Use of virtual reality as a learning environment in dentistry

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Second Life (SL) is an online virtual world with a social environment that may serve as a valuable learning supplement to traditional preclinical teaching methods. The educational advantages of this virtual world include immersion and interactivity. The aim of this study was to compare the efficacy of using 3-dimensional interactive platforms (3DIPs) designed in SL to that of traditional teaching methods for developing students' understanding of dental clinical situations that are difficult to simulate in real life. For this study, 3DIPs were developed to compare the acquisition of 3 learning objectives: understanding concepts, procedural aspects of interaction with the patient, and spatial interpretation of anatomical structure interactions. A representative dental topic, the use of a semiadjustable articulator, was selected. A quasi-experimental design with 2 groups and pretest-posttest comparison was used. The students in the control group received the conventional teaching established for the subject, which does not include SL experiences. The students in the experimental group received conventional instruction and had access to all 3DIPs for 4 weeks without limitation. The pretest and posttest consisted of a multiple-choice test with 20 questions. A Student *t* test was used to compare the test results of the groups (significance level $\alpha = 0.05$). The posttest scores for the understanding of concepts and spatial interpretation were significantly higher in the experimental group than in the control group ($P < 0.05$). However, there was no statistically significant difference between groups in posttest scores on the topic of procedural aspects. Students who used cooperative methods for acquisition of knowledge were observed to be highly motivated. The results suggest that the SL environment helps students to understand anatomical interactions that are difficult to observe in real life, is attractive to students, and contains tools with high didactic potential.

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There are few studies on the use of virtual reality in the field of dental education. However, some of the reported advantages of virtual reality for this application include its high motivational potential, flexibility for scheduling activities, and favorable contexts for constructivist creative collaboration.[1-4] In addition, this approach allows adequate, safe instruction without violating ethical principles for interaction with patients.[5]

Second Life (SL; Linden Lab) is a popular, free, multiuser virtual environment; it is one of the best known 3-dimensional (3D) environments currently enabling social interaction.[6,7] It is a flat-earth simulation providing roughly 1.8 billion m^2 of virtual space.[8] Learning experiences in the medical sciences accomplished through SL have utilized several approaches, such as having students role-play to train them in professional-patient communication, simulating activities that would be costly and dangerous in the real world, and exploring anatomical simulations.[3,9-13] The virtual environment has also been used as a meeting place for participants in different parts of the world, enabling them to communicate and interact.[3]

One of the few experimental studies on the dental educational experience in SL was carried out in Alexandria, Egypt.[14] In the within-subject design, students acting as their own controls expressed satisfaction with the SL experience. There were no statistically significant differences between posttest scores for the SL-taught subject and the topic presented only traditionally, comparing practical skills for applying topical fluoride and pit and fissure sealants to teeth.[14]

Clark analyzed the value of SL simulations for learning in situations that are difficult to replicate in real life.[15] Genome Island provides a genetic laboratory environment in which first-year university students can experience activities (eg, data collection) in less time than would be required in the real world. Student performance on the final examination was found to be better on topics covered in the SL environment.[15]

Berney et al suggested that 3D spatial representation in virtual environments has a positive influence on learning anatomical structures, particularly for inexperienced students.[16] Phillips & Berge described the use of SL in dentistry as a valuable supplement to preclinical teaching methods for problem solving.[17]

Many educational qualities of SL have been described, including the advantages of virtuality, immersion, and interactivity.[18] Virtuality, according to Hendricson, is computer simulation of real-life clinical scenarios for teaching purposes.[19] Use of virtual technologies has been reported to improve manual dexterity, alleviate student stress, and improve student cooperation in pursuit of collaborative learning.[20,21] Second Life allows actions, learning settings, and situations that are impossible to replicate in real life, such as the absence of gravity, changing the physical properties of objects (structure, size, shape, and elasticity), immateriality (eg, the ability to pass through objects), teletransportation, and having the ability to fly from place to place, all in real time. Moreover, SL does not require participants to be at the same geographic location.

