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ORIGINAL ARTICLE

Is there any sustained effect of the coronavirus disease 2019 pandemic? – A controlled trial comparing pre- and post-pandemic oral radiology courses

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Abstract

Purpose/objectives: Due to the coronavirus disease 2019 (COVID-19) pandemic, undergraduate education shifted towards online-only formats from April 2020 until July 2021. Previous research indicated a negative effect on students' competence development, and it remains unclear whether blended learning concepts could provide compensation. Therefore, the present study aimed to compare pre- to post-pandemic students' performance in standardized baseline (BL) and final exams (FE), as well as the associated knowledge gain (KG) in three consecutive undergraduate blended learning-based oral radiology courses (C1-3).

Methods: Ninety-four students participated during two pre-pandemic semesters (October 17–July 18), and ninety-eight students during two post-pandemic semesters (October 21–July 22). Before the pandemic, conventional face-to-face lectures were combined with an oral radiology platform. Two years into the COVID-19 pandemic, additional video-based e-learning modules were adopted from the pandemic online-only curriculum. In each semester, skills and KG were assessed by conducting standardized BL and FE. Students' performance in BL, FE, and the associated KG during pre-pandemic semesters was compared to post-pandemic semesters.

Results: In post-pandemic courses, students showed significantly lower BL scores, whereas KG was significantly higher in post- compared to pre-pandemic semesters (27.42% vs. 10.64%, $p < 0.001$, respectively). FE scores in C1 significantly improved from pre- to post-pandemic semesters.

Conclusions: Within the limitations of our study, the lower BL scores confirmed the negative effect of the pandemic on competence development. Blended learning concepts seem to compensate for this effect and enable students to return to

pre-pandemic levels. Future studies are needed to assess the additional impact of video-based e-learning modules.

KEYWORDS

assessment, blended learning, COVID-19, dental education, E-Learning, oral radiology, radiology, teaching methods, video-based learning modules

1 | INTRODUCTION

Blended learning seamlessly integrates the advantages of e-learning and face-to-face (F2F) teaching,[1] harnessing their potential to optimize learning outcomes. F2F teaching facilitates critical cognitive engagement through interactive social interactions and dynamic discussion, promoting deep reflection and higher-order thinking skills. Conversely, e-learning empowers educators to design and develop student-centered learning materials,[2] tailoring content to individual needs and preferences. This modality enables the modular delivery of complex and high-quality educational content, effectively managing students' cognitive load. Therefore, blended learning has emerged as a prominent instructional approach in medical education, gaining recognition for its effectiveness in content delivery.[2–9] Moreover, blended learning offers learners unparalleled flexibility in terms of time and location, fostering self-paced learning and promoting autonomy.[10,11] Its adaptable nature is believed to facilitate robust memory consolidation, resulting in enhanced knowledge acquisition and retention among medical students.[12,13]

The coronavirus disease 2019 (COVID-19) pandemic, in which restrictions and social distancing measures were decreed to prevent excessive numbers of infections,[14–17] forced a temporary shift toward online-only learning environments.[18] In the case of undergraduate dental education at German universities, most courses were held online, except for a few clinical courses involving patients. Thus, it was speculated that students may no longer be adequately trained, especially during clinical courses. Therefore, they were assumed to develop difficulties acquiring competencies, specifically in technical dental procedures.[19]

At Heinrich Heine University Düsseldorf (HHU), a blended learning approach has been implemented for teaching oral radiology across three successive courses (C1, C2, and C3) since 2016. Evaluation of its efficacy and students' perception was conducted as part of a pilot study until 2017.[20] Since its introduction, the instructional methods combine F2F seminars held four times per week and access to a digital oral radiology platform (ORP) featuring annotated radiographs. In response to the COVID-19 pandemic in April 2020, an additional six video-based e-learning modules (VBLMs) were introduced and seamlessly integrated into the online-only learning environment (two VBLMs for C1, four VBLMs for C2, and six VBLMs for C3).

A previous study comparing pre- to pandemic semesters indicated an inferior knowledge gain (measured as the score difference between baseline and final exams) in one course (C2) and constant knowledge gain in two other courses (C1 and C3) during the pandemic. Additionally, students in C1 and C2 performed significantly worse in their final exams during the pandemic semesters. In contrast, students in C3 who had received the highest amount of VBLMs did not show a deficit in diagnostic competence development.[21]

Even as the COVID-19 pandemic slowly lapses, the VBLMs are continuously employed in the blended learning concept owing to students' positive feedback. However, it is not yet known whether our current concept allows for compensating deficits that might have been acquired during the pandemic. Thus, the present study aimed to compare pre- to post-pandemic students' performance in baseline and final exams, as well as the associated knowledge gain in three consecutive undergraduate oral radiology courses to evaluate if implementing blended learning, including VBLMs, allowed students to return to pre-pandemic competence levels.

