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Dental Students' Perceptions of the Use of 2D and 3D Vision in Dental Education Using a 3D Haptic Simulator: A Qualitative Study

Abstract

Objective: To assess the perceptions of novice and experienced undergraduate dental students of virtual learning with two-dimensional (2D) and three-dimensional (3D) vision.

Materials and methods: This qualitative study involved 21 students from the second and fourth years of a five-year BDS program. They first performed three operative tasks in virtual reality (VR) training sessions using both 2D and 3D vision. Subsequently, they participated in one of four online focus group discussions (FGDs). The FGDs were recorded and transcribed, and the data obtained from the transcriptions were coded and thematically analyzed.

Results: Three main themes emerged from the focus groups. With regard to their perceptions of 2D and 3D vision, most of the participants preferred 3D over 2D vision, mainly due to an improved ability to perceive depth. With regard to the theme of practicing 3D vision in the VR environment, some participants performed their tasks faster with 3D vision than with 2D vision, while others did not perceive any difference between them. Under the same main theme, some participants experienced headache and eye fatigue with 3D vision. With regard to their perception of technical aspects, with 3D glasses, the participants experienced unpleasant sensations and saw darker images.

Conclusion: All the participants placed greater value on practicing with 3D than with 2D vision in the VR environment. They believed that VR training should be used in the early years of dental education as an adjunct to the phantom head as it helps students acquire the skills needed by dental professionals.

Keywords: Education, Dental. Patient simulation. Virtual reality.

1 INTRODUCTION

Simulation has been accepted as a valid virtual learning tool in dentistry that enhances the quality of teaching and allows students to learn new skills.¹ Dentistry is relatively unique and demanding compared to other healthcare specialties; undergraduate dental students are required to learn specific dental skills that can be acquired only from special laboratory training.²

Advanced software programs have the ability to simulate virtual patients in three dimensions (3D), in addition to providing skills-based exercises.³ The ability to judge positions, distances, proportions, and depth plays an important role in dentistry; thus, 3D technology has numerous benefits in dental education.⁴ The increased interest in and need for new 3D technologies has resulted in the development of improved simulators with 3D settings.⁵ Stereopsis, which was defined by Stevens and Brookes in 1988 as “information about 3D objects produced by retinal image differences,” is the highest configuration of depth perception and depends on the ability to blend the retinal images from both eyes into one fused image.^{6,7} The human brain receives two slightly different images from each eye. Depth estimation comes from the fusion of these two images.^{8,9} Perceptions of 3D space are generated from the fused image in the brain, and several depth cues exist to explain the spatial relationship between an object and its environment.¹⁰ Depth cues play a large role in dental practice, as depth perception is an essential and fundamental requirement for practicing dentistry.^{11,12} The ability to estimate and measure depth accurately are also significant factors.^{13,14} Dimitrijevic et al. conducted a study that aimed to determine how early-year dental students judge depth and estimate distances. The study revealed that 73% of the participants overestimated depth.⁴ Al-Saud et al. (2017) found that experienced dentists made fewer depth-related errors while working with 3D than they did while working with Two-dimensional (2D) vision when using a haptic dental simulator.¹⁵

The current literature suggests that in all decisions involving learning, students' perceptions of their curriculum should be carefully considered, as the students need to be actively engaged with the education method used and with the course requirements.¹⁷ Nevertheless, few studies have been conducted on dental education that focused on students' perceptions and thoughts about their learning environment.¹⁸ Listening to students' views and opinions on an education program and considering their feedback on specific courses can help educators identify any program deficiencies that need to be addressed. Students' perceptions can also be useful in teaching, educational research, and improving dental schools' curriculums.^{19,20}

To the authors' knowledge, there is minimal evidence of dental students' perception and satisfaction with the use of 3D dental simulators. Thus, this study aimed to assess the perceptions of novice and experienced dental students of the use of three-dimensional versus two-dimensional vision in the virtual reality (VR) dental environment.

2 METHOD

2.1 Study Design

This qualitative study was conducted in the VR simulation suite of the School of Clinical Dentistry at the University of Sheffield in the United Kingdom. Ethical approval from the University of Sheffield was obtained for this study (Ref: 032730).