Immersion is defined as the subjective impression of taking part in a comprehensive, realistic experience. Dede stated that "Immersion in a digital experience involves the willing suspension of disbelief..."[22] He noted that attainment of this disbelief relies on sensory, symbolic, and actional factors built into the immersive experience. Actional factors are those that enable the individual to have experiences that are impossible to replicate in the real world; they are powerful, intriguing, and create intense concentration.

Interactivity in computer-based learning involves reciprocal activity in which the actions and reactions of the student and the multimedia learning system depend on each other.[23] Researchers believe that the student's interaction with the environment is important because it enables the student to establish his or her own learning pace. Several researchers in higher education have selected the SL environment because of the way it fosters constructivist (experience-based, active) learning.[24] Wen et al concluded that internet-based learning environments feature many attributes of the constructivist model of teaching, such as inquiry-based learning and reflective thinking activities.[25]

Moreover, 3D dynamic models can help students to construct mental images and develop an understanding of complex spatial transformations, such as those required in the study of functional anatomy.[16] Functional anatomy and other concepts in dentistry are based on interactions among tissues. Such is the case of maxillomandibular interdental relationships and their corresponding interactions with the condylar joint in the glenoid cavity of the temporomandibular joint. This kind of concept clearly cannot be appreciated anatomically in real life, since it is difficult to obtain an anatomical preparation from a cadaver; neither the muscle nor the joint elasticity is appropriate for replicating masticatory function. Students acquire concepts in this particular field through the extensive, careful explanations presented by teachers and books. These traditional means of education, however, are often unsuccessful at conveying adequate understanding of anatomical relationships, leaving the success of learning to the student's imagination and the teacher's skill.

Anatomical measurements and relationships in the patient's mouth must be conveyed accurately to the laboratory to ensure correct diagnosis, treatment planning, and restoration. The semiadjustable articulator (SA) is the instrument currently recommended for prosthetic rehabilitation and surgical planning.[26,27] The SA is used from the first stages of dental school through professional practice. However, understanding the relationships among the anatomical elements involved has been a major challenge for students of dentistry.[28] Another difficulty involves transferring the patient's anatomical features to the dental laboratory through the use of a facebow, a device that has been in use, almost unchanged, for more than 100 years.[29]

Second Life enables educators to show intricate anatomical relations by allowing objects to be transposed, thereby enabling students to observe the functional relationships between teeth and joints, facilitating understanding of the physiology of anatomical tissues. However, a large initial investment is required to prepare these 3D constructions.[30] Development of these simulations involves hours of joint work by health professionals, computer scientists, and educators.[31] Kim et al reported that there is little experimental research that adequately covers the potential applications of virtual worlds in learning.[32] In addition, resources for state-of-the-art educational technologies are often unavailable in developing countries.[33]

The aim of this study was to evaluate the effectiveness of the use of 3D interactive platforms (3DIPs) in SL for presenting dental clinical situations and concepts that are difficult to simulate in real life and compare the success to that of traditional teaching methods. The initial investment, beginning with the first contact with SL and including planning for the study and didactic methodology, took approximately 2 years. Eight 3DIPs were built in the order of students' usual sequence of acquiring knowledge about the use of the SA and its accessories.[34]

Materials and methods

Study design

The study was approved by the institutional review board at the Faculty of Dentistry, St Martín de Porres University (FO-USMP), Lima, Peru (No. 420/FE-UPG/2012). This was an analytical, quasi-experimental study involving 2 groups and pretest-posttest comparisons. Two groups of students were compared while attending a course at FO-USMP on the preclinical subject of occlusion.

Students for both groups were screened to ensure that this was their first contact with the subject. For the experimental group, students whose computers met minimum software and hardware requirements to enable them to use SL adequately were selected. Therefore, it was a nonrandom convenience sample, which is a limitation in the study design. The control group was made up of the other students in the course. All students signed informed consent prior to participating in the study.

Learning was evaluated by means of a theoretical test to assess the students' cognitive comprehension of concepts related to physical interactions of the different mechanical components of the SA and the anatomical components of the joint. The tests for the initial (pretest) and final (posttest) evaluations contained 20 multiple-choice questions with 5 answer choices each, structured according to the 3 learning objectives:

1. Understanding of concepts: use of the SA, including structure, parts, advantages, and programming according to the patient's anatomical features
2. Procedural aspect of interaction with the patient: facebow management, including use and handling
3. Spatial interpretation of anatomical structure interactions: relationships among teeth, temporomandibular joints, and SA components

Participants and environment

The study population consisted of 130 students who were attending a course on the subject of occlusion during the fifth semester of the dentistry course (third year) at FO-USMP.