2 | METHODS AND MATERIALS

2.1 | Participants and course outline

The present study was approved by the University Hospital Düsseldorf ethics committee under IRB no: 5596. Prior to the beginning of each semester and, therefore, of data collection, comprehensive instructions regarding the study were communicated to the participants verbally and in writing. In addition, written consent was obtained from the students, signifying their willingness to participate and share their data for the study (Figure 1). It is important to note that participation in the study was voluntary and unrelated to successfully completing the respective

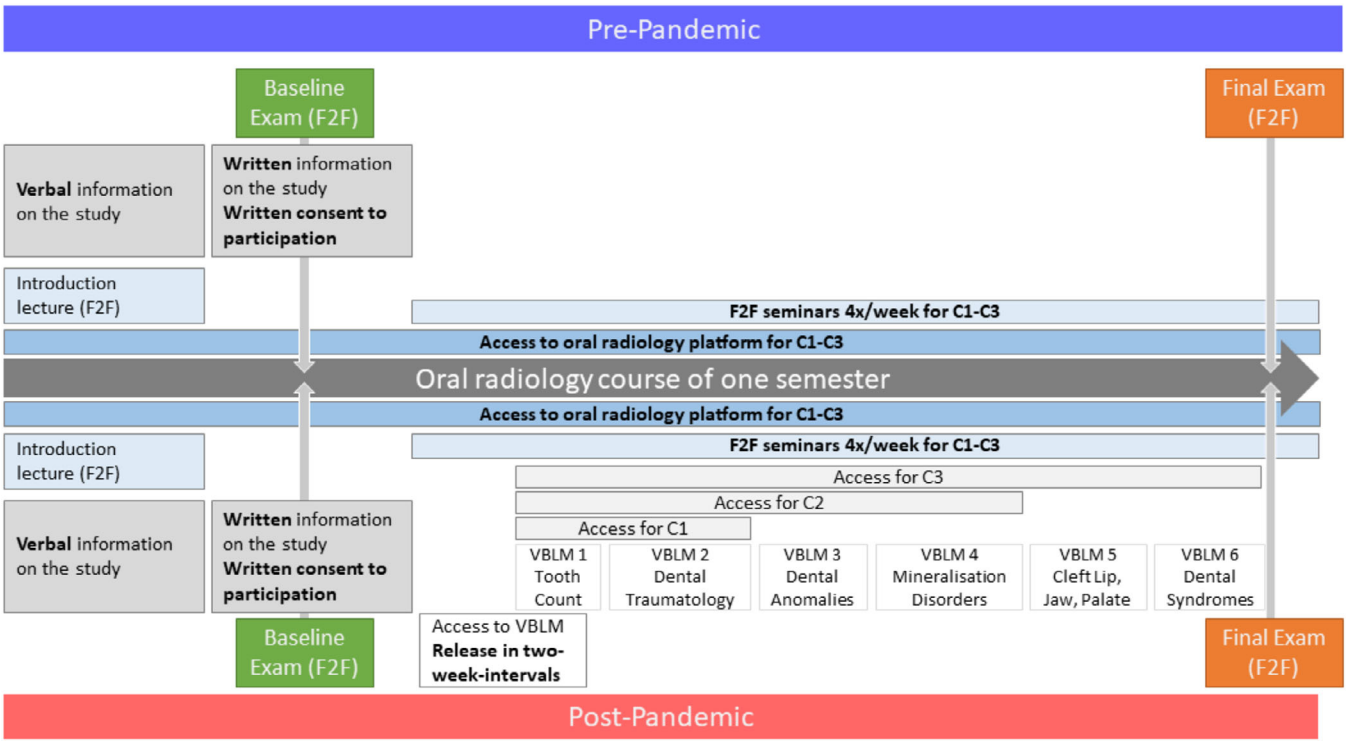

FIGURE 1 Timeline of oral radiology course, distinguishing between the pre- (blue, top part) and post-pandemic (red, bottom part) semesters and the associated study elements. Verbal information regarding the study was provided to students during a face-to-face (F2F) introductory lecture at the beginning of each semester. Students were also given written information about the study and were invited to participate by providing written consent. Following the baseline exam at the start of each semester, six video-based e-learning modules (VBLMs 1-6) were provided to courses 1-3 (C1-3) at 2-week intervals. Access to the oral radiology platform was granted throughout the entire semester. Finally, students concluded the course by participating in the final exam.

courses. Nonetheless, all courses in which blended learning was utilized were integral components of the undergraduate dental curriculum and thus compulsory for all students.

