Using different technologies and gamification to deliver active learning strategies on caries detection training during pandemics – case study and economic impact of two dental schools experiences

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Research Article

Keywords: Dental education, Active learning, Cariology, Hands-on, Covid19, Pandemic

Posted Date: February 13th, 2024

DOI: https://doi.org/10.21203/rs.3.rs-3911653/v1

Additional Declarations: No competing interests reported.

Abstract

Background

In 2020, due to the restrictions imposed by the coronavirus pandemic, the teaching methodologies had to be adapted to allow social distancing and avoid contamination at universities. Technology was an important aid to cross those barriers. This study describes and assesses the economic impact of including information and communication technology (ICT) in adapting educational activities at two universities during the COVID-19 pandemic.

Methods

Dental School of the University of São Paulo (FOUSP) in Brazil and The Indiana University School of Dentistry (IUSD) in the United States are engaged in Initiatives for Undergraduate Students' Training in Cariology (IuSTC). Their educational staff modified teaching approaches to continue training dental students for caries detection with tutored and active learning strategies using available ICTs. Resources used during the activities were valued considering the perspective of the educational Institution. The costs of implementing the adapted methodologies were valued in the local currency and converted to international dollars.

Results

Teaching methods for caries detection during the pandemic were implemented by hybrid teaching models, mixing online and in-person activities. The ICT strategies were created based on a previous base methodology, part of IuSTC. The innovative approaches included gamification and virtual laboratory (FOUSP, n = 80), virtual classes, and online feedback (IUSD, n = 105) to engage the students using active learning methodologies. Both institutions successfully taught a complete group of students during the pandemic. The cost of developing and delivering the adapted teaching methodologies was about $64 to $71 per student for the FOUSP and $78 per student for the IUSD. In the overall cost composition, values assigned to facilities and instructional materials were less significant. Even based on ICT, human resources in teaching strategies represented the most expensive ingredient for both institutions, constituting 95% and 51% of the expenses for FOUSP and IUSD, respectively. Some adaptations have been used after pandemic control.

Conclusions

The adaptations based on ICT permit the institutions to proceed with their active methodologies, given the barriers imposed by the pandemic. The imposed challenge demanded creativity and a considerable university investment, but the benefits surpassed the pandemic.

Trial registration

IuSTC-01: https://doi.org/10.2196/resprot.7414. Economic analysis associated with IuSTC-01: www.osf.io/wa6x2.

BACKGROUND

The highly transmissible coronavirus disease emerged in China at the end of 2019. At that moment, probably no one could predict the greater dimensions that this deadly respiratory disease took and nor the consequences that we are still observing in the present time [1]. In 2020, the World Health Organization (WHO) declared a global pandemic and a state of emergency. Different countries' governments started to take measures to keep people safe and prevent the virus from spreading. The strict measures adopted were full lockdowns, border closure, household disinfection, and mask-wearing [2]. Despite those actions, countries like the United States and Brazil still revealed some internal deficiencies/difficulties in controlling the contagions, leading the two countries to maintain the highest number of deaths worldwide for a long time.

The COVID-19 pandemic brought many challenges, but its effect on the health and education sectors was the more problematic. Besides the several deceases registered in short periods and a higher workload for the health personnel [3], there were other problems, like learning disruption in all education levels and increasing absenteeism rates [4] were also evident problems. Almost certainly, the entire education sector was severely impacted when all in-person activities had to be interrupted to prevent more infections. Therefore, students and professors were forced to adapt to the new teaching-learning conditions in which remote activities were mandatory, and information and communication technology (ICT) was essential to overcome such barriers.

In dental education, the circumstances were not different. Although patients' dental care must have been continued, teaching methods demanded adaptation to maintain students' learning activities and disciplines. Some reports of teaching experiences during the pandemic are found in the literature [5–8]. Nevertheless, as far as we know, they are not focusing on exploring a specific teaching-learning framework in different contexts or analyzing its economic aspects.