Prospective participants were invited to enrol in this study via e-mail. The study group consisted of two cohorts of students, one from the second and one from the fourth year BDS program. A Google Form was created where students were able to choose their preferred dates and times for their participation in the study. Seven second-year and 14 fourth-year BDS students participated in the study. The second-year students were chosen because they had limited

experience performing basic dental tasks and were still in the early learning stage. The fourth-year students were included because they had already obtained some clinical experience. All the participants had previous experience with the VR simulation unit as a part of their dental school curriculum, so they were familiar with using the device and the available tools. Inclusion criteria included participants in their 2nd and 4th-year dental school who expressed their willingness to complete the full training sessions and participate in the focus group. Students in other years of the program and students who were unable to attend all the sessions were excluded.

2.2 Procedure

The participants gave their informed, written consent and were provided with an information sheet about the study. They were briefly introduced to the study and given instructions on how to use the simulator to refresh their knowledge and ensure a baseline of common knowledge and skills.

The Virteasy Dental Simulator (Didhaptic, Laval, Pays De La Loire, France) was used in this study (Fig. 1). It consists of a touchscreen, an active stereoscopic 3D screen that displays two superimposed images with disparities, and the stereo images. These stereo images permit the visualization of the stereoscopic 3D object when viewed in conjunction with the active shutter glasses. Stereoscopic active 3D shutter glasses are used with the simulator to interpret the 3D images.²¹ Shutter glasses work by blocking the image in the right eye while presenting it to the left eye and vice versa.²² There is a monitoring display on the top of the stereoscopic 3D screen. A contra-angled handpiece allows calibration of finger support, which is controlled by a foot pedal. The device also has a mirror tool and a 3D mouse. In addition, the Virteasy simulator offers immediate feedback, including feedback on surgery time, drilling time, target progress, accuracy, target, and outside volume.²³

The participants were assigned to one of the following groups:

Group 1: The participants practiced with 3D conditions while wearing the 3D glasses.

Group 2: The participants practiced with 2D conditions while wearing the 3D glasses but with the 3D effect disabled.

To ensure a suitable posture and stable hand movement, the participants were asked to adjust their chairs' height and calibrate their finger rests before the experiment commenced. Then, all the students participated in a cross-shaped preparation exercise, after which they completed the first exercise, which involved removing the target area (blue zone) in the middle of the block (Fig. 2). All participants were asked to use the pear-shaped ISO 238 bur for standardization purposes. The participants repeated the same exercise three times so that the effect of the repetition on their perception could be measured. After the completion of the first session, group 1 switched from the 3D to the 2D condition, and group 2 switched from the 2D to the 3D condition. All participants had the 3D glasses on in both exercises, and the same procedure was repeated (Fig.3).

The impact of stereoscopic 3D vision on students' performance compared to 2D vision in a VR simulator was measured quantitatively and described in a separate article.²⁴

2.3 Focus Group Discussions

After completing both VR sessions, the participants were invited to participate in an online focus group discussion (FGD). Four online FGDs were conducted through Google Meet 61.0.0, with five to six students in each group;²⁵ 21 students participated in FGDs, which were moderated by two members of the research team (S.N. and H.A.). This method was chosen as open discussion among research participants can provide a richer understanding of their experiences²⁶ with 2D and

3D. The participants were informed that the FGDs would be audio recorded with a digital voice recorder, but their responses would be kept anonymous. After introductions and a general welcome, the moderators guided the discussion by posing open-ended questions about the students' experiences during the experiment. The questions (Table 1) were developed by the research team (S.N., H.A., and N.M.) based on the relevant literature.¹⁶ Data saturation was reached after the fourth FGD; at this point, no new information or ideas were generated.²⁷

DATA ANALYSIS

Thematic analysis, a method of identifying patterns and themes in qualitative data, was performed in this study.²⁸ First, the data obtained from the audio recordings of the FGDs were transcribed. Consistent with Braun and Clarke's approach, two researchers reviewed the transcripts carefully (S.N. and H.A.) Reading the data actively and repeatedly is an essential step at this stage to allow the researchers to become familiar with the content.²⁹ Initial coding was performed using Delve (Twenty to Nine LLC 2021, New York, USA). Data coding, which is an essential step in qualitative data analysis, involves attaching labels to specific words and phrases in the transcribed text so that similar information can be grouped together.²⁸ After the coding process, potential themes were developed, mainly through a deductive method using a predefined set of codes. (Themes combine data with causal relationships and similar ideas.)³⁰ Next, the codes and emerging themes were reviewed and named.²⁹ The entire process was performed independently by two researchers (S.N. and H.A.), who resolved any differences through discussion later.