A total of 192 undergraduate dental students from HHU participated in this study. Based on their time point of radiology course enrollment, they were assigned to the pre- or post-pandemic group. In the pre-pandemic group, 94 students (73 females and 21 males) participated during two semesters (October 2017–July 2018). In the post-pandemic group, 98 students (74 females and 24 males) participated during another two semesters (October 2021–July 2022).

During pre- and post-pandemic times, oral radiology was taught throughout three consecutive courses (C1, C2, and C3) as part of the clinical teaching to acquire diagnostic competencies in diagnostic imaging in oral radiology. C1 is recommended to students in the 2nd clinical semester. At this point, students are assumed to have basic knowledge of oral radiology. Students in C2 are usually in their 3rd clinical semester. Here, students are expected to have intermediate previous knowledge. A prerequisite for participation is passing C1. C3 mainly consisted of students in their 4th clinical semester. Here, students are considered to have advanced prior knowledge. A prerequisite for participation is passing C1 and C2.

Standardized e-exams were held at the beginning and end of each semester as part of the oral radiology courses (Figure 1). The exams were always composed of 50 validated questions (two points each), amounting to a total score of 100 points per exam. The question types were heterogeneous (e.g., multiple-choice questions types A and B, multiple-select questions, and kprim questions).

The exams were conducted using computers operating in a 'kiosk' mode, effectively restricting any external access to information. To successfully pass the examinations, students were required to answer at least 60% of the questions correctly. In order to also receive certification for competence in oral radiology, 70% of the questions needed to be answered correctly. This was voluntary and not relevant to passing the oral radiology courses.

2.2 | Teaching method

During pre-pandemic semesters, oral radiology was taught using a blended learning concept comprising mandatory

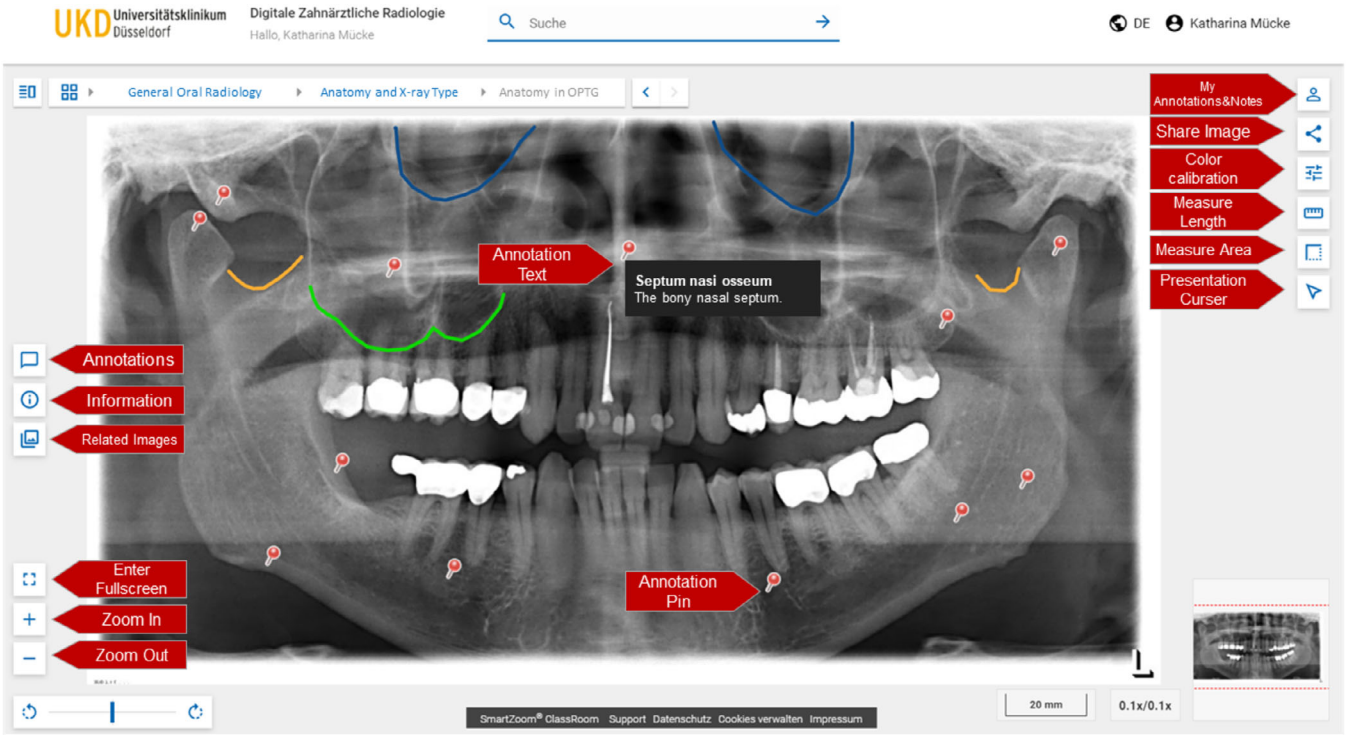

FIGURE 2 Example of an annotated panoramic X-ray on the oral radiology platform. The oral radiology platform provided annotated images, explanatory texts, and several interactive tools such as user annotations and notes, measurement tools, presentation cursor, and a communication system to contact the teachers.