In this paper, we explored issues emanating from the modifications made in two dental educational institutions, one in Brazil and the other in the United States, that reinvented themselves to continue applying a teaching method for caries detection in undergraduate education. Besides, we also aimed to raise some insights about the economic aspects of the adapted teaching methodologies, to start understanding and discussing the magnitude of such impact on the university system. By bringing these issues to light and reporting these two experiences, we expect to help solve some difficulties, even simpler than the pandemic, which may improve the educational environment and highlight how educators could address challenges and benefit from such changes.

METHODS

This paper was written according to AME Case Series Checklist –Adapted from CARE Checklist and PROCESS Checklist [9].

Study Design

This paper describes the teaching experience of two different dental schools in training predoctoral dental students to detect caries lesions as part of their learning activities during the COVID-19 pandemic and how the adaptations still influence today on the instruction of the subsequent classes. It reports those crucial actions that must be taken to maintain the educational quality (contents) and student engagement in active learning activities previously planned as part of the Initiatives for Undergraduate Students' Training in Cariology (IuSTC). The two institutions were the Dental School, University of São Paulo (FOUSP), in Brazil and the Indiana University School of Dentistry (IUSD), in the United States.

Both institutions are members of the collaborative research group IUsTC and centres involved in the multicenter study IuSTC-01. Then, both institutions presented a similar framework of active-learning teaching activities to instruct students about caries detection. Nevertheless, in each university, some specific adaptations or variations were necessary to meet the particular context of the Institution and face the stage of the pandemic they were going through. The adaptations occurred at different times of the pandemic, according to each country's conditions imposed by the particular health situation.

The multicentre study protocol was approved by the Ethics in Research Committee (CAAE 39632614.0.0000.0075). However, this paper does not comply with participant data, only the experience report. The original protocol was published and is considered the official registration of the IuSTC01 study [10]. The educational economic analysis plan was available in an open repository (www.osf.io/wa6x2)[11]. The adaptations described here are considered protocol deviations due to pandemics (The adaptations described here are protocol deviations due to pandemics further included in the main publications but followed the initial registration). The final centre results will be further included in the main publications.

Scenario/Sample

Brazilian scenario – FOUSP

In Brazil, on February 26, 2020, the first case of COVID-19 was confirmed in São Paulo. In March, some government actions started to be applied to prevent the spread of the infectious disease. Among them, the lockdown, instituted as a security measure for the community. Due to the emergency, the University of Sao Paulo authorities also decreed the suspension of all in-person activities and recommended a rapid transition to distance education. Vaccination was not regularly available up to January 2021.

United States scenario

Public health agencies noted the Covid-19 cases in the United States between January and February 2020; however, it was declared a national emergency on March 13th. Nonetheless, at some point, with the vaccination campaign started and with the reduction in the number of new cases registered, some universities were able to return and have some in-person activities on campus. IUSD had to prepare this return and develop a complete "roadmap" [12] to slowly restart the lectures, clinics, and preclinical laboratory activities at the Dental School without neglecting the health and safety of students, patients, administrative staff and faculty members.

Faculty members from the Department of Cariology, Operative Dentistry and Dental Public Health had already planned the implementation of the IuSTC's original method for the class of 2020, as one of the sites of this multicenter research initiative [13]. However, and due to pandemic conditions, a limited number of people were allowed to be in the dental school building simultaneously, according to the rules of the IUSD biosafety committee. Therefore, they had to change the logistics and redesign how the activity would be delivered to students.

Adaptations described in Results section were performed for the 2020 classes, the first affected since the pandemic started (FOUSP = 80 students and IUSD = 105 students).

Original teaching method

The tutored-mediated theoretical and laboratory teaching method originated and was first implemented in 2009 in the Pediatric Dentistry Department at the University of Sao Paulo [13]. Since then, several universities have applied it, motivated by a multicentre project designed to test this method's efficacy and economic impact [10]. The original teaching-learning strategy consists of three important moments that are summarized below.

