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ORIGINAL ARTICLE

Mobile virtual tooth morphology teaching environment for preclinical dental students

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Abstract

Objectives: Extended reality as an additional digital learning concept comprises virtual reality (VR), augmented reality, and mixed reality. In particular, VR allows an interaction in the virtual world. The aim of this study was to evaluate the students' attitude toward a mobile VR application for teaching tooth morphologies.

Methods: Eighty-two first year dental students were enrolled. After using the VR learning environment with mobile VR glasses at home for 1 week, the students were asked to fill in a questionnaire with 21 questions regarding intuitive handling, and supplemental learning information in comparison to the use of conventional textbooks. Nine questions provided predefined answer options, another nine had the form of a visual analog scale (VAS, range 0%-highly negative to 100%-highly positive), and three allowed free text answers. The data were checked for normal distribution (Kolmogorov-Smirnov test) and was analyzed descriptively.

Results: Forty-four percent of the students rated their perception of understanding of dental morphologies much better with VR than with conventional learning. The potential of the VR learning environment for further dental topics was assessed with a median VAS score of 75.8%. Its intuitive handling was evaluated with a median VAS score of 67.1%. The haptic, visual, and auditory supplemental learning information was consistently rated positively with VAS scores of 73.9%, 80.0%, and 71.6%, respectively. Overall, a majority of the students (85.5%) recommended the VR learning environment for dental morphology.

Conclusions: The VR dental learning environment allows dental students an additional learning opportunity of dental morphologies, recommended by more than 85% of students.

KEYWORDS
mobile learning, Oculus Quest 2, tooth morphology, VR learning environment

1 | INTRODUCTION

Not least driven by the demands of the Covid-19 pandemic, medical teaching is rapidly developing various research-based digital concepts.[1–13] Due to the restrictions to provide face-to-face teaching, digital teaching has been used in recent months via various formats. For the students at home, however, it is especially difficult to learn practical contents of undergraduate dental education. Therefore, hybrid teaching was installed. This means, the practical contents were taught on-site at the phantom head or on patients following the necessary hygiene measures, whereas all other contents were imparted via digital teaching formats, which the students could access from home.

Digital teaching formats represent an all-encompassing term for various formats: (a) online teaching formats offering lectures or seminars either live or recorded,[14] (b) computer simulations and three-dimensional (3D) viewings via computer screens providing education in fields like communication skills, reporting skills, interpretation of radiographs, polymerization of dental fillings, or cavity and crown preparations,[1,2,5,7–11,15–19] and (c) extended reality (XR) for dental communication, surgical procedures, anatomy morphologies (e.g., relevant to administer anesthesia), and patient case simulations.[6,12,16,20–27]

XR represents a general term for virtual reality (VR), augmented reality, and mixed reality. These formats differ in how the information is technically applied, for example, using glasses and hand controllers, or regarding the degree of immersion into another reality. VR glasses are mainly used with two hand controllers that allow interaction within the VR world and have a high degree of immersion.[24,27]

Evaluations of digital teaching formats are predominantly conducted using questionnaires. The literature regarding the effectiveness of computer simulations and especially virtual formats, although being sparse, shows promising results.[2,6,21,28] It has been reported that 74% of the studies showed an improvement in knowledge in medical education.[13,29] A web-based dental recognition examination in virtual space for first year dental students has been reported to be effective and efficient in comparison to the conventional examination.[30]

Based on the authors' promising experience with a preclinical VR dental learning environment regarding dental morphologies, which was used by the students in the dental school by fixed VR glasses,[31] now a new approach was initiated due to the demand for social distancing during the pandemic. The same VR learning environment was reprogrammed for the use of mobile VR glasses to enable the students to use it flexibly at home. The purpose of the present investigation was to evaluate this mobile application of the dental VR learning environment considering its possible added value for remote dental education.

2 | MATERIAL AND METHODS

The study protocol was approved by the Ethics Committee of the Medical Faculty of the University of Munich (project number 21-0081 KB).

2.1 | VR learning environment and virtual equipment

In addition to the VR learning environment of tooth morphologies, students had all respective conventional learning materials available such as the classic two-dimensional textbook and real extracted human teeth.

