the 3D immersion group had a significantly greater improvement (1.16 vs. 0.55 out of 5; $P = 0.013$; 95% CI for difference from 0.30 to 1.10 higher for 3D group; $P = 0.0013$).

Table 3
The mean score out of 5 for the multiple choice questions (shown in Table 1), pre- and post-intervention, for each immersion exposure.

	3D-immersion (n = 177 for changes)	2D-immersion (n = 17 for changes)	*P*-value
Pre-test	2.27	2.33	0.868
Post-test	3.43	2.88	
Change	1.16	0.55	**0.0013**
P-value	< **0.001**	**0.030**	

P-values in the final column are from a *t*-test. *P*-values comparing the change within each immersion computed using a paired *t*-test. The *P*-values in bold are < 0.05.

Table 4
The discomfort scores for students exposed to the 3D (n = 170) and 2D (n = 17) immersion techniques.

Discomfort rating	3D: % (n)	2D: % (n)
None	78.2% (133)	64.7% (11)
Minor	11.8% (20)	23.5% (4)
Moderate	8.8% (15)	5.9% (1)
Severe	0.6% (1)	5.9% (1)
Incapacitated	0.6% (1)	0.0% (0)

4.2. Discomfort ratings

Students using the 2D and 3D immersion techniques rated their level of discomfort on a 10-point ordinal scale from 1 (no discomfort) to 10 (incapacitating), combined into five groups (combining 1 and 2; 3 and 4; and so on) as shown in Table 4 (note that no student used the original score of 10). In general, the 3D immersion caused little discomfort to students and there is no evidence that the immersion techniques differ in terms of their discomfort proportions (Fisher exact test; $P = 0.153$).

4.3. Satisfaction scores

Students' satisfaction with the immersion techniques was rated with

Table 2
The percentage of students getting each knowledge-acquisition question correct, pre- and post-intervention, for each immersion exposure.

Question		3D immersion (n = 177 for changes)	2D immersion (n = 17 for changes)	*P*-value comparing 3D and 2D
Q1	% correct: pre	39.7	38.8	1.000
	% correct: post	64.9	29.4	
	% correct: change	25.3	−9.5	**0.008**
	P-value for change	< **0.001**	0.480	
Q2	% correct: pre	35.3	27.8	0.702
	% correct: post	60.5	35.3	
	% correct: change	25.1	1.63	0.183
	P-value for change	< **0.001**	1.000	
Q3	% correct: pre	57.6	55.5	1.000
	% correct: post	66.1	76.5	
	% correct: change	8.5	20.9	0.666
	P-value for change	0.097	0.371	
Q4	% correct: pre	53.3	72.2	0.195
	% correct: post	75.1	70.6	
	% correct: change	21.9	−1.6	0.135
	P-value for change	< **0.001**	1.000	
Q5	% correct: pre	41.3	38.9	1.000
	% correct: post	74.6	76.5	
	% correct: change	33.3	37.6	1.000
	P-value for change	< **0.001**	**0.0412**	

P-values for comparing pre-immersion scores of each immersion group in the final column computed using a chi-square test. *P*-values for comparing *changes* in percentages in the final column computing using Fisher's exact test by recording the change in each students' score for that question as −1, 0 or 1. *P*-values comparing the change within each immersion computed using McNemar's test. The *P*-values in bold are < 0.05. Sample sizes differ slightly for each question, and for pre, post and changes in scores. *P*-values have not been adjusted for multiple testing.

Table 5
Summaries of the ratings out of 5 for the three SESS subscales (Strongly disagree = 1; Strongly agree = 5) for the 3D (n = 195) and 2D (n = 18) immersion groups.

	3D: mean	2D: mean	*P*-value
Debrief and reflection	4.18	3.96	0.29
Critical thinking & clinical reasoning	4.14	3.86	0.11
Clinical learning	4.03	3.71	0.06

a subset of the SSES-Modified scale, as described earlier. For SSES, higher scores represent better outcomes. There were three subscales: Debrief and Reflection; Critial Thinking & Clinical Reasoning; and Clinical Learning. Students generally were satisfied with both immersion techniques (Table 5) and scores for the 3D immersion were higher for each subscale, but not statistically significant.