1. *Didactic Lecture* an approximately 60-minute conventional in-person lecture, carried out in a lecture hall, where the caries diagnosis process is contextualized, together with important aspects to be evaluated for caries prognosis and the progression of caries lesions. This lecture also explores caries detection using the International Caries Detection and Assessment System (ICDAS) as a system to aid visual inspection. Afterwards, the possible management decisions concerning the different lesion severity stages and activity status are also discussed.
2. *Tutored-mediated activity with images*. Students are divided into smaller workgroups composed of 8 to 10 participants. One or two tutors (lecturers or graduate students) led each group. In this activity, 30 images (clinical photographs) representing different lesion severities and activity are assessed by the students, including lesion severity and activity status, as well as its possible management approach. Strategies of active learning methodology, such as a thinking-pair approach and tutored feedback, are used to stimulate the students to reason behind their decisions. Discussions are initiated by students' several answers (and not tutors' correct ones).
3. *Tutored-mediated laboratory training practice with extracted teeth.* This hands-on training experience is carried out in a student dental simulation laboratory. The educational strategy is similar to the previous phase. However, at this stage, they are supposed to examine the assigned surface without any indication, as in the pictures, simulating a closer-to-the-clinic situation.

As described above, the teaching strategy was originally idealized as an IuSTC strategy to work on caries detection topics with the students by combining both "passive" (lecture) and "active" (strategies above) educational resources. Such an approach has proved effective in promoting learning and developing practical skills for clinical caries detection and being well accepted among students (unpublished data). Nevertheless, the strategy, before the social distance induced by COVID-19 pandemic had designed for an "in person format". Given, the COVID-19 pandemic circumstances and the safety guidelines recommending social distancing, some modifications were needed to guarantee the student teaching-learning processes for caries detection during this period.

ICT Intervention – Adapted IuSTC method

Given the scenario described above, educational staff in each one of the universities had to adapt the original IuSTC proposed in the pre-pandemic period to their context and pandemic situation. They tried to ensure the principles of the teaching method could be maintained, but some adaptations were inevitable due to safety concerns at that time. For these adaptations, available ICT were used. The detailed description of methods proposed are being reported in the next section. However, it is important to note that educational staff has to act promptly to minimize educational losses for the students. Therefore, they were supposed to use readily identified resources and innovate in a short period of time.

Implementation outcomes

As a primary description of these adapted strategies based on ICT for the pandemic, for this paper, we considered the feasibility and the sustainability of the educational activities as implementation outcomes. To assess feasibility, we considered if the activity could be conducted successfully as planned and if any unanticipated events were observed or reported [14]. To sustainability, we reported if the strategies were maintained or institutionalized in future occasions [14].

Cost Assessment

The cost assessment provided in this paper includes detailed resources and costs associated with the development and delivery phases of these teaching methodologies. A perspective of the Institutions (provider's) was adopted. A time horizon for the immediate application of methods was then considered.

A micro-costing approach was used to identify and measure all the resources required to implement the activities in each educational context. All resources considered were first valued in the local currency and then, converted to international dollars ($) using *Purchasing Power Parities* (PPPs) [15]. (Exchange rate: 2.53).

Three main categories were considered to organize the resources: 1) Personnel (human resources involved in the teaching activities), 2) Supplies (instructional materials provided by the educational institutions) and 3) University facilities (used during the teaching activities). The total estimation of the cost for each teaching strategy was calculated by aggregating the cost of each cost component (Fig. 1) and following the "Ingredients method" theory [16, 17]. More information about cost valuation may be found in the protocol (www.osf.io/wa6x2)[11].

Monte Carlo simulations were used to estimate the uncertainties. We assumed a triangular distribution of costs using the calculated cost at each institution as the mean value and varied the costs ± 10%, simulating other possible contexts. Then, the mean and the 95% confidence interval was calculated to estimate the uncertainty in the values.

Figure 1 Final cost composition, considering the development and delivering phases of educational strategies.

The final cost of implementing the whole activity was calculated for the total number of students registered in the class of 2020, and then the cost per student was also reported. We assumed the immediate educational intervention was a one-off event, and no inflation or discount values needed to be included.

RESULTS

Different teaching modalities were initially adopted in each Institution (FOUSP/IUSD). Figure 2 illustrates the adaptations performed during the COVID-19 pandemic, contrasting with the original version presented above. In the next sections, a detailed description of the arrangements that each Institution implemented will be embedded.