The on-site VR learning environment of dental morphologies has been described in detail previously.[31] The major difference between the evaluation conducted before and the current evaluation lies in VR's possibility to be used at home. There has been an important evolution from the strict university-bound VR dental learning environment with the HTC Vive (San Francisco, USA) toward the data transfer of the learning application to the mobile and flexibly usable Oculus Quest 2 All-in-one (Menlo Park, CA, USA; 1832 × 1920 pixels; RAM memory: 6 GB; internal storage capacity: 64 GB). Both systems are provided with a VR headset and handheld controllers. The VR learning environment was programmed with Unity 2019.1.7f1 software (Unity Technologies, San Francisco, USA) for the Oculus Quest 2 mobile glasses. In the following, the VR learning environment was launched and could be used by students at home without the need of an active internet access.

The students had the opportunity to use the VR learning environment for 1 week to get familiar with the three-dimensionally displayed teeth using the auditory, visual, and haptic elements. The learning environment could be viewed flexibly regarding time and place. Sample images

FIGURE 1 Handling of teeth objects in virtual reality (VR) learning environment

of the dental learning environment are shown in Figure 1. The tooth learning environment starts with a tooth island giving the general information about the tooth features for better differentiation. Further, students are able to jump (teleport) from this starting island to other tooth islands to view specific teeth (anterior or posterior), interact (turning, magnifying, etc.) with them using hand controllers, and gain information visually and auditorily via display boards (Figure 1).

2.2 | Evaluation

The use of this VR learning environment of dental morphologies was voluntary and anonymous and consequently also the participation in the subsequent evaluation.

There was no compensation for participation. A total of 82 first year students participated in the study. The evaluation questionnaire followed the questionnaire of the previous investigation modified according to its new mobile and flexible application. The questionnaire was given to the students along with the VR glasses to take home. After a learning period of 1 week, the questionnaire was returned together with the VR glasses. The questionnaire consisted of a total of 21 questions, 9 of which provided given answer options, another 9 had the form of a visual analog scale (VAS), and 3 allowed free text answers. For the VAS questions, students marked their response on a given 10-cm line with a vertical mark, corresponding to a range between 0% (negative) and 100% (positive). The questionnaire is presented in Table 1.

2.3 | Data analysis

The analysis of the test results was performed with the statistical program SPSS Version 26 (IBM, New York, NY, USA). Normality of data distribution was analyzed using the Kolmogorov-Smirnov test. The data were analyzed descriptively by giving the median, minimum, maximum, range, and inter quartiles range (IQR), which also described the data distribution. The Cronbach alpha test was performed as a reliability analysis to verify the compilation of questions.

3 | RESULTS

As the data showed no normal distribution, the analysis was performed non-parametrically. For the scale-based questions, reliability resulted in a Cronbach's alpha value

TABLE 1 Questionnaire, including given answer possibilities, visual analog scale (VAS), and open questions

Question no.	Question	Answer possibility	Median (IQR/Min/Max)
1	How much money would you invest in the equipment to view the VR learning environment?	VAS range: 0–100 Euro (0–109.31 US dollar)	378.90 (468.40/0.00/1663.20)
2	Understand the different tooth morphologies:	a. Much better by learning in the VR learning environment b. Better by learning in the VR learning environment c. As good as with the traditional textbook d. Better by learning with the traditional textbook e. Much better by learning with the traditional textbook	a. 1.3% b. 44.0% c. 42.7% d. 9.3% e. 0.0%
3	When did you primarily use the VR learning environment?	a. In the morning b. At noon c. In the evening d. At night	a. 12.0% b. 5.3% c. 66.7% d. 1.3%
4	On which days did you mainly use the VR learning environment?	a. Weekdays b. Weekend (Friday evening to Sunday evening) c. Both	a. 47.4% b. 51.3% c. 1.3%
5	How often did you use the VR learning environment in 1 week?	Free text (number)	3.1 (2.0/1.0/10.0)
6	How long did you use the VR learning environment per session?	Free text (minutes)	30 (25.0/5.0/120.0)
7	How did you use the VR learning environment?	a. Stationary b. Moving in the room c. Both	a. 44.6% b. 47.3% c. 6.8%
8	How do you assess the tooth dimensions in the VR learning environment?	a. Too small b. Optimal c. Too large	a. 5.2% b. 77.9% c. 16.9%
9	Have you had any health problems after prolonged use (e.g., nausea, dizziness, and eye pain)?	a. Yes b. No	a. 46.8% b. 53.2%
10	Did the VR learning environment allow you to focus on the content better than using traditional learning methods?	a. Yes b. No	a. 50.0% b. 50.0%
11	Did you experience any technical malfunctions or problems? If yes, which ones?	a. Yes b. No Free text	a. 14.5% b. 85.5% Problems to find the learning application directly
12	How do you assess the innovation potential of the VR learning environment for other dental topics (e.g., joint trajectories and articulators)?	VAS range: 0 as "not innovative at all"–100 as "very innovative"	75.8% (31.8/47.4/94.7)