case-based F2F seminars four times a week and optional access to an online ORP. During post-pandemic semesters, the pre-pandemic blended learning concept was enhanced with additional interactive VBLMs introduced in April 2020 due to the COVID-19 pandemic and continuously integrated in the following semesters. The number of available VBLMs was based on the courses (Figure 1). The use of the ORP and VBLMs was voluntary.

2.3 | Oral radiology platform

The ORP to which students received access was developed and maintained by a commercial software provider (Smart in Media AG) using their proprietary classroom solution, SmartZoom. Implemented as a web application, the ORP offered accessibility from various devices, including PCs, tablets, and mobile phones. During the time of the study, the platform hosted a comprehensive dataset comprising 481 images. The provided images were mainly dental radiographs but also histopathological slides and clinical images. The dental radiographs were further categorized into specific domains, such as prosthodontics, endodontics, orthodontics, and oral surgery, with additional subcategories for better organization. Access to the ORP was granted to all students enrolled in the courses mentioned above (C1, C2, and C3) since 2016, thus including the pre- and post-pandemic semesters.

Following the selection of a radiograph (Figure 2), students had access to various interactive learning functionalities. First, annotation pins were strategically placed on the radiographs to highlight specific anatomical structures or pathologies, with each pin linked to additional information texts. Secondly, a sub-menu provided access to all annotation texts, supplementary information, and related images for further exploration. Thirdly, an array of interactive tools empowered students to personalize their learning experience, offering features such as creating individual annotations, adding pins, and facilitating image sharing through QR codes. Lastly, students could directly pose questions to the academic staff, fostering active engagement and knowledge acquisition.

2.4 | Video-based e-learning modules

Learning objectives, didactic methods, and examination formats were aligned (constructive alignment). First, learning objectives were extracted from the national competencies-based catalog for dentistry (*German: Nationaler Kompetenz-basierter Lernzielkatalog Zahnmedizin*, *NKLZ*). Then, they were mapped to the

respective e-learning modules, and the difficulty level was adopted according to the NKLZ. Each VBLM adhered to a standardized structure, encompassing the following components: (1) an introductory section featuring patient examples, clearly defined learning objectives, and a comprehensive overview of the topic presented in an image-text combination, following a textbook format; (2) a video lecture that delved into the subject matter, providing detailed and in-depth coverage; (3) a self-evaluation quiz comprising of 7–10 formative questions designed to gauge the learner's understanding and immediate automated feedback to facilitate knowledge consolidation; (4) a concise summary and conclusion segment that encapsulated the core concepts and key findings presented throughout the module.

The videos were professionally pre-recorded and subsequently enhanced with PowerPoint slides. The final length of the videos varied between 20–39 min. All videos were embedded in the VBLMs on the open-source learning-management system ILIAS (in Engl.: *integrated learning, information, and work cooperation system*, ILIAS open-source e-Learning e.V.). The VBLMs were made accessible during the post-pandemic semesters at two-week intervals. In addition, weekly notifications and reminders were sent out via university mail. The completion time per VBLM was estimated at approximately 60–90 min.

Six orthodontic-based radiology topics were covered in the VBLMs. Depending on the anticipated difficulty level and the students' existing knowledge, the VBLMs were assigned to the three courses (Figure 1). The VBLMs with the lowest difficulty level covered "Tooth Count" and "Dental Traumatology" and were provided to C1–3. The VBLMs with intermediate difficulty covered the topics "Dental Anomalies" and "Mineralisation Disorders" and were provided to C2 and C3. VBLMs with the highest difficulty level covered "Cleft Lip, Jaw, Palate" and "Dental Syndromes" and were given only to C3.

2.5 | Statistical analysis

Statistical analysis was performed using R (R Core Team). For each variable and group (exams at the beginning and end of the semester), descriptive statistics were computed, including the respective means, standard deviations, medians, quartiles, and minimum as well as maximum values. Boxplots were generated using the R package *ggplot2*[22] and used to validate normal data distribution. Paired t-tests for partially dependent data[23] were conducted for intra-semester comparisons, considering the exclusion of a small number of students who did not attend both exams. The comparison of exams and knowledge gain between pre- and post-pandemic semesters was performed using unpaired t-tests. The level of significance was set at $p < 0.05$.