Figure 2 Comparison of the pandemic adapted methodologies to the IuSTC original teaching strategy (pre-pandemic version).

The FOUSP experience

In the 1st semester of 2020, preclinical activities in caries detection had been performed in March, immediately before the lockdown. In the 2nd semester, approximately 4 months after the beginning of the lockdown in Brazil, Pediatric Dentistry Department offered a new innovative course, proposing distance-learning activities to 80 last-year students.

Caries detection was usually taught in one or two in-person moments comprising the didactic-practical laboratory training we have previously described, which usually lasts 1.5 hours. The initial idea was to maintain the nuances of active learning in the activities and stimulate students to engage with the content despite the social distancing (to substitute in-person interaction with the faculty). Firstly, instead of proposing a regular online class (as many other lecturers were doing due to the circumstances), a gamified self-instructional online module was provided, giving students even more responsibility in learning. Besides, using game resources, they could check their performance and receive immediate feedback. This feedback is supposed to be the message a lecture could deliver in a regular class. In this way, in the end, the student who finished the gamified course would have been exposed to the same content presented in the regular class.

Didactic material was prepared in advance by professors and postgraduate students of the department. It was posted for students on a free educational platform (Google Classroom) so they could study at home and rehearse the contents anytime. Feedback from lecturers was also allowed on such a platform, and a virtual forum permitted lecturers and students to meet after practising with the game so the main lessons and doubts could be discussed online.

The self-instructional material (caries detection game) was initially constructed as a prototype using the Google Forms web application [18]. Game-based headliners were used to engage the students and contribute to their active participation in the didactic content. The students could access them via mobile phones, tablets, or computer devices anytime and several times. The gamified material comprised three phases with specific learning outcomes (Figure 3). The three phases (A, B and C) had different stages, including several paths according to students' answers. In the end, the same lecture content would have been explored for any student (even if they had followed different pathways). In the pathways, diverse educational resources were used to explore the different topics on caries detection, such as explanatory videos, flowcharts, decision trees, brainstorming questions, and quizzes.

Figure 3 Self-directed game using learning phases that stimulated students to interact with the caries detection contents.

In phase A, the student explored caries diagnosis and prognosis of caries lesions. In phase B, questions about caries detection in the clinical environment and concepts learned in the previous phase were asked. Finally, in phase C, arguments about complementary methods for caries diagnosis, effects of overdiagnosing, and possibilities to adequately manage carious lesions were broadly studied. In all the stages, students received immediate feedback. For that, different paths to help them understand why the chosen answer was correct (or not).

Suppose the students had chosen the incorrect answers. In that case, they receive a message that stimulated them to think about the issue (immediate feedback) and encouraged them to return to the question and answer it again (Figure 4). This approach aimed not to score more points or get a higher final score but to make the students recognize their inaccuracies and try again until they understand the reasoning behind a particular alternative for each question. At the end of the game, it was also pointed out if the student may still need to study or learn more (Figure 4), but the most important it was the pathway travelled.

Figure 4 Flowchart represents the different pathways followed according to students' answers, allowing immediate feedback.

A second stage was proposed fifteen days after the material was posted. A synchronous online session via Google Meet Platform [19] was scheduled with the class (80 students), and a virtual caries detection laboratory was conducted with the students. The virtual activity was also an active teaching strategy, substituting the first part of the original in-person laboratory training, performed with images (Figure 4). The students were divided into smaller session groups, using an innovative tool of the Google Meet platform at that time called "breakout rooms". The virtual meeting rooms were created with 8-to-10 students each, and one or two tutors were assigned to guide the activity. Tutors were the graduate students (from master's and doctorate programs) who collaborated in developing the self-directed learning material, so they were all previously trained and calibrated to interact with students.

The virtual session took about 40 minutes. The tutors shared some images of clinical cases used in the original in-person laboratory training on their screens and followed the same didactic strategy of in-person teaching activities. An online game was another active learning strategy in this virtual session to wind up the activity. A Kahoot game-based learning platform was used due to its attractive design and interactive approach (Figure 5) [20]. The idea was to summarise the main messages about caries detection using healthy student competition. The lecturer was responsible for giving small pieces of advice customized according to the student's performance at each question.