Three-dimensional scale models that replicated the ideal anatomical characteristics of a male patient, a dentate jaw, and Whip Mix–type SA were constructed (Figure). The SA is an accessory that replicates the patient's anatomical features and is

Figure. Second Life virtual world designed for dental education. A. Three-dimensional interactive platforms, including the 8 academic skills taught in the program. B. Design of a semiadjustable articulator with accessories. The activities contain scripts, providing dynamism and interactivity. C. Representation of a semiadjustable articulator with a cranium, designed to show dental and joint contacts in parallel. The situation is not replicable in real life.

widely used at most universities to analyze, design, and develop dental prostheses.[35,36]

The 3D constructions were made in the SL environment using the program's construction tools. Teeth and related bones were modeled on Hexagon Bridge software (version 2.5, Daz 3D Studio) and imported to SL. Teeth were modeled according to the standardized proportions described by Fuller & Denehy.[37] Surface textures on teeth and jaw were designed with Adobe Photoshop CS4 (Adobe Systems).

The SL program provides a tool that enables animation of 3D objects by entering scripting language. To improve student motivation, the 3DIPs were endowed with movements and informational pop-ups, and participants were invited to interact and follow the automatically programmed movements. Students could initiate the animation sequence at any time and as often as they liked, which gave the 3DIPs a game-like environment.

All these constructions were entirely developed by teachers of dentistry on their own initiative and without prior instruction in 3D construction. They were able to do so after spending about 2 years researching and self-training in the use of SL. The 3DIPs in this study belong to the virtual island of the various schools at USMP in SL, which were designed by taking into account students' progressive learning (Table 1).

Study procedures

The students selected for the experimental group received previous training on how to use the SL software; move about in SL; use SL tools; manage viewers to zoom in, zoom out, and change the viewing angle; and use visual, audio, and texting communication tools.

The study was initiated during week 5 of the course, which is an appropriate time to introduce the concepts included in the 3DIPs. The students in both groups had equal opportunity to use the SA with its complete accessories and received the conventional teaching established in the practical planning for the subject. The students in the control group did not receive the SL experiences.

The 3DIPs were available to the students in the experimental group for 4 weeks without limitation. During these 4 weeks using the 3DIPs in SL, 4 instructors were present to help students during their visits to the 8 platforms. A visit counter, a script-based device in SL for recording the number and duration of each participant's visits, was used to ensure that each student had visited all the 3DIPs.

Statistical analyses

The reliability of the pretest and posttest was evaluated with a pilot test using the Kuder-Richardson statistic, finding a mean value of 0.86 (of a possible 1.00), which indicated that the instrument had acceptable reliability.

To verify the validity of the content, 8 dentists who were educational experts analyzed the test. After the experts gave their opinions, the test was analyzed using the Aiken *V* statistic, which obtained a value of $P = 0.004$, enabling the multiple-choice options to be accepted. The test included 20 multiple-choice questions with no time limit and was administered simultaneously to both study groups during the pretest and posttest periods.

The normality of the evaluations in the comparison between groups was tested using a parametrical Student *t* test for independent groups. The pretest and posttest comparisons within each group were performed through a Student *t* test for related groups. Analyses were performed using SPSS statistical software (version 21.0, IBM Corporation) with a significance level of $\alpha = 0.05$.

Of the 130 students in the study population, only 25 were included in the experimental group and 37 in the control group. The rest were excluded because they did not complete the tests for the initial (pretest) and/or final (posttest) evaluations. Two of the students in the experimental group were excluded because they said they received instruction on the topic outside the school subject.

The experimental group consisted of 13 women and 10 men, while the control group consisted of 22 women and 15 men. Ages ranged from 19 to 23 years.