(Continues)

TABLE 1 (Continued)

Question no.	Question	Answer possibility	Median (IQR/Min/Max)
13	How intuitive do you consider the handling of the VR learning environment?	VAS range: 0 as "not intuitive at all"–100 as "very intuitive"	67.1% (32.2/26.3/94.7)
14	How did you find the presentation quality of the VR learning environment?	VAS range: 0 as "not good at all"–100 as "very good"	64.5% (37.9/3.7/94.8)
15	How do you rate the accessibility of the virtually represented tooth morphologies?	VAS range: 0 as "very poorly accessible"–100 as "very easily accessible"	61.1% (24.2/22.6/94.7)
16	Did the additional spoken information (auditory content) lead to an improvement in learning comprehension?	VAS range: 0 as "strongly disagree"–100 "strongly agree"	71.6% (35.8/0.0/94.7)
17	Did the individual interaction with the hand controllers (haptic content) lead to an improvement of the learning content?	VAS range: 0 as "strongly disagree"–100 "strongly agree"	73.9% (41.2/0.0/94.7)
	If not, why didn't the individual interaction with the hand controllers help you to better understand the learning content? Please briefly justify your statement:	Free text	
18	Did the additional information on the info boards (visual content) lead to an improvement in learning comprehension?	VAS range: 0 as "strongly disagree"–100 "strongly agree"	80.0% (36.3/0.0/94.7)
	If not, why didn't the additional information on the info boards help you to understand the learning content better? Please give brief reasons for your statement:	Free text	
19	How did you manage to navigate in the VR learning environment?	VAS range: 0 as "very poor"–100 "very good"	67.9% (38.4/3.2/94.7)
	If you had trouble navigating in the VR learning environment, what was the reason? Please briefly describe your statement:	Free text	
20	Would you recommend the VR learning environment to others?	a. Yes b. No	a. 85.5% b. 11.8%
21	Do you have any suggestions for improvement?	Free text	1. Playing audio was perceived as somewhat cumbersome 2. Like more interaction 3. Information boards should have more structure like colors 4. Audio and information boards should have different information 5. Audio should have more information 6. Panels are a bit too high when using in seating position

Abbreviation: IQR, inter quartiles range; VR, virtual reality.

TABLE 2 Frequency of use of virtual reality (VR) learning environment by students

Frequency of use (Quantity)	Result (%)
1	9.5
2	20.3
3	37.8
4	16.2
5	10.8
6	0.0
7	1.4
8	2.7
9	0.0
10	1.4

of 0.749, indicating a good compilation. The detailed results were summarized in Table 1.

3.1 | Cost evaluation

Students indicated that they would invest on average 378.90 Euro (414.20 US dollar; conversation rate: 1 Euro = 1.09 US dollar, calculated via Google) in median value (IQR: 468.40, min: 0.00, max: 1663.20) and, as much as 452.50 Euro (494.65 US dollar; conversation rate shown above) for the equipment to use the VR learning environment.

3.2 | Understanding of tooth morphology and usage

Students indicated that their perception of understanding dental morphologies was much better (1.3%), better (44.0%), the same (42.7%), or worse (9.3%) by using VR rather than the conventional textbook.

Overall, the VR learning environment was used by 12.0% of the students in the morning, by 5.3% at noon, by 66.7% in the evening, and by 1.3% at night. In addition, 8.0% of the students indicated that they used the VR learning environment in the morning and in the evening, 4.0% in the afternoon and in the evening, and 2.7% in the evening and at night. Focusing more closely on the preferred days of use, 47.4% of the students reported that they use the VR glasses on weekdays, 51.3% at weekends, and 1.3% both, during the week and at weekends.

Overall, the frequency using the VR glasses showed a median of 3.1 times (IQR: 2.0, min: 1.0, max: 10.0). The detailed results regarding the frequency during the test week are shown in Table 2. The duration of use per session showed a median of 30.0 min (IQR: 25.0, min: 5.0, max: 120.0).