Scores for the 3D immersion were higher for each individual SSES question except Question 5 and 14, but the only statistically significantly difference ($P = 0.047$) was for Question 21 ("The visualisation enhanced my understanding of the autonomic nervous system and how this system controls resting heart rate").

This suggests further research could be instructive. For the additional question (Q25), the 3D immersion mean (4.05) was higher ($P = 0.121$) than the 2D immersion (2.72).

5. Discussion

The percentage of students getting correct answers to each of the questions (Table 2) significantly increased after exposure to 3D visualisation, and for 1 out of 5 questions after exposure to 2D visualisation. Students in both 2D and 3D groups had statistically significant increases in their "out of 5" scores (Table 3) and the increase for 3D was statistically better than for the 2D (increases of 1.16 vs. 0.55 out of 5; 95% CI for difference from 0.30 to 1.10 higher for 3D group; $P = 0.0013$). These results are consistent with those of Richardson et al. (2013) who reported improvements in post-test scores when 3D technology was used to teach drug-receptor interactions to pharmacology students.

Table 4 reveals no statistically significant difference in discomfort. This is an interesting finding as concerns for cybersickness has been reported as a barrier to using 3D immersion as a learning strategy (Hale and Stanney, 2006; Polcar and Horejsi, 2015). Nonetheless, the relationship between cybersickness and learning and what factors contribute to low levels of discomfort in virtual environments remain unclear. Polcar and Horejsi (2015) compared a standard computer workstation, stereo-projection and Oculus Rift™ and found no difference in knowledge acquisition between a self-navigated tour of a standard computer screen and stereoscopy, but poorer results with Oculus Rift. Cybersickness was highest in the stereo-projection group but more intense with Oculus Rift™. Polcar and Horejsi (2015) also found that people who regularly use 3D programs had higher knowledge acquisition than non-users and were more resistant to cybersickness. Polcar and Horejsi (2015) conclude that stereoprojection is suitable for mass narrated learning and provides similar knowledge acquisition to a standard computer 3D tour but there is a greater possibility of cybersickness. Conversely, the findings presented here demonstrate minimal cybersickness in the 3D stereoscopic group (n = 184) and substantiate the conclusions of Taylor and Layland (2018) who reported 3D virtual environments did not produce significant levels of cybersickness (n = 60). These two findings suggest that this symptomology is not always present with stereoscopic projection even with larger cohorts of students. Rebenitsch and Owen (2016) found a strong correlation between cybersickness, the field of view and navigation of the artifact. This suggests that passive viewing of an artifact results in less cybersickness that direct manipulation of the images by the user.

The mean scores for the SSES subscales (Table 5) were higher for the 3D immersion in each case. While not statistically significant better, each subscale has a higher mean for the 3D immersion suggesting that the 3D immersion is at least no worse than the 2D immersion. These findings are similar to Richardson et al. (2013) who found that those students experiencing 3D presentations expressed increased enthusiasm for the course. The mean response to the additional question was higher for the 3D immersion students. Again, while the improvements are not statistically significant, on almost every criterion the mean for the 3D immersion is higher (better) than the mean for the 2D immersion, suggesting that the 3D immersion is at least no worse than the 2D immersion. In summary, the 3D immersion appears at least as good in terms of discomfort, satisfaction on the SSES scores on the three sublevels, the additional Q25, and produces statistically significant better improvement in test scores (out of 5) compared to the 2D immersion.

Ethical considerations and constraints posed by the university approval authority prevented the use of a control group as it was deemed inequitable to have a student group that did not experience the intervention and the potential educational benefits. Fewer students used the 2D wide screen options due to the availability of the facilities and the size of the cohort, and random allocation to the 2D and 3D was not possible. The literature suggests that the impact that learning by visualisation has on clinical practice and safe medication practice is dependent on nurses developing pharmacologic knowledge and pharmacologic competence (Bullock and Manias, 2002; Holdforth and Leufer, 2013; Lim and Honey, 2014; Sherwood, 2011; Vaismoradi et al., 2014). The scope of this project focused on evaluating pharmacodynamic knowledge and further research should evaluate the transfer of knowledge generated through 3D technology to those studying clinical courses. This would be valuable given the need for accurate diagnosis and enhanced medication safety.