Results

Students were noticeably motivated to use the 3DIPs immediately from the first session. This enthusiasm was reflected by the fact that they attended the preliminary training sessions assiduously, received the indications they needed, and began to work. During the first week, some students needed technical support to view the 3DIPs properly.

Visit records showed that, although SL was available 24 hours a day, most visits took place during the evening and usually in groups. There was social interaction for collaborative learning purposes; students commented on the dynamism of the constructions, initiating a discussion of the importance of the different dental contacts and their temporomandibular joint limitations. During the course of the study, students told instructors that social interaction in the virtual world helped them to feel more comfortable and spend more time in SL than when they visited alone.

At the beginning of the study, both groups were assessed using an objective written test to determine participant baseline. The mean number of questions answered correctly by the experimental group was 5.96 (SD 2.46) of 20 (30%); the control group achieved a mean score of 4.92 (SD 1.89) of 20 (25%). No statistically significant difference was found between groups ($P = 0.071$). The mean final scores for the 3 learning objectives evaluated were 11.30 of 20 questions (57%) correct for the experimental group and 10.11 of 20 (51%) correct for the control group. The 6% (CI 5%-17%) difference between means was statistically significant ($P = 0.033$).

Table 1. Three-dimensional interactive platforms (3DIPs) according to their featured educational focus.

Learning objective	3DIPs
Understanding of concepts	Parts of the semiadjustable articulator
	Parts of the facebow (semiadjustable articulator accessory)
Procedural aspects of interaction with the patient	Reference planes for transferring the patient's anatomical features with the facebow
	Positioning the facebow on the patient
	Steps for recording with the facebow
	Mounting plaster casts obtained from the patient in the semiadjustable articulator
Spatial interpretation of anatomical structure interactions	Representation of functional relationships between the temporomandibular joint and the teeth
	Reproduction of mandibular movements in the semiadjustable articulator

Questionnaire results were broken down according to the 3 learning objectives established for both groups (Table 2 and Charts 1 and 2). Analyses revealed statistically significant differences ($P < 0.05$) for 2 of the learning objectives: understanding of concepts and spatial interpretation.

Discussion

In the present study, 3D virtual environments were clearly motivating to young dentistry students, who described their experience as exciting. These attitudes are in agreement with those found by other researchers.[38,39] The virtual programs forced the participants of the present study to think and act like teachers, particularly when learning was collaborative, and provided satisfaction when the aims of the learning modules were achieved as a joint effort of all the students involved.

Hendricson reported that distance education based on virtual technology increases student enthusiasm and motivation; broadens access to educational materials at the time and place of choice; improves learning outcomes and speed; facilitates communication, interpersonal exchange, and active participation with the learning content; aids decision-making; and provides feedback.[19] Comparin et al reported that the fact that learning takes place in a group setting reinforces the experience by allowing discussion and exchange of opinions.[40] The results of Comparin are similar to the results of the present study; their students reported positive learning experiences, including reinforcement of memorization, rapid comprehension, increased motivation and interest, and stimulation of learning.

The significant differences in the learning outcomes in the experimental group are encouraging. The results suggest the usefulness of this new way of teaching concepts that are difficult to understand in real life, particularly those involving interaction of anatomical elements or requiring an understanding of complex physiologic, biochemical, or mechanical concepts. For

Table 2. Mean test scores for experimental and control groups according to learning objective.[a]

	Understanding concepts			Procedural aspects			Spatial interpretation		
Group	n	Mean (SD)	*P*	n	Mean (SD)	*P*	n	Mean (SD)	*P*
Experimental	23	3.43 (1.37)	0.034[b]	23	3.70 (1.60)	0.148	23	4.17 (2.14)	0.035[b]
Control	37	2.73 (1.12)		37	4.30 (1.50)		37	3.08 (1.73)	

[a] Scores are based on the number of correct responses to the questions, but the questions were weighted in response to observations by expert evaluators during the validation process. Therefore, the mean values do not correspond with the total number of questions for the learning objective: understanding of concepts (10 questions); procedural aspects of interaction with the patient (4 questions); and spatial interpretation of anatomical structure interactions (6 questions).