Figure 5 Different types of questions used for summing up the main lessons learned by students (kahoot).

This set of activities comprised a complete distance learning method adapted at FOUSP. Considering that at that time (end of the year 2020), the social distance had not ended in São Paulo, the practical in-person training stage (hands-on with extracted teeth) could not be carried out with these students. When it was possible to resume in-person activities a new hybrid teaching approach was promptly implemented for the subsequent classes (2021-2022).

FOUSP's Hybrid adaptation

In the new hybrid teaching modality offered, the self-directed gamified learning phase and the virtual laboratory, including game-based activities, were maintained as distance learning tasks because of their promising results. The hands-on training activity component was reincorporated with assessing extracted teeth in a preclinical laboratory. It is important to point out that as the students could attend the university facilities if they wanted to, they could even use the informatics lab provided by the educational institution to complete and interact with the distance self-directed and gamified content. Figure 6 illustrates how this new modality of teaching worked.

Figure 6 FOUSP Hybrid adaptation for the classes that were able to receive in-person training

The IUSD experience

The caries detection module was offered to first-year dental students as part of the Risk Assessment, Prevention, and Early Management of Dental Disease course. A total of one hundred and five students were exposed to the adapted methodology in IUSD (2020 class). At first, an experienced lecturer gave two didactic online lectures on caries detection and ICDAS as part of their curriculum. Lectures were given by Zoom and lasted about 60 minutes each. They were delivered to the entire class in a synchronous online single session.

As part of a hybrid teaching model, the preclinical laboratories of the IUSD building were prepared to receive students after one week. This second part of the teaching strategy (a tutored practical laboratory training with images and extracted teeth) was performed in person following the main structure proposed in the pre-pandemic period. However, given the high number of students, the training could not be carried out in the same lab for all students. To minimize the number of attendants on the same day and to maintain the recommended physical distance between students during the evaluations (6 feet), the class had to be divided into 12 smaller groups of 7, 8, or 12 students, reflecting the capacity of each of the adopted lab spaces within the school facilities.

Practical training was delivered to different groups in four different moments (two per week). On each occasion, three groups were separated in different laboratory spaces, totalizing 12 different activities delivered at all. Besides the coordinator, two faculty members and three graduate students participated as tutors for these practical activities.

Pandemic response measures, such as clustering the students in unchangeable groups during the semester were strictly maintained. Safety protocols were adopted each week in the three different environments that students received. Temperature checking at the entrance, use of personal protective equipment, and different organizations for the flow of people entering and leaving the building were implemented to avoid contagion among the students and staff.

Fixed workstations were assigned to students at the beginning of the activity. Then, students remained in the same place until the end of the training. First, the image laboratory training was performed. For this, each student had access to a computer screen attached to their dental simulation units (Figure 7). The tutor discussed 30 clinical images presenting caries lesions of different severities, and the students could interact with the faculty remotely to solve all possible doubts about detecting and managing the lesions displayed.

Figure 7 The image training was performed in the preclinical laboratories with fixed workstations.

For the second part of the laboratory training activity, with the assessment of extracted teeth, three sets of extracted teeth were selected, one per group. Before the laboratory training started each week, the models were sterilized in an autoclave and wrapped in disinfectant towelettes (CaviWipeTM) (Figure 8).

Figure 8 Models of teeth prepared for the laboratorial training. After each evaluation, students must disinfect them.

The models with teeth were rotated among the students to avoid contamination. Intermediate stations were created to disinfect the model before passing it to the next student. Once the first model was evaluated, the cleaning process was undergone, and then the model was deposited in the intermediate station. The subsequent student could then get up next and take it. This way allowed that there was not any direct contact or interaction between students.

At the stations, each student also received a sealed envelope with the consented answers for the models evaluated, which the lecturers had previously scored. Students were instructed only to open the envelopes once they completed the evaluations to compare their answers as a way of feedback. One tutor (professor) was available for the respective small group of students at the lab and interacted with students only if they had doubts or questions after comparing the answers, minimizing close contact.