3 RESULTS

The data obtained from the four online FGDs, in which a total of 21 participants participated and generated 137 comments, were categorized into three major themes reflecting the students'

experience with 2D and 3D vision. Three subthemes were identified in the first theme—students’ perceptions of 2D and 3D vision—student preferences, introducing dentistry via 3D, and realism. Two subthemes were identified in the second theme—practicing 3D vision in VR—faster performance and 3D vision side effects. In the third theme—relating to the technical aspects—two subthemes were identified: using 3D glasses and improving the 3D experience. The identified themes and subthemes are presented in Table 2.

3.1 Students’ Perceptions of 2D and 3D Vision

3.1.1 Student Preferences

Most of the fourth-year participants valued 3D over 2D vision, and the improved depth perception 3D offered was one of their main reasons. They discussed how they “*went off track*” when they were using 2D vision: “*I prefer 3D vision because of the depth perception, which we cannot find in 2D vision as it felt less sort of tactile*”; “*With 2D vision, I didn’t feel quite the same feedback on my eyes that I felt with 3D vision*”; “*I feel that it was easier to interact with the 3D image than the flat 2D image*”; “*3D vision helped me assuming how deep and how far I was drilling*”.

On the other hand, while some second-year students preferred 3D vision over 2D vision, they did not appreciate the value of depth perception while working in 3D. In fact, some of the second-year students preferred 2D vision over 3D vision: “*I think 2D vision provides a more comfortable experience and looks a bit clearer.*”

A handful of students did not find any difference between 2D and 3D vision while using the dental simulators: “*I didn’t really find a difference between 2D and 3D vision. I think they were quite similar.*”

3.1.2 Introducing Dentistry via 3D

There was a consensus among both the second- and fourth-year students that the VR dental simulator with the 3D condition is a more valuable and helpful tool than the 2D condition, especially in the early years of dental education when theoretical dentistry is the focus. As mentioned earlier, the VR dental simulator with 3D vision introduces students to the idea of dealing with the third dimension. In addition to the 3D aspect, it is an excellent tool for practicing how to improve students' posture, hold a handpiece, have a good finger rest, and use the foot pedal. Some students commented, *"I think it's great to start off as an introductory tool. It gives you some sort of preparation."* *"It really helped me with things like posture and seeing the difference between enamel and dentin."*

The second-year students appreciated the value of practicing in the VR simulation units using 3D vision in combination with the phantom head more than the fourth-year students did. One second-year student said, *"Practicing with 3D definitely has its place in the course."*

3.1.3 Realism

The fourth-year students mentioned that 2D vision did not seem realistic as it lacked the third dimension. One student said, *"When I was doing 3D, I could see the difference, and it felt more realistic than 2D."*

However, the second-year students had a different experience and view. One commented, *"I don't have any experience yet of how a drill feels on a real tooth tissue; I've had experience only with plastic teeth. I can tell, though, that it's fairly realistic, but the bur tends to jump quite a bit."*

3.2 Practicing 3D Vision in VR

3.2.1 Faster Performance

Some students indicated that they performed more quickly while practicing with 3D than with 2D:

“I don’t know how long it took me to finish the task with 2D, but because 3D was so much easier to visualize, it took me a lot less time to complete the task with it.”

Most second and fourth-year students indicated that their performance improved with each task, achieving greater accuracy and shorter task durations. However, they were not able to determine the difference in time between 2D and 3D vision. This was also true with regard to their experience in the second session: *“I did improve from time to time, and I felt better than I did the first time, and I might have felt a bit better the third time than the second time”; “I think I improved from the first to the last time, as I was doing the task more times, I was getting more confident in the way that I needed to control the handpiece.”*

3.2.2 3D Vision Side Effects

Some students experienced headaches with 3D vision, which was why they preferred 2D vision to 3D vision: *“From my personal experience, 3D vision gave me a headache, so I’m not inclined to go for that in the future”*. In addition, some students experienced eye fatigue: *“I felt that the 3D image was a bit shaky, and it hurts my eyes when I’m doing it, so I prefer the 2D.”*