3 | RESULTS

3.1 | Performance in baseline exams

Comparing results in baseline exams of all three courses pooled between the two groups, scores in baseline exams within pre-pandemic semesters were significantly higher compared to post-pandemic semesters (62.11% vs. 49.38%, $p < 0.0001$). On a course level, only C1 showed similar initial baseline scores during pre- and post-pandemic semesters (56.24% vs. 50.52%, $p < 0.67$). As depicted in Figure 3, scores during baseline exams in C2 and C3 were significantly lower during post-pandemic semesters compared to pre-pandemic semesters (C2: pre-pandemic: 62.43% vs. post-pandemic: 46.71%, $p < 0.0001$, C3: pre-pandemic: 66.98% vs. post-pandemic: 50.81%, $p < 0.0001$).

3.2 | Performance in final exams

Comparing the performance in final exams, scores of all courses within post-pandemic semesters were significantly higher than pre-pandemic semesters (pre-pandemic: 72.75% vs. post-pandemic: 76.81%; $p = 0.0043$). However, on a course level, only C1 showed significantly better performance in final exams during post-pandemic semesters compared to pre-pandemic semesters (pre-pandemic 73.47% vs. post-pandemic 82%; $p < 0.001$), whereas no differences were found in students' performance in final exams in C2 (pre-pandemic: 73.73% vs. post-pandemic: 76.56%; $p = 0.11$) and C3 (pre-pandemic: 71.29% vs. post-pandemic: 72.44%; $p = 0.71$) between pre- and post-pandemic semesters (Figure 4).

3.3 | Knowledge gain

Overall, in all three courses (C1, C2, and C3), scores in final exams at the end of the semesters were significantly higher than the scores in baseline exams at the beginning of the semesters ($p < 0.05$, respectively), presenting significant knowledge gains in each course during each semester. As shown in Figure 5, during pre-pandemic semesters, students showed a less pronounced knowledge gain than during post-pandemic semesters, and the differences were significant ($p < 0.05$, respectively).

In all three courses (C1, C2, and C3) and across the two post-pandemic semesters (October 2021–July 2022), students' knowledge gain was significantly higher in