Implementation outcomes

Both institutions successfully taught their respective complete group of students during the pandemic. No major issues were detected or reported. At FOUSP, the model presented in Figure 6 was strictly used from 2020 to 2022, and it has been used on some occasions until now despite the pandemic's end. Incorporated ICT was maintained, but some online sessions were substituted for in-person sessions, even using the resources developed for online purposes (Figure 9). At IUSD, the adaptations were maintained during 2020 and 2021. With pandemic control, in-person classes were reestablished, and no disinfection concerns and student rotation were still needed, returning to the model similar to the pre-pandemic period. Nevertheless, they still have online tutoring as one alternative for cases where social distancing or absenteeism may be needed.

Figure 9 Students in 2023 (after pandemic) using the gamified contents in the laboratory workshop training activity.

Cost of the instructional strategies

For the completely virtual education program proposed at FOUSP (the approach used in the first semester of the pandemic), a total cost of $5091 (95%CI: $4582-5600) was spent for 80 students ($64 per student) (Table 1). As all the next deliveries at FOUSP were performed in a hybrid format of training, the cost estimated slightly increased for this second methodology at FOUSP, totalling $5670 (95%CI: $5103-6238) for a class of 80 learners ($71 per student) (Table 2).

Table 1 Costs related to the first adapted methodology at FOUSP, in Brazil, and delivered completely online.

Table 2 Costs related to the FOUSP hybrid subsequent offerings, delivered partially online and partially in-person.

In FOUSP, the development phases of the teaching methodologies were largely costlier than the delivery phase, registering more than 90% of the total composition of costs (Tables 1 and 2). Besides, in the two different scenarios performed at FOUSP, the composition of costs was very similar and human resources cost was much higher than the cost spent on instructional materials and/or facilities (Table 1), even for the hybrid modality that involved and in-person laboratory training at the university accommodations (Table 2).

The IUSD training program's total cost for teaching activities using a hybrid model with 105 students during the pandemic was $8209 (95%CI: $7388-9030) – ($78 per student) (Table 3). At IUSD, the most expensive phase was the laboratory training (in-person workshop), representing 98% of the total cost. However, in this specific phase, although the delivery of the activity registered a representative cost (37%), the development of the activity was still demonstrated to be the costliest (63%) (Table 3). The human resources component was also the more expensive item, representing 51% of the total amount spent, followed by instructional materials and facilities costs with 27% and 22%, respectively (Table 3).

Table 3 Costs related to the IUSD adapted methodology, in USA, delivered in a hybrid teaching modality.

DISCUSSION

The COVID-19 pandemic significantly impacted education and drastically changed how dental schools function [21]. However, the effects of those urgent adaptations are still present nowadays because the difficulties presented allowed us to reinvent ourselves and maybe step out of our comfort zones by embracing new instructional practices and educational perspectives. The experiences described in the present paper certainly promoted a new standard for dental education quality, specifically for cariology teaching innovative approaches. They are useful and successful during the pandemic, but they will be appropriate and promising for other present and future situations.

Using gamification and other active learning tools showed that the teaching methods can be versatile and adaptable, providing more flexibility for educators and learners. Besides, in the present report, we identified areas where we can improve as educators. Many adaptations/innovations are still used (2023/2024), even in a complete in-person teaching modality. For example, FOUSP maintained the gamified content for the in-person laboratory activity (Fig. 9). A great involvement has been observed in those new groups of students and faculties after the pandemic, showing the sustainability of the implemented activity.

The self-directed gamified learning material provided gave the students greater autonomy over their learning experience. Furthermore, the different pathways that students used in the self-directed learning material were very important for the engagement of the students and for helping them to learn from their mistakes. They can return to the beginning of the game at any moment (to fail and restart), which allows students to experiment without fear and student engagement [22]. Positive results have been shown when online feedback is provided [23]. Reflective practice involves actively analyzing your experiences and actions to help yourself improve and develop.