[b] Statistically significant difference (Student *t* test).

example, de Boer et al reported that students using 3D constructs can develop competencies without requiring patients, providing more opportunities for learning with improved safety, lower costs, and greater ease of use.[41]

It is important to highlight that it took great effort and expense to create the learning scenarios for the present study, which involved hours of training and time spent building the learning tools, the procurement of internet bandwidth appropriate to the graphic requirements, and the purchase of hardware appropriate for supporting adequate definition and reproduction in real time as well as strong motivation among the work team. Nevertheless, simulation technology is a key element that ensures educational quality in health sciences. Integrating this kind of technology into curricular contents is a challenge that requires further research, as noted in 2011 at the consensus conference of the Society for Simulation in Healthcare.[42]

When the experiment was designed, it was decided to center the educational components around learning about the SA, a commonly used accessory in clinical dental practice. The results should also be applicable to many other areas of healthcare education that require interpretation of concepts during the acquisition of knowledge.

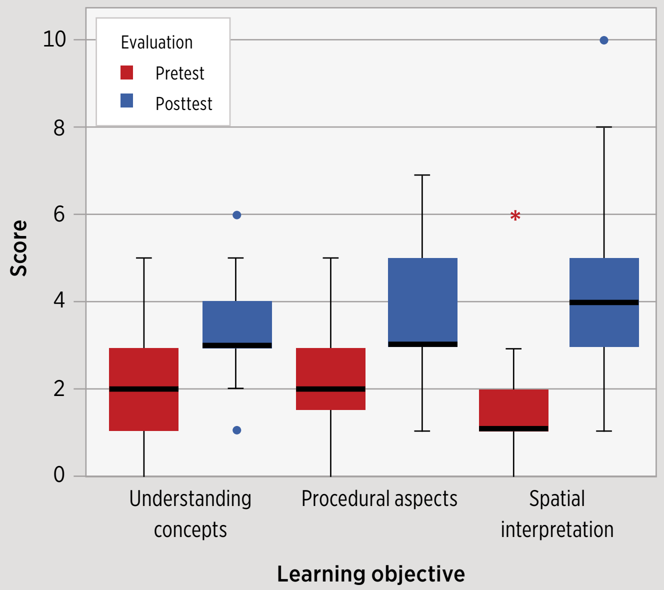
In the present study, the educational goal of understanding of concepts involved memorizing the names of the structural components of the SA and facebow. A statistically significant difference was found in favor of the group that used the 3DIPs in SL. The 3D graphic representation of the different parts of the articulator and facebow, reinforced by pop-up text describing concepts when students interacted with the platforms, seemed to improve memorization of the structures. This seemingly was facilitated by the game-like setting achieved with the help of scripts and component movements. Student interaction with the accessories could be observed by any other students who were present, fostering memorization.

For the education goal of learning procedural aspects of interaction with the patient, the student needed to make contact with the mechanical accessories of the facebow. The students used these devices to transfer the patient's anthropometric measurements by adjusting screws and taking into account anatomical positions and the most appropriate reference planes. The fact that there was no significant difference between groups in learning to use the facebow may be due to the fact that the procedure involved interaction between the patient and the various components to be assembled. Learning to use facebows depends more on personal interaction with the patient, enabling the facebow to be placed accurately and the anatomical characteristics to be transferred to the articulator. El Tantawi et al also reported no difference in a comparison of practical skills for applying topical fluoride (taught via SL) and pit and fissure sealants (taught conventionally) to teeth.[14]

There were statistically significant differences in favor of the experimental group with regard to the educational goal of spatial interpretation. This suggests the importance of student immersion in the learning object through the special properties provided by SL. For example, the possibility of passing through objects, in this learning scenario, was the only way to understand the combined functioning of distant anatomical structures linked by functions and by joints. This kind of experience is not replicable in the real world; to understand the topic, a student must imagine the complex structures of the temporomandibular joint functioning in coordination with dental occlusion. Dalgarno & Lee noted that, for this immersion to be complete, the virtual world requires high fidelity in representation that the student can manipulate interactively to create a strong sensation of being present.[43] These realistic 3D virtual environments can be used to replicate learning situations and tasks that could not be easily staged in the real world.[43]