Other students mentioned that they did not experience headache or eye fatigue as both sessions were not very long. However, they experienced headaches and eye fatigue from previous experiences: *“Not this time, but I remember in the first year when we used 3D vision for the first time. I got a bad headache after that because we did it like for more than one hour.”*

3.3 Technical Aspects

3.3.1 3D Glasses

In this study, the participants used 3D glasses for both 2D and 3D tasks for standardization purposes. However, the participants in both the second and fourth-year groups did not like the idea of wearing 3D glasses for 2D vision. Thus, most of them reported that the glasses were uncomfortable as they made the images darker and less clear, especially with 2D vision: *“Just because wearing the glasses did make the image look darker while doing it in 2D, it was a bit strange.”*

A participant who was wearing eyeglasses stated: *“I think that adding an extra pair of glasses on your face when you’re already wearing eyeglasses feels a bit much on your face.”* Some participants stated that they did not like to practice in 3D only because of the 3D glasses: *“As a glasses-wearer, I don’t tend to enjoy 3D, even 3D cinema because I tend to feel a bit light-headed.”*

3.3.2 Improving the 3D Experience

One student gave her opinion on how the dental students’ experience could be improved while using the VR with 3D vision: *“If it’s possible to make the vision clearer. Especially with the glasses on, the image does seem a bit blurred, which is why some of us got a headache”. “I think the glasses make the picture blurred compared to 2D.”*

4 DISCUSSION

This qualitative study was conducted to investigate the perceptions of undergraduate dental students with different levels of training experience with 2D and 3D conditions while using the Virteasy haptic simulator. During the experiment, the participants were aware of which type of vision they were working with, as this type of information cannot be hidden. When the participants looked at the screen without glasses, they could see whether there were two images (3D) or just one image (2D). All the participants in this study had previous experience with 3D gaming or 3D cinema, as well as VR experience in dental school. The Virteasy haptic simulator provides users with a 3D virtual environment that exposes them to a variety of realistic clinical scenarios instead of generic, standardized morphology in plastic teeth.²³

The focus group method was chosen to gather a variety of perspectives from different students. In focus groups, the discussion between the moderator and participants provides an opportunity to hear what participants think and feel about specific aspects of their experience. Additionally, conversations among participants can lead to a broader discussion and a richer understanding of the students' different points of view.³¹

4.1 Students' Perceptions of 2D and 3D Vision

4.1.1 Student Preferences

Most of the fourth-year student participants in this study preferred 3D vision to 2D vision, and depth perception was one of the main reasons they gave for this preference. Depth perception is an essential and fundamental requirement for practicing dentistry, and several factors contribute to student perception of depth.¹² An absence of true 3D presentation often compromises our ability to see high-dimensional data, which we often encounter in computing and technological

disciplines. Essentially, 2D presentations rely on a person's ability to compose a 3D image in their brain. Although the capability of the human visual system is impressive, visual perception is not valid in the absence of certain depth cues. Stereopsis depends on the ability to blend the retinal images from both eyes into one fused image.^{7,32} The brain receives two slightly different images from each eye. Depth estimation comes from the fusion of these two images.^{8,9} 3D spatial vision plays an important role in proper navigation and collaboration within the environment. The human brain can develop these images to extract 3D properties.³³

The results of this study align with those of a quantitative study conducted by De Boer et al. (2016), who compared dental students who practiced with 2D and 3D vision using the Simodont dental simulator. Their study's results revealed that 90% of the students preferred using 3D vision to 2D vision.¹⁶ The results from laparoscopic surgery studies also support the superiority of 3D vision over 2D vision results.³⁴

4.1.2 Introducing Dentistry via 3D

The participants in the current study agreed that practicing with 3D vision using dental simulators could be used as a tool to introduce dentistry at the beginning of the course and as an adjunct to the phantom head. In a study conducted by Quinn et al., they found that using a combination protocol of phantom head and VR simulation rather than either technique alone was optimal, as using a single method could not enable the students to acquire all the needed operative skills.³⁵ Practicing using 3D vision in VR may improve students' visual inspection before they start practicing in the clinic.³⁵ Ultimately, the two methods can support each other in enabling students to develop the necessary skills.