6. Conclusions

The use of 3D technology was successful in increasing the percentage of students correctly responding to post-test questions. Student satisfaction ratings with the visualisation experience were high and minimal discomfort associated with the stereoscopic virtual environment was reported. The implementation of immersive 3D visualisation as a teaching strategy in the education in nursing and midwifery is an innovative move to improve and expand the curriculum by providing new opportunities for learning. The results of this research, with regard to the use of digital technologies, support the reform of curricula and demonstrate that strategic changes to teaching will enhance the student learning experience.

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Ethical approval

University of the Sunshine Coast Human Research Ethics Committee approval: A/17/912.

Declaration of Competing Interest

None declared.

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References

Allen, L.K., Eagleson, R., de Ribaupierre, S., 2016. Evaluation of an online three-dimensional interactive resource for undergraduate neuroanatomy education. Anat. Sci. Educ. 9 (5), 431–439. Retrieved from. https://search-proquest-com.ezproxy.usc.edu.au/docview/1871575737?accountid=28745.

Andersen, P., Inoue, K., Walsh, K., 2012. An animated model for facilitating understanding of Grounded Theory and the processes used to generate substantive theory. J. Res. Nurs. 18 (8), 734–743.

Bartley, A.J., 2011. Review: building capacity and capability in patient safety, innovation and service improvement: an English case study. J. Res. Nurs. 16 (3), 252–253.

Bryant, B., Knights, K., Darroch, S., Rowland, A., 2018. Pharmacology for Health Professionals, 5th ed. Mosby Australia, Australia.

Bullock, S., Manias, E., 2002. The educational preparation of undergraduate nursing students: a survey of lecturers' perceptions and experiences. J. Adv. Nurs. 40 (1), 7–16.

Chickering, A.W., Gamson, Z.F., 2009. Seven principles for good practice in undergraduate education. Internet High. Educ. 7, 217–232.

Choo, J., Hutchinson, A., Bucknall, T., 2010. Nurses' role in medication safety. J. Nurs. Manag. 18, 853–861. https://doi.org/10.1111/j.1365-2834.2010.01164.x.

Dilles, T., Elseviers, M.M., Van Rompaey, B., Vander, M., 2011. Barriers for nurses to safe medication management in nursing homes. J. Nurs. Scholarsh. 43, 171–180.

Hale, K.S., Stanney, K.M., 2006. Effects of low stereo acuity on performance, presence and sickness within a virtual environment. Appl. Ergon. 37, 329–399.

Hoffler, T.N., Leutner, D., 2007. Instructional animation versus static pictures: a meta-analysis. 17 (6), 722–738.

Holdforth, J.C., Leufer, T., 2013. The strategic role of education in the prevention of medication errors in nursing: part 2. Nurse Educ. Pract. 13 (3), 217–220. https://doi.org/10.1016/j.nepr.2013.01.012.

Jang, S., Vitale, J.M., Jyung, R.W., Black, J.B., 2017. Direct manipulation is better than passive viewing for learning anatomy in a three-dimensional virtual reality environment. Comput. Educ. 106, 150–165. https://doi.org/10.1016/j.compedu.2016.12.009.

Levett-Jones, T., McCoy, M., Lapkin, S., Noble, D., Hoffman, K., Dempsey, J., Arthur, C., Roche, J., 2011. The development and psychometric testing of the Satisfaction with Simulation Experience Scale. Nurse Educ. Today 31 (7), 705–710.

Lim, A.G., 2012. Nurses as Emergent Prescribers in New Zealand: A Descriptive Comparative Study Using a Multiple Case Approach, 2012. School of Nursing. University of Auckland, Auckland, New Zealand.

Lim, A.G., Honey, M., 2006. Integrated undergraduate nursing curriculum for pharmacology. Nurse Educ. Pract. 6 (3), 163–168. https://doi.org/10.1016/j.nepr.2005.11.005.

Lim, A.G., Honey, M., 2014. New Zealand newly graduated nurses medication management: results of a survey. Nurse Educ. Pract. 14 (6), 660–665. https://doi.org/10.1016/j.nepr.2014.08.005.