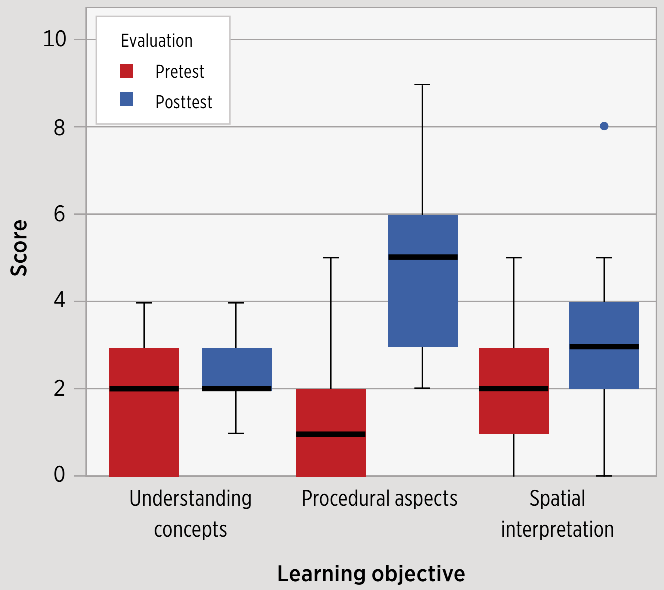
Immersive learning technologies are useful for subjects that require scenarios that are impossible to replicate in real life as well as concepts involving spatial intelligence. Motivation plays an important part in success and is reinforced when new knowledge is constructed socially. Although the advantages of these technologies have been amply proven, they are not widely used in developing countries. The fact that they are rarely used at universities may reflect the high cost of equipment and maintenance in addition to the need for many hours of research and training to enable teachers to design learning strategies based on the multiple learning theories to which this platform can be applied. In the present research project, creating these learning scenarios demanded a great deal of effort from the persons involved, the bandwidth had to be changed, and the computer laboratory had to obtain special permits for access to the IP addresses and exclusive data transfer. The computers also needed video cards with large memory capacity, a difficulty also mentioned by Badilla Quintana & Meza Fernández.[38]

Chart 1. Scores of the experimental group for the 3 learning objectives.



Scores are based on the number of correct responses to the questions, but the questions were weighted in response to observations by expert evaluators during the validation process. Therefore, the values do not correspond with the total number of questions for the learning objective: understanding of concepts (10 questions); procedural aspects of interaction with the patient (4 questions); and spatial interpretation of anatomical structure interactions (6 questions). Upper and lower bounds of the boxes indicate the 75th and 25th percentiles of the interquartile range, respectively. Lines within the boxes indicate the median. Upper and lower whiskers indicate the minimum and maximum values, respectively, excluding outliers. Dots represent outliers. *Extreme outlier.

Chart 2. Scores of the control group for the 3 learning objectives.



Scores are based on the number of correct responses to the questions, but the questions were weighted in response to observations by expert evaluators during the validation process. Therefore, the values do not correspond with the total number of questions for the learning objective: understanding of concepts (10 questions); procedural aspects of interaction with the patient (4 questions); and spatial interpretation of anatomical structure interactions (6 questions). Upper and lower bounds of the boxes indicate the 75th and 25th percentiles of the interquartile range, respectively. Lines within the boxes indicate the median. Upper and lower whiskers indicate the minimum and maximum values, respectively. Dot represents an outlier.

Moreover, students also need previous training in using the virtual environment and must commit to developing, exploring, and experimenting in a manner consistent with constructivist learning theories. These requirements often conflict with a lack of free time in students' university schedules.

The use of this didactic tool may be limited by other major obstacles, which should be studied within each specific context. The current lack of knowledge regarding the use of virtual worlds as a learning tool is not consistent with technological progress. Barrow et al suggested that the results of this kind of learning are particularly good in developing countries because the motivation provided by these approaches may reduce the student dropout rate.[44]

Conclusion

Results of the present study suggested that the SL environment helps students to understand anatomical interactions that are difficult to see in real life. The program is attractive to students and contains tools with high didactic potential. However, this educational approach does not improve learning for situations requiring personal relations, requires a large amount of resources, and involves a steep learning curve.