4.1.3 Realism

The student participants in this study were asked how they found 2D and 3D vision in terms of mimicking the clinical setting. As the fourth-year students were already undergoing clinical training, they realized that even with the depth perceived in 3D, there was no difference in density between enamel and dentin. However, the second-year students did not perceive that difference as they had not experienced drilling into natural teeth. Questions about realism can be interpreted in different ways, so it is hard to know if, by realism, the participants were referring to how the image visually appeared on the screen, the tactile sensation, or even the sounds made.³⁶ Furthermore, the participants' expectations could have affected how they perceived realism.³⁷

4.2 **Practicing 3D Vision in VR**

4.2.1 Faster Performance

In previous studies on dental surgery, learning time, task duration, and task errors were all decreased with the use of 3D vision.⁵ Furthermore, a considerable amount of literature has shown that task performance improved and task duration time was reduced with practice and experience gained^{38,39} which aligns with the results of the current study.

4.2.2 3D Vision Side Effects

Most of the participants in this study indicated that wearing 3D glasses in general was unpleasant, especially with 2D vision. However, this was required to make it possible to compare students' experiences with 2D and 3D vision. Eye fatigue and headache are very common side effects when using 3D haptic simulators; few students experienced these side effects in this study. Time might have been a factor, as the students noted that they developed a headache when they practiced with 3D vision for more than one hour. These side effects vary among people. Headaches

can be caused by wearing bulky eyeglasses or by perceiving objects that move quickly in depth. Superimposed images that generate 3D vision can also cause eye fatigue.⁴⁰

4.3 Technical Aspects

4.3.1 3D Glasses

As 3D technology still has some limitations, right-eye images can suffer some leakage from the left-eye image, and vice versa. This is why a “ghost” or second image can appear next to the main image, which sometimes makes 3D sight unclear.^{41,42}

The COVID-19 pandemic led to significant changes that posed major challenges in delivering dental education in 2020.⁴³ Using VR dental simulators, especially during that period, provided dental students with a safe, relaxed environment for dental training.

While this study investigated students’ perceptions of using such tools in dental education, the study was not without challenges, as qualitative studies are time-consuming due to the time required for data analysis. Additionally, the analysis or interpretation of FGD data can be affected by the subjectivity of the researchers, which might increase the potential risk of bias. Further, as the research problem in this study is limited to a specific teaching environment, the results of this study cannot be generalized to other dental student populations. However, the data obtained from this study was rich in depth, so it is useful for improving undergraduate dental curricula and could lead to future changes in dental education.

CONCLUSION AND RECOMMENDATIONS

Despite the limitations of this study, it can be concluded that the participants showed some differences in their feedback and thoughts on the use of VR dental simulators for dental education due to the differences in their experiences with dental education so far. The results of this study showed that the fourth-year students displayed a positive attitude toward working with 3D vision in VR and viewed 3D vision as superior to 2D vision because they appreciated the depth dimension they perceived in the former. Further, both the second- and fourth-year students agreed that 3D VR training should be maintained in the early years of the dental education curriculum as an adjunct to the phantom head as it can enable students to acquire the skills they need as future dental professionals. Future studies are still needed to compare advanced-level students' preferences and performance differences.

Conflicts of interest

The authors confirm they have no conflicts of interest.

Tables and Figures



Figure 1. The Virteasy dental simulator.