3.3 | Specific application

The VR learning environment was used in motion by 47.3% of the students, stationary without room movement by 44.6% of the students and with and without movement by 6.8% (1.4% gave no answer).

Regarding the question whether the VR learning environment enabled the students to better concentrate on the learning content, equal ratings in favor of VR or conventional learning materials were obtained (50% each).

3.4 | Innovation potential

The innovation potential of the VR learning environment for other dental topics, such as articulators and joint trajectories, was rated with a median value of 75.8% (IQR: 31.8, min: 47.4, max: 94.7) (0%, "not innovative"; 100%, "highly innovative").

Intuitiveness of use was rated with a median of 67.1% (IQR: 32.2, min: 26.3, max: 94.7), with 0% indicating "not at all intuitive" and 100% "very intuitive." The display quality of the VR learning environment was rated with a median of 64.5% (IQR: 37.9, min: 3.7, max: 94.8), with 0% indicating "not at all good" and 100% "very good" on the VAS.

3.5 | Technical evaluation

In the VR learning environment, 5.2% of students judged the tooth sizes being too small, 77.9% optimal, and 16.9% too large.

Technical malfunctions or technical problems occurred in 14.5% of the students, whereas 85.5% stated that they did not encounter problems. Students described it as somewhat difficult to find and start the learning application on the VR glasses at once.

The accessibility of the virtually displayed tooth morphologies was rated with a median score of 61.1% (IQR: 24.2, min: 22.6, max: 94.7), whereas 0% indicates "very poorly accessible" and 100% "very easily accessible" on the VAS.

The improvement of learning perception by additional spoken information (auditory content) within the VR learning environment was rated with a median of 71.6% (IQR: 35.8, min: 0.0, max: 94.7), the individual interaction possibility using the hand controllers (haptic content) with a median of 73.9% (IQR: 41.2, min: 0.0, max: 94.7), and the additional written information on the information boards (visual content) with a median of 80.0% (IQR: 36.3, min: 0.0, max: 94.7) (0%, "I do not agree at all"; 100%, "I fully agree.").

The orientation within the virtual space was judged with a median of 67.9% (IQR: 38.4, min: 3.2, max: 94.7) on

the VAS scale, 0% indicating "very poor" and 100% "very good."

Overall, 85.5% of the students would recommend the additional learning method using VR glasses when teaching dental morphology, whereas 11.8% of students would not recommend it, and 1.3% did not answer.

3.6 | Side effects

No health problems (e.g., dizziness, nausea, or eye pain) occurred in 53.2% of the students, whereas 46.8% stated that they had noticed such side effects. The health problems were not queried individually.

3.7 | Personal student feedback

Students indicated in their free text recommendations concerning technical and conceptual feedback that playing the audio file was somewhat cumbersome and that they would appreciate even more interaction. Regarding the information boards, they would welcome more structure, for example, with the help of colors. They criticized that the contents of the audio file and the information boards were not identical, the audio file displaying important additional information. Further, the panels should hang a bit lower when using the VR learning environment in a seated position.

4 | DISCUSSION

The present investigation evaluated the virtual teaching of dental morphologies by a mobile VR application with glasses that can be used at home. The evaluation was done by a questionnaire covering different aspects, such as the students' perception of understanding of the tooth morphology in comparison with the use of conventional learning materials, the handling, technical difficulties, its potential for widening the scope, and side effects. The questionnaire showed mainly positive and neutral results, however resulting in an overall recommendation for the use of the VR with 85.5%.

To the best of the authors' knowledge, no comparable mobile dental VR learning environment for tooth morphologies exists in dental education and research using VR glasses. Therefore, the discussion predominantly refers to the work of two authors.[31] There was also an investigation dealing with the teaching and testing of dental morphologies but using a web-based computer simulation rather than VR with complete immersion as shown here.[30]