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Disclaimer

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References

1. Brown JF. Applications of simulation technology in psychiatric mental health nursing education. *J Psychiatr Ment Health Nurs.* 2008;15(8):638-644.
2. Wehner AK, Gump AW, Downey S. The effects of Second Life on the motivation of undergraduate students learning a foreign language. *Comput Assist Lang Learn.* 2011;24(3):277-289.
3. Richardson A, Hazzard M, Challman SD, Morgenstein AM, Brueckner JK. A "Second Life" for gross anatomy: applications for multiuser virtual environments in teaching the anatomical sciences. *Anat Sci Educ.* 2011;4(1):39-43.
4. Larach DU, Cabra JF. Creative problem solving in Second Life: an action research study. *Creat Innov Manag.* 2010;19(2):167-179.
5. Maran NJ, Glavin RJ. Low- to high-fidelity simulation: a continuum of medical education? *Med Educ.* 2003;37(Suppl 1):22-28.

6. Dickey MD. The pragmatics of virtual worlds for K-12 educators: investigating the affordance and constraints of Active Worlds and Second Life with K-12 in-service teachers. *Educ Technol Res Dev.* 2011;59(1):1-20.
7. Boulos MN, Hetherington L, Wheeler S. Second Life: an overview of the potential of 3-D virtual worlds in medical and health education. *Health Info Libr J.* 2007;24(4):233-245.
8. Linden Labs. *Secondlife World Maps*. https://maps.secondlife.com/. Accessed May 23, 2019.
9. Beard L, Wilson K, Morra D, Keelan J. A survey of health-related activities on Second Life. *J Med Internet Res.* 2009;11(2):e17.
10. Stewart S, Pope D, Duncan D. Using Second Life to enhance ACCEL an online accelerated nursing BSN program. *Stud Health Technol Inform.* 2009;146:636-640.
11. Toro-Troconis M, Mellström U, Partridge M, Meeran K, Barrett M, Higham J. Designing game-based learning activities for virtual patients in Second Life. *J Cyber Ther Rehabil.* 2008;1(3):225-238.
12. Heinrichs LW, Youngblood P, Harter PM, Dev P. Simulation for team training and assessment: case studies of online training with virtual worlds. *World J Surg.* 2008;32(2):161-170.
13. Kameg K, Mitchell AM, Clochesy J, Howard VM, Suresky J. Communication and human patient simulation in psychiatric nursing. *Issues Ment Health Nurs.* 2009;30(8):503-508.
14. El Tantawi MM, El Kashlan MK, Saeed YM. Assessment of the efficacy of Second Life, a virtual learning environment, in dental education. *J Dent Educ.* 2013;77(12):1639-1652.
15. Clark MA. Genome island: a virtual science environment in Second Life. *Innovate J Online Educ.* 2009;5(6):1-6.
16. Berney S, Bétrancourt M, Molinari G, Hoyek N. How spatial abilities and dynamic visualizations interplay when learning functional anatomy with 3D anatomical models. *Anat Sci Educ.* 2015;8(5):452-462.
17. Phillips J, Berge ZL. Second Life for dental education. *J Dent Educ.* 2009;73(11):1260-1264.
18. Zhang H. Pedagogical challenges of spoken English learning in the Second Life virtual world: a case study. *Br J Educ Technol.* 2012;44(2):243-254.
19. Hendricson WD. Changes in educational methodologies in predoctoral dental education: finding the perfect intersection. *J Dent Educ.* 2012;76(1):118-141.
20. de Boer IR, Wesselink PR, Vervoorn JM. Student performance and appreciation using 3D vs. 2D vision in a virtual learning environment. *Eur J Dent Educ.* 2016;20(3):142-147.
21. Hansen MM. Versatile, immersive, creative and dynamic virtual 3-D healthcare learning environments: a review of the literature. *J Med Internet Res.* 2008;10(3):e26.
22. Dede C. Immersive interfaces for engagement and learning. *Science*. 2009;323(5910):66-69.