Their critical thinking was stimulated since they were supposed to choose their pathways, and different answers could direct them to different pathways. Moreover, this material has a special part regarding decision-making. This inclusion was motivated since, in previous studies conducted by our research group [24, 25], one of the main difficulties of students regarding caries detection is to link that to the decision-making process. This innovative approach was an intriguing and differential manner of exploring that. It could not be coequally reproduced in the previous non-gamified techniques used.

A recent systematic review discussed the changeover aspects of medical education during the pandemic, highlighting the importance of sharing our different teaching experiences and analyzing our methods [26]. From that perspective, the main objective of this paper was to raise some relevant aspects of cariology teaching strategies performed during the pandemic and their relationship with economic outcomes. In the past, distance education resources were used just as support for face-to-face activities. Currently, the pandemic has increased their application [7]. There was a belief that online activities or distance learning could have a less positive effect than in-person education, but previous studies demonstrated this could not be true [27]. Facing our results, we can add that ICT can even be used when dental students' practical abilities involving caries detection and decision-making are in demand.

Thinking about predoctoral dental education, the student must acquire many practical skills that cannot be learned directly in the clinic. One of these practical abilities is appropriately detecting and assessing caries lesions to make an appropriate decision. Then, preclinical laboratory activities always seemed to be a good option. Caries detection is a topic that will be used in all disciplines as a basis of knowledge [28]. Due to that, the methods used to teach students must be well-designed [29].

Since 2009, a Brazilian institution (FOUSP) has proposed a teaching method for caries detection instruction as part of the IuSTC [13]. It incorporates active learning techniques, primarily promoting critical thinking and problem-solving skills. The original teaching method was effectively used in several universities (as part of the IuSTC-01 Trial). In 2020, due to the pandemic, some aspects had to be transformed to permit teaching students about caries detection without losing the quality of education since such competencies are very important for any professional in the current century [30].

The FOUSP and the IUSD schools maintained the original pre-pandemic IuSTC method basis but implemented particular solutions to the challenges of such a moment. The institutions created resources according to the moment they were experiencing, considering the local and students' characteristics. For example, in FOUSP, instead of having conventional distance online classes (passive learning), it was decided to include innovative educational resources, like self-directed learning and gamification. The option was chosen to engage students [26] and minimize concerns with the reduced interaction observed with students at that moment of the pandemic.

Indeed, many students did not turn on their cameras or microphones for several personal and technical reasons [31]. Some studies have shown, however, that the interaction among students and instructors tends to be better in informal channels than online platforms, for example [32]. Those aspects motivated the faculty members to innovate even in the more traditional stage of educational learning, the initial lecture, and create other less formal channels to interact with them, even the online format was needed due to the pandemic circumstances.

The complete structure of a game should be designed and computationally developed. Consequently, that process demanded significant time and effort from the teaching staff and directly impacted the final cost of the strategy. As observed in previous studies, human resources were the most expensive component for the development and delivery phases [33]. The staff used the available ICT to adjust to their imminent needs quickly. Then, the proposed adaptation was simple. It did not demand a significant investment in materials, supplies, or technical staff, concentrating the cost on delivering phases. The game's final devise may probably require much investment from the educational team.

At IUSD, different from the first example, the students could return earlier to the university for in-person laboratory activities. Therefore, the major concerns were related to the physical structure of the building, the people flow, and the safety protocols. The adaptations were made according to the capacity of the dental school's laboratories. A more approximate format from the original version could be reached since the first group of students. The ICT was mainly used for minimizing social contact in tutored activities, which is a differential when the IuSTC active-learning strategy was devised.

On the one hand, they gained access to extracted teeth to practice. On the other hand, they could not be exposed to in-pair discussion, another differential of the mentioned strategy. However, lecturers tried to minimize such impossibility by giving online feedback for possible doubts after comparing the students' answers to the lecturers' answers. The adapted organization was devised to allow students to carry out the activities while respecting the minimum distance between them and ensuring that there would be no direct interaction with either colleagues or tutors, use the appropriate protection equipment and avoid aerosols emission when using the air/water syringe. At this point, we cannot assure if these changes impact the student's learning, but certainly, the possible for the moment was done. These adaptations and the need to deliver the training several