In the present investigation, the students stated that they were willing to spend 378.90 Euro (median; 414.16 US dollar; conversation rate is given earlier) for the VR equipment in contrast to the previous study with 500 Euro (546.53 US dollar; conversation rate is given before).[31] Currently, the price for the VR glasses used in the study is around 370 Euro (404.43 US dollar; conversation rate is given earlier) and has a decrease in price in recent years, being well within the stated price, besides that the VR glasses would be provided by the university and the student councils. Similar indications were given for the perception of understanding of dental morphologies through the VR learning environment. Regarding student self-reported comparison of using XR versus traditional materials, 1.3% said their understanding was much better, 44.0% said it was better, and 42.7% said it was equally good. Unfortunately, 9.3% said that traditional methods (such as textbooks and polymer teeth) were better. Interestingly, this finding contrasts with the students' high overall recommendation rate of 85.5%. We tend to conclude that traditional teaching methods cannot be replaced and that VR teaching should serve as an additional method. In the previous investigation using stationary VR glasses, the understanding of tooth morphologies was rated better (34.9% much better, 57.1% better, and 7.9% equally well).[31] We speculate that the difference in perception might be derived from the use of the VR at home.

Regarding the tooth sizes in the VR learning environment, 5.2% of students considered them to be too small, 77.9% optimally large, and 16.9% too large. The sizes of the teeth remained identical in the stationary and mobile VR learning environment. Although the students did not find them too large in any case in the previous investigation, there was a good agreement considering the sizes optimal (71.4%).[31] The difference could have been due to the sitting position when using the stationary VR instead of the present mobile use. It was found that the students used the mobile VR learning environment with spatial movements, such as walking around the room (47.3%), but also stationary in the room (mostly at the desk) with an increased percentage of 44.6.

Students mainly used the mobile VR glasses in the evening, which is not surprising as lectures and practical dental courses took place in the daytime. There was only slightly more use of the glasses on weekends (51.3%) than during the week. The survey showed that the frequency of use was 3.1 times (median) with a wide range between 1 and 10 times reflecting varying interest in virtual teaching. The duration of use was on average 30 min, even in the group of students who reported adverse health effects such as dizziness and nausea (46.8%). The health problems were not surveyed further, which could be part of a future investigation. According to the students' personal statements, the health complaints disappeared on their own after a short time; there was no need to take medication or

see a physician. Possible reasons might be the following: First, several students gave the feedback that they had forgotten to adapt their individual interpupillary distance before using the glasses. Second, the image of the mobile VR glasses had slightly less resolution image quality than the stationary programming glasses, which might have caused the so-called cyber sickness. With a further development of the VR technology and an improvement of the image quality of mobile VR glasses, these side effects could probably be reduced in the future. We conclude that a use of longer than 25–30 min may represent an increased risk for side effects. A specific qualitative analysis about cyber sickness would be beneficial.

There were predominantly no technical problems encountered (85.5%). The technical problems that came up in 14.5% of the students were difficulties to find the app in the virtual start environment, or a lack of the environment building up completely. The latter could be solved by restarting the VR glasses. In general, a more detailed (written) instruction might have reduced such problems. The potential of widening the VR's scope of topics was rated with a median value of 75.8%, underlining the general innovation potential toward all dental but also medical fields. Furthermore, the intuitive handling was rated good with a VAS score of 67.1%, as well as the presentation quality (64.5%). However, the limitation of the resolution of the mobile VR glasses mentioned before must be considered here.

The additionally provided haptic, visual, and auditory learning information were consistently rated positively with VAS results of 73.9%, 80.0%, and 71.6%, respectively. These results were in accordance with the initial study.[31] Problems in using the supplemental information could be explained by lack of VR knowledge. The orientation in the virtual space was rated good (median 67.9%). Overall, the feedback of the students toward this modern learning method was positive, which is reflected by the recommendation rate to other students of 85.5%.

The time limit of 1 week and the tooth morphology as sole learning topic might be limitations of this study. It would be interesting to evaluate other dental fields. Nevertheless, new technologies especially in digital and virtual teaching attract great interest in the scientific literature and educational research, which has been significantly strengthened by the pandemic.[2,3,13,21,24,28,29]

5 | CONCLUSIONS

Within the limitations of the present investigation, the following conclusions can be drawn:

1. In comparison with traditional learning material, 45.3% of the students thought that the mobile VR application improved their perception of better understanding of morphologies, whereas it was nonetheless recommended to other students by 85.5%.
2. The haptic, visual, and auditory supplemental learning information was consistently rated positively and should be further improved according to the feedback, including a higher resolution to avoid cyber sickness.
3. The VR learning environment cannot replace traditional learning methods and should be used as an additional method, especially useful for distance teaching.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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