23. Domagk S, Schwartz RN, Plass JL. Interactivity in multimedia learning: an integrated model. *Comput Human Behav.* 2010;26(5):1024-1033.
24. Inman C, Wright VH, Hartman JA. Use of Second Life in K-12 and higher education: a review of research. *J Interact Online Learn.* 2010;9(1):44-63.
25. Wen ML, Tsai CC, Lin HM, Chuang SC. Cognitive-metacognitive and content-technical aspects of constructivist Internet-based learning environments: a LISREL analysis. *Comput Educ.* 2004;43(3):237-248.
26. Infante L, Yilmaz B, McGlumphy E, Finger I. Fabricating complete dentures with CAD/CAM technology. *J Prosthet Dent.* 2014;111(5):351-355.
27. Walker F, Ayoub AF, Moos KF, Barbenel J. Face-bow and articulator for planning orthognathic surgery, 1: face-bow. *Br J Oral Max Surg.* 2008;46(7):567-572.
28. Obrez A, Briggs C, Buckman J, Goldstein L, Lamb C, Knight WG. Teaching clinically relevant dental anatomy in the dental curriculum: description and assessment of an innovative module. *J Dent Educ.* 2011;75(6):797-804.
29. Starcke EN. The history of articulators: from face-bows to the gnathograph, a brief history of early devices developed for recording condylar movement, II. *J Prosthodont.* 2002;11(1):53-62.
30. Nicholson DT, Chalk C, Funnell WR, Daniel SJ. Can virtual reality improve anatomy education? A randomised controlled study of a computer-generated three-dimensional anatomical ear model. *Med Educ.* 2006;40(11):1081-1087.
31. Taylor KC, Chyung SY. Would you adopt Second Life as a training and development tool? *Perform Improv.* 2008;47(8):17-25.
32. Kim SH, Lee JL, Thomas MK. Between purpose and method: a review of educational research on 3D virtual worlds. *J Virtual Worlds Res.* 2012;5(1):1-18.
33. Cristia J, Czerwonko A, Garofalo P. Does technology in schools affect repetition, dropout and enrollment? Evidence from Peru. *J Appl Econ.* 2014;17(1):89-111.
34. Factulty of Dentistry, University of San Martín de Porres. *Dimensional Interactive Platforms*. http://slurl.com/secondlife/Second%20USMP/73/50/3002/. Accessed November 3, 2016.
35. Joshi PR, Bhat GS, Dixit S. Selection of articulator for general dental practice. *Kathmandu Univ Med J (KUMJ)*. 2008;6(1):112-116.
36. Petropoulos VC, Rashedi B. Complete denture education in U.S. dental schools. *J Prosthodont*. 2005;14(3):191-197.
37. Fuller JL, Denehy GE. *Concise Dental Anatomy and Morphology.* 4th ed. Chicago: Yearbook Medical; 2001:41-135.
38. Badilla Quintana MG, Meza Fernández S. A pedagogical model to develop teaching skills. The collaborative learning experience in the immersive virtual world TYMMI. *Comput Human Behav.* 2015;51(Pt B):594-603.
39. Mahon J, Bryant B, Brown B, Kim M. Using Second Life to enhance classroom management practice in teacher education. *Educ Media Int.* 2010;47(2):121-134.
40. Comparin C, Hans-Filho G, Wen CL, Figueiró-Filho EA. The Virtual Human in team-based learning: assessing students' perceptions. *Med Educ.* 2015;49(5):531-532.
41. de Boer IR, Wesselink PR, Vervoorn JM. The creation of virtual teeth with and without tooth pathology for a virtual learning environment in dental education. *Eur J Dent Educ.* 2013;17(4):191-197.
42. Dieckmann P, Phero JC, Issenberg SB, Kardong-Edgren S, Ostergaard D, Ringsted C. The first Research Consensus Summit of the Society for Simulation in Healthcare: conduction and a synthesis of the results. *Simul Healthc.* 2011;(6 Suppl):S1-S9.
43. Dalgarno B, Lee MJW. What are the learning affordances of 3-D virtual environments? *Br J Educ Technol.* 2010;41(1):10-32.
44. Barrow L, Markman L, Rouse CE. Technology's edge: the educational benefits of computer-aided instruction. *Am Econ J Econ Policy.* 2009;1(1):52-74.