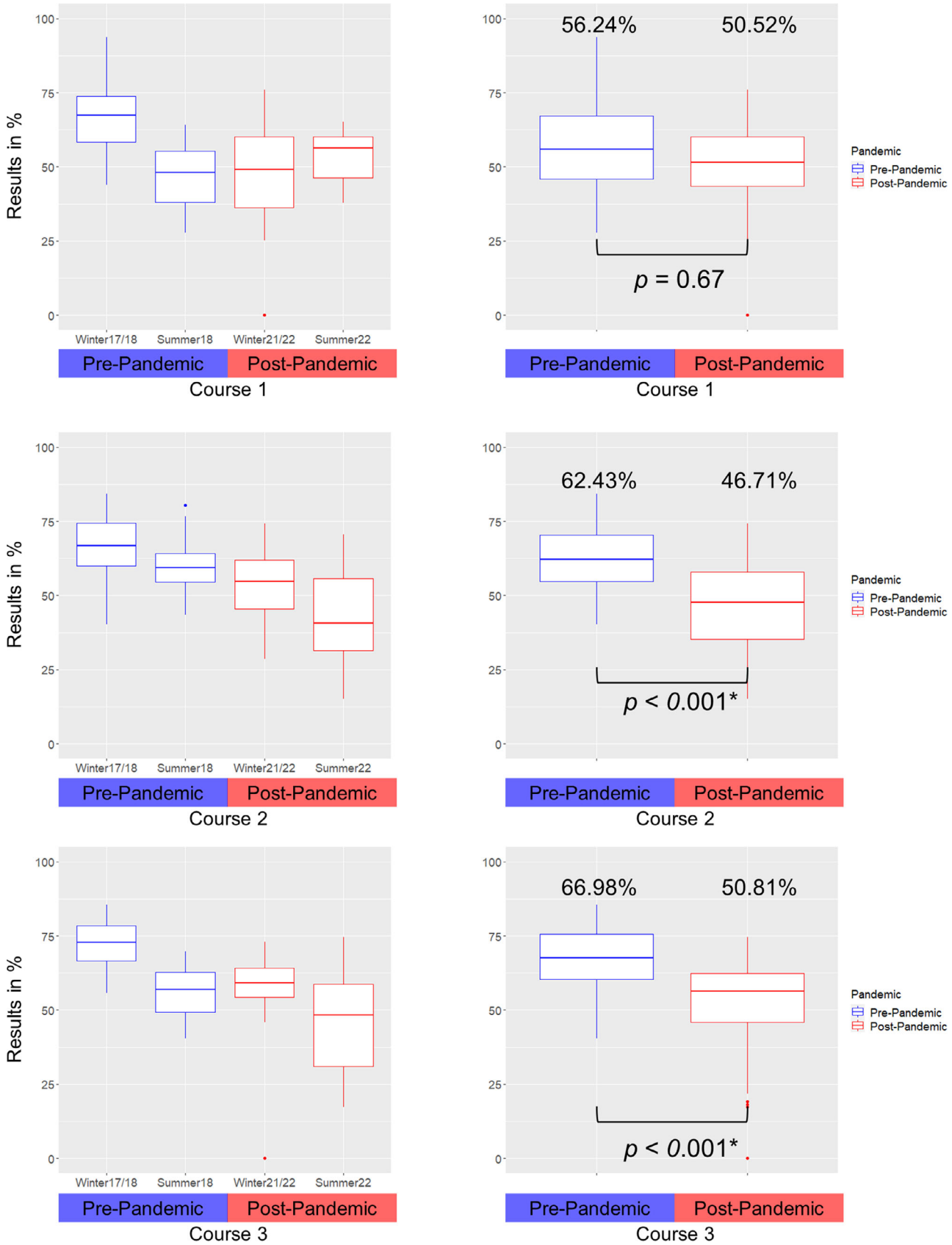

FIGURE 3 Scores at baseline exams (in %) during pre- (blue) and post-pandemic (red) semesters for the courses C1, C2, and C3 (from top to bottom). The left column shows the individual semester (left), whereas the right column shows pooled data representing the comparison between pre- versus post-pandemic semesters.