Lloyd, H., Hinton, T., Bullock, S., Babey, A., Davis, E., Fernandes, L., ... Ziogas, J., 2013. An evaluation of pharmacology curricula in Australian science and health-related degree programs. BMC Med. Educ. 13, 153. http://dx.doi:http://dx.doi.org.ezproxy.usc.edu.au:2048/10.1186/1472-6920-13-153.

Low, R., 2001. Beyond "eye candy": improving learning with animations. In: Smythe, N. (Ed.), Proceedings of the Apple University Consortium Conference. James Cook University, Australia.

Lu, M.C., Yu, S., Chen, I.J., Wang, K.W., Wu, H.F., Tang, F.I., 2013. Nurses' knowledge of high-alert medications: a randomized controlled trial. Nurse Educ. Today 33 (1), 24–30.

Lui, C.L., Uang, S.T., 2011. Effects of presence causing cybersickness in the elderly within a 3D virtual store. In: International Conference on Human-Computer Interaction. Users and Applications. HCI 2011. Lecture Notes in Computer Science, 6764. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-21619-0_61.

Merchant, Z., Goetz, E.T., Cifuentes, L., Keeney-Kennicutt, W., Davis, T.J., 2014. Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: a meta-analysis. Comput. Educ. 70, 29–40.

Polcar, J., Horejsi, P., 2015. Knowledge acquisition and cybersickness: comparison of VR devices in virtual tours. Sci. J. 613–616. http://dx.doi.org/10.17973/MMSJ.2015_06_201516.

Pölönen, M., Järvenpää, T., Bilcu, B., 2013. Stereoscopic 3D entertainment and its effect on viewing comfort: comparison of children and adults. Appl. Ergon. 44 (1), 151–160. https://doi.org/10.1016/j.apergo.2012.06.006.

R Core Team, 2018. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria URL. https://www.R-project.org/.

Rebenitsch, L., Owen, C., 2016. Review on cybersickness in applications and visual displays. Virtual Reality 20 (2), 101–125.

Richardson, A., Bracegirdle, L., McLachlan, S., Chapman, S.R., 2013. Use of three-dimensional virtual environment to teach drug-receptor interactions. Am. J. Pharm. Educ. 77 (1), 1–5.

Schweitzer, D., Brown, W., 2009. Using visualization to teach security. J. Cent. Plains Conference 24 (5), 143–150.

Sherwood, G., 2011. Integrating quality and safety science in nursing education and practice. J. Res. Nurs. 16 (3), 226–240.

Silén, C., Wirell, S., Kvist, J., Nylander, E., 2008. Advanced 3D visualisation in student-centred medical education. Med. Teach. 30 (5), 115–124.

Stewart, M., 2012. Understanding learning: theories and critique. In: Hunt, L., Chalmers, D. (Eds.), University Teaching in Focus, A Learning Centred Approach. ACER Press, Camberwell.

Swords, J., Askin, K., Jeffries, M., Butcher, C., 2013. Geographic visualisation: lessons for learning and teaching. Planet 27 (2), 6–13. http://doi.org/10.11120/plan.2013.00001.

Taylor, N., Layland, A., 2018. Comparison study of the use of 360-degree video and non-360-degree video simulation and cybersickness symptoms in undergraduate healthcare curricula. In: BMJ Simulation and Technology Enhanced Learning, https://doi.org/10.1136/bmjstel-2018-000356. (Retrieved August 10, 2018 from https://stel.bmj.com/content/early/2018/06/28/bmjstel-2018-000356).

Vaismoradi, M., Jordan, S., Turunen, H., Bondas, T., 2014. Nursing students' perspectives of the cause of medication errors. Nurse Educ. Today 34 (3), 434–440. https://doi.org/10.1016/j.nedt.2013.04.015.

Wa, James Ta, Speranza, F., Yano, S., Shimono, K., 2011. Stereoscopic 3D-TV: Visual Comfort. Broadcasting IEEE Transactions on 57 (2), 335–346. https://doi.org/10.1109/TBC.2011.2125070.

WHO, 2018. WHO launches global effort to halve medication-related errors in 5 years. http://www.who.int/mediacentre/news/releases/2017/medication-related-errors/en/.

Yeung, A., Schmid, S., George, A., King, M., 2007. Still pictures, animations or interactivity – what is more effective for e-learning? In: Proceedings of the UniServe Science 2007 Conference, Sydney, Australia.