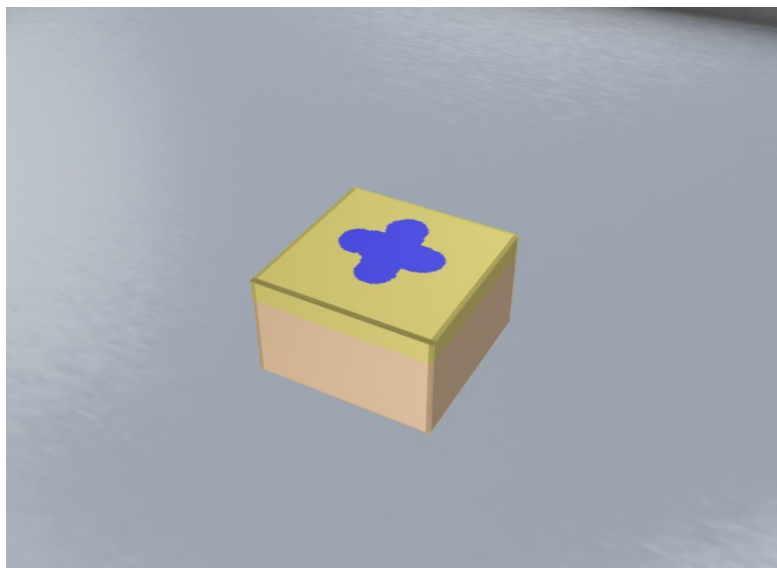


Figure 2. Cross-shape exercise.

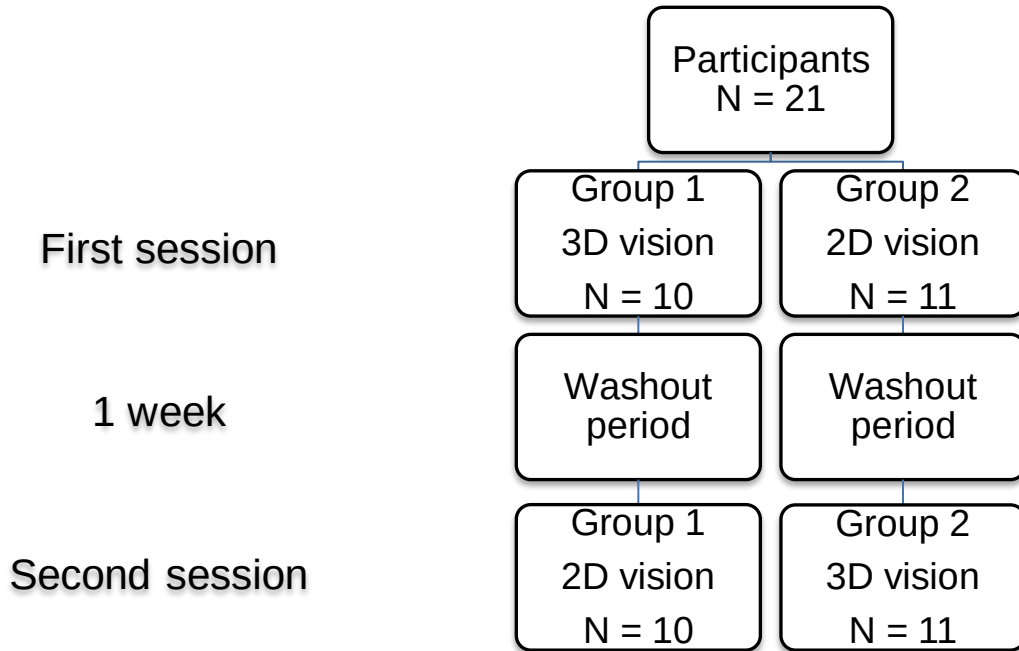


Figure 3. Flow diagram showing participants' involvement in each session.

-
1. When was your first experience with 3D technology?
 2. What do you know about 3D technology?
 3. What are your general feelings about VR simulation with 2D and 3D graphics?
 4. While using the Virteasy haptic simulator, which experience did you prefer, 2D or 3D? Why?
 5. Was there a sense of depth in 2D? Explain.
 6. Was there a sense of depth in 3D? Explain.
 7. Which task did you perform faster, 2D or 3D?
 8. Did you experience physical side effects (e.g., eye fatigue, headache, or muscle cramping) while working with 2D or 3D vision?
 9. How could your experience 3D using the Virteasy simulator be improved?
 10. Is there anything that has not been covered by our questions that you would like to add?
-

Table 1. Focus group discussion questions.

Themes and Subthemes	Number of Comments
Theme 1: Students' perceptions of 2D and 3D vision	71
Students' preferences	28
Introducing dentistry via 3D	24
Realism	19
Theme 2: Practicing 3D vision in VR	38
Faster performance	22
3D vision side effects	16
Theme 3: Technical aspects	28
Using 3D glasses	13
Improving the 3D experience	15

Table 2. Identified themes and subthemes.