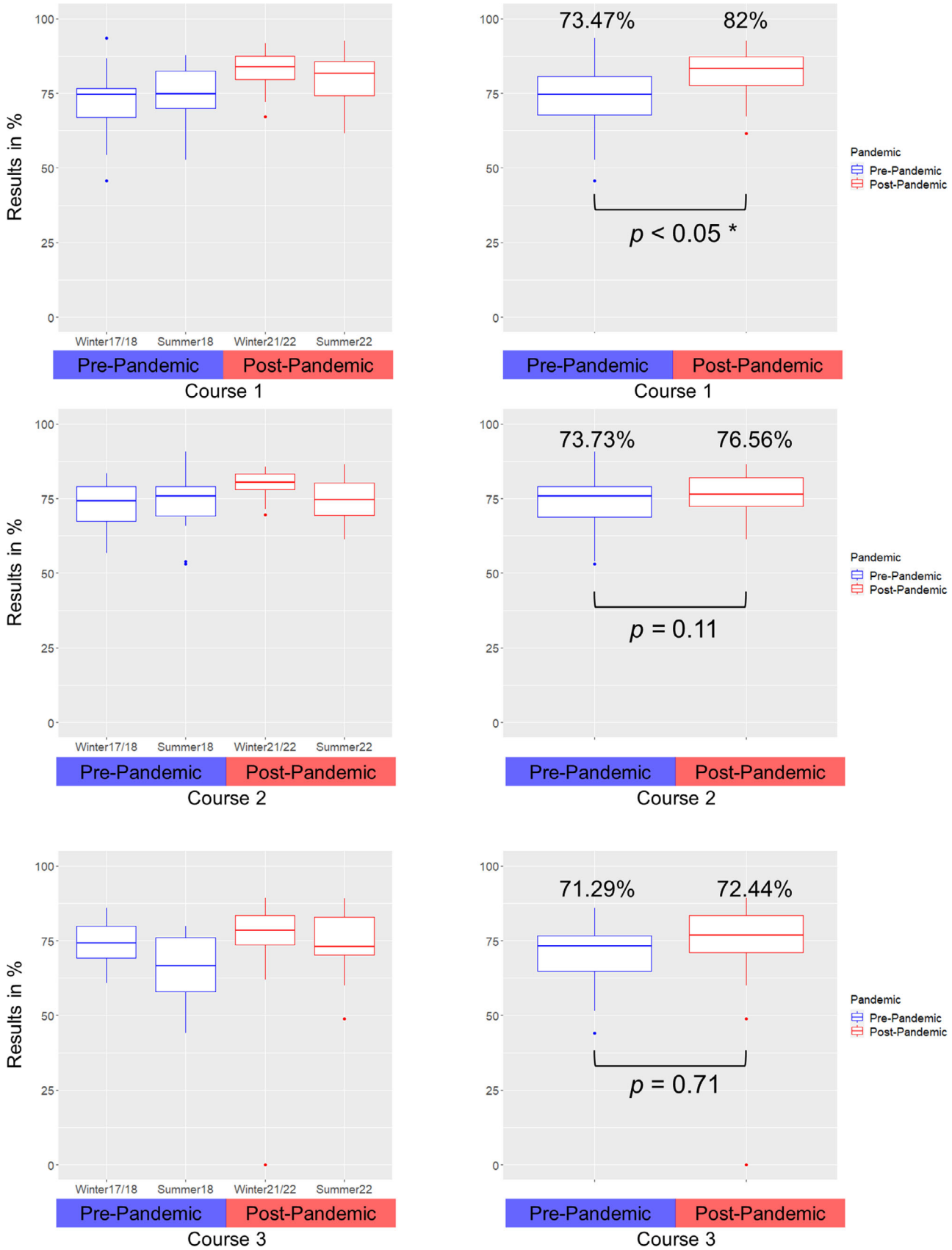

FIGURE 4 Scores in final exams (in %) during pre- (blue) and post-pandemic (red) semesters for the courses C1, C2, and C3 (from top to bottom). The left column presents the individual semesters, whereas the right column shows the pooled data representing a comparison between pre- versus post-pandemic semesters.

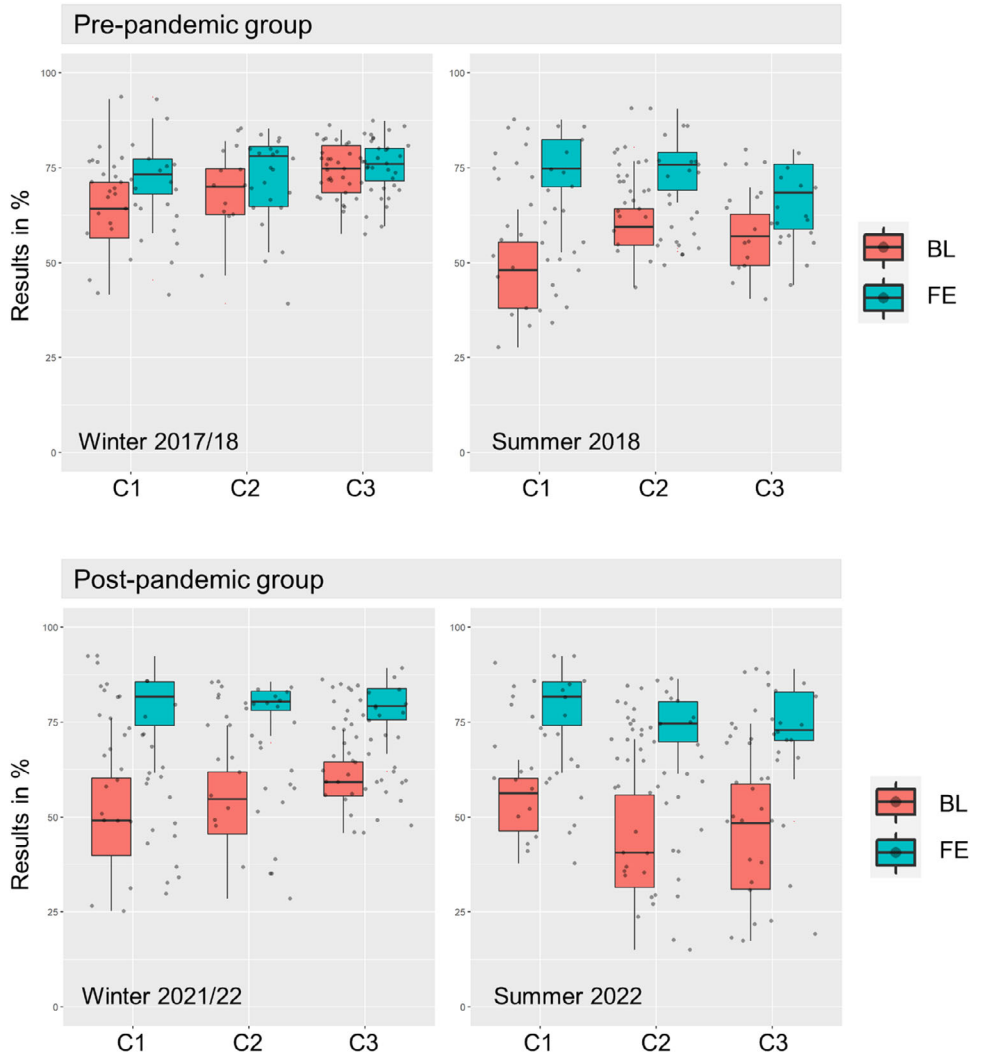

FIGURE 5 Students' knowledge gain of all semesters. The knowledge gains correspond to the difference between the final exams (FE, in turquoise) and baseline exams (BL, in red). Data are presented for all three oral radiology courses (C1-C3).