References

1. Sedrakyan G, Snoeck M, Poelmans S. Assessing the effectiveness of feedback enabled simulation in teaching conceptual modeling. *Computers & Education*. 2014;78:367-382. doi:<https://doi.org/10.1016/j.compedu.2014.06.014>
2. Iacopino A. The influence of "new science" on dental education: current concepts, trends, and models for the future. *J Dent Educ*. 2007;71(4):022-0337.
3. Perry S, Bridges SM, Burrow MF. A review of the use of simulation in dental education. *Simul Healthc*. Feb 2015;10(1):31-7. doi:10.1097/SIH.0000000000000059
4. Dimitrijevic T, Kahler B, Evans G, Collins M, Moule A. Depth and distance perception of dentists and dental students. *Oper Dent*. 2011 Sep-Oct 2011;36(5):467-77. doi:10.2341/10-290-L
5. Fraser JF, Allen B, Anand VK, Schwartz TH. Three-dimensional neurostereoeendoscopy: subjective and objective comparison to 2D. *Minim Invasive Neurosurg*. Feb 2009;52(1):25-31. doi:10.1055/s-0028-1104567
6. Banks MS, Hooke IT, Backus BT. Perceiving slant about a horizontal axis from stereopsis. *J Vis*. 2001;1(2):55-79. doi:10.1167/1.2.1
7. Wickens CD, Merwin DH, Lin EL. Implications of graphics enhancements for the visualization of scientific data: dimensional integrality, stereopsis, motion, and mesh. *Hum Factors*. Mar 1994;36(1):44-61. doi:10.1177/001872089403600103
8. Chadwick RG. Factors influencing dental students to attend for eye examination. *J Oral Rehabil*. Jan 1999;26(1):72-4.
9. Leach CD. Staining technique for teaching preparation depth in natural teeth. *J Dent Educ*. Sep 1983;47(9):626-8.
10. Goldstein EB. *Sensation and Perception*. 7th ed. Wadsworth-Thomson Learning; 2007.
11. Dunne SM. The limitation of visual perception in restorative dentistry. *Dent Update*. Jun 1993;20(5):198-201, 203-5.
12. Nick DR, Clark M, Miler J, Ordelheide C, Goodacre C, Kim J. The ability of dental students and faculty to estimate the total occlusal convergence of prepared teeth. *J Prosthet Dent*. Jan 2009;101(1):7-12. doi:10.1016/S0022-3913(08)60281-4
13. Saladin JJ. Stereopsis from a performance perspective. *Optom Vis Sci*. Mar 2005;82(3):186-205.
14. Rawlinson A. A simple eyesight screening programme for dental undergraduates: results after 7 years. *Aust Dent J*. Oct 1993;38(5):394-9.

15. Al-Saud LM, Mushtaq F, Mirghani I, et al. Drilling into the functional significance of stereopsis: the impact of stereoscopic information on surgical performance. *Ophthalmic Physiol Opt.* 07 2017;37(4):498-506. doi:10.1111/opo.12393
16. de Boer IR, Wesselink PR, Vervoorn JM. Student performance and appreciation using 3D vs. 2D vision in a virtual learning environment. *European Journal of Dental Education.* 2016;20(3):142-147.
17. Henzi D, Davis E, Jasinevicius R, Hendricson W, Cintron L, Isaacs M. Appraisal of the dental school learning environment: the students' view. *J Dent Educ.* Oct 2005;69(10):1137-47.
18. Divaris K, Barlow PJ, Chendea SA, et al. The academic environment: the students' perspective. *Eur J Dent Educ.* Feb 2008;12 Suppl 1:120-30. doi:10.1111/j.1600-0579.2007.00494.x
19. Harvey L. Student feedback. *Qual Higher Educ.* 2003;9(1):3-20.
20. Levin B. Putting students at the centre in education reform. *J Educ.* 2000;1(2):155-172.
21. Cormier J, Pasco D, Syllebranque C, Querrec R. VirTeaSy a haptic simulator for dental education. *The 6th International Conference on Virtual Learning ICVL.* 2011;
22. Joseph D, Jehl JP, Maureira P, et al. Relative contribution of haptic technology to assessment and training in implantology. *BioMed Research International* 2014;2014doi:10.1155/2014/413951
23. Cormier J, Pasco D, Syllebranque C, Querrec R. VirTeaSy a haptic simulator for dental education. *The 6th International Conference on Virtual Learning ICVL.* 2011;
24. Al Ali H, Nassief S, Towers A, Field J, Martin N. The value of stereoscopic three-dimensional vision on dental students' performance in a virtual reality simulator [Unpublished manuscript]. Sheffield University; 2022.
25. Barbour RS. Making sense of focus groups. <https://doi.org/10.1111/j.1365-2929.2005.02200.x>. *Medical Education.* 2005;39(7):742-750. doi:<https://doi.org/10.1111/j.1365-2929.2005.02200.x>
26. Grudens-Schuck N, Allen BL, Larson K. Methodology Brief: Focus Group Fundamentals. *Extension Community and Economic Development.* 2004;Iowa State University
27. Stalmeijer RE, Mcnaughton N, Van Mook WN. Using focus groups in medical education research: AMEE Guide No. 91. *Med Teach.* Nov 2014;36(11):923-39. doi:10.3109/0142159X.2014.917165
28. Boyatzis R. Transforming qualitative information: Thematic analysis code development. sage, thousand oaks. 01/01 1998;
29. Braun V, Clarke V. Using thematic analysis in psychology. *Qualitative Research in Psychology.* 01/01 2006;3:77-101. doi:10.1191/1478088706qp063oa
30. Rosala M. How to Analyze Qualitative Data from UX Research: Thematic Analysis. Nielsen Norman Group; 2019.

31. Rabiee F. Focus-group interview and data analysis. *Proc Nutr Soc.* Nov 2004;63(4):655-60. doi:10.1079/pns2004399
32. Stevens KA, Brookes A. Integrating stereopsis with monocular interpretations of planar surfaces. *Vision Res.* 1988;28(3):371-86.
33. Cutting JE, Vishton PM. Perceiving layout and knowing distances: The integration, relative potency, and contextual use of different information about depth. *Perception of space and motion.* Academic Press; 1995:69-117. *Handbook of perception and cognition (2nd ed.).*
34. Tanagho YS, Andriole GL, Paradis AG, et al. 2D versus 3D visualization: impact on laparoscopic proficiency using the fundamentals of laparoscopic surgery skill set. *J Laparoendosc Adv Surg Tech A.* Nov 2012;22(9):865-70. doi:10.1089/lap.2012.0220
35. Quinn F, Keogh P, McDonald A, Hussey D. A study comparing the effectiveness of conventional training and virtual reality simulation in the skills acquisition of junior dental students. *Eur J Dent Educ.* Nov 2003;7(4):164-9. doi:10.1034/j.1600-0579.2003.00309.x
36. Wages R, Grünvogel SM, Grützmacher B. How Realistic is Realism? Considerations on the Aesthetics of Computer Games. Springer Berlin Heidelberg; 2004:216-225.
37. Towers A, Field J, Stokes C, Maddock S, Martin N. A scoping review of the use and application of virtual reality in pre-clinical dental education. *Br Dent J.* 03 2019;226(5):358-366. doi:10.1038/s41415-019-0041-0
38. Diedrichsen J, Kornysheva K. Motor skill learning between selection and execution. *Trends Cogn Sci.* Apr 2015;19(4):227-33. doi:10.1016/j.tics.2015.02.003
39. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Acad Med.* Oct 2004;79(10 Suppl):S70-81. doi:10.1097/00001888-200410001-00022
40. Lambooi M, Ijsselsteijn W, Fortuin M, Heynderickx I. Visual Discomfort and Visual Fatigue of Stereoscopic Displays: A Review. *Journal of Imaging Science and Technology - J IMAGING SCI TECHNOL.* 05/01 2009;53(3):30201–30201. doi:10.2352/J.ImagingSci.Technol.2009.53.3.030201
41. Siegel M. Perceptions of crosstalk and the possibility of a zoneless autostereoscopic display. *Proc SPIE.* 06/01 2001;4297doi:10.1117/12.430852
42. <http://paulbourke.net/stereographics/stereorender/>. Accessed 5 May, 2019.
43. Liu X, Zhou J, Chen L, Yang Y, Tan J. Impact of COVID-19 epidemic on live online dental continuing education. *European journal of dental education.* 2020;24(4):786–789.