TABLE 1 Knowledge gain (mean difference in %, ± standard deviation) during pre- and post-pandemic semesters. On course level and in all courses in sum, students show significantly higher knowledge gain during post- compared to pre-pandemic semesters.

Course	Pre-pandemic Semesters	Post-pandemic Semesters	*p*-Value
C1	17.23% ± 14.51	31.48% ± 14.09	$p < 0.0001$*
C2	11.30% ± 13.58	29.85% ± 14.59	$p < 0.0001$*
C3	4.32% ± 9.41	21.63% ± 25.66	$p < 0.0001$*
All Courses	10.64% ± 13.57	27.42% ± 19.56	$p < 0.0001$*

post- compared to pre-pandemic semesters ($p < 0.0001$). Table 1 summarizes the knowledge gain in mean difference during pre- and post-pandemic semesters.

4 | DISCUSSION

The present study aimed to compare pre- and post-pandemic students' performance in baseline and final exams, as well as knowledge gain in three consecutive undergraduate oral radiology courses. The overall goal was to assess whether a blended learning concept might compensate for deficits that students developed during pandemic semesters. As expected, baseline exam scores were significantly lower in post- compared to pre-pandemic semesters. Moreover, students' performance in final exams slightly improved in post-pandemic courses but revealed significance only for C1. In line with this, knowledge gain

was significantly higher in all three oral radiology courses in post- versus pre-pandemic courses.

Our results confirm previous findings reporting that students developed deficits during the pandemic.[21] However, the present data also show that the blended learning concept could compensate for the deficits acquired during the pandemic. Nonetheless, it has to be noted that students were already familiar with the ORP, which had been introduced in winter 2016/17 and tested in a pilot study during two semesters.[20] Whereas minor knowledge gains were noted only during the pilot phase, it took some years of adaptation to show more enhanced effects.

Interestingly, students performed slightly better during post-pandemic semesters, which might partially be due to the addition of VBLMs. This effect was most pronounced in C1, and it might be due to the fact that novice learners are supposed to interact with e-learning more efficiently due to an increased motivation towards new learning tools and higher flexibility in developing a novel and individualized learning method.[24,25] On the other hand, students in higher semesters (C2 and C3) might already have developed their own learning methods and be less curious about e-learning. Consequently, these students might be more reluctant to adapt to new learning methods and strategies.

It is also worth noticing that students in C2 and C3 had partially participated in previous courses during pandemic semesters (C1 or C2 and C1). Enhanced levels of anxiety, depression, and stress have been reported during the pandemic[26,27] and might have influenced students' performance in C2 and C3. With decreasing COVID-19 restrictions, social and recreational activities increased. Hence, students in higher semesters who had already experienced a pronounced diminishment in their social student life during the pandemic semesters may have had less motivation to complete additional online work at home. Beyond that, the daily clinical schedule shifted back to the pre-pandemic curriculum, with small group demonstrations held live on-campus and practical work on actual patients. Consequently, the additional stress and unfamiliarity of mandatory clinical tasks might have resulted in less participation in voluntary e-learning activities.

It is important to note that the generalizability of our results may be limited since we only examined data from one university and the immediate post-pandemic episode. Implementation procedures in other universities might differ, affecting exam results. Furthermore, future studies investigating the additional effect of the VBLMs are required, as in the present study, the pandemic might have been detrimental to the overall performance. Furthermore, owing to the COVID-19 pandemic, the attitude towards digital media might have changed,[28] and comparability with pre-pandemic studies might be limited. Potential psychological effects such as frustration, depression, and anxiety associated with social isolation have been reported,[26,29–31] and it is difficult to control or subtract these effects for post-pandemic courses.

5 | CONCLUSION

Within the limitations of our study, the COVID-19 pandemic had a detrimental impact on students' performance in baseline exams in oral radiology courses at HHU. In contrast, scores in final exams tended to be higher during post-pandemic semesters, which was corroborated by a significantly higher knowledge gain during post-pandemic semesters. Thus, the blended learning concept seemed to compensate for the acquired deficits. Future studies, including students unaffected by the pandemic, are needed to assess the additional effect of the video-based learning modules provided to students in post-pandemic semesters.

AUTHOR CONTRIBUTIONS

Kathrin Becker, Dieter Drescher, and Jürgen Becker conceived the ideas; Kathrin Becker set up the oral radiology platform. Katharina Mücke designed and recorded the video lectures and developed the video-based e-learning modules. Kathrin Becker, Justine Igelbrink, Caroline Busch, and Katharina Mücke conducted the student exams. Kathrin Becker, Justine Igelbrink, and Katharina Mücke analysed the data. Katharina Mücke led the writing. All authors discussed the results and contributed to the final manuscript. All authors approved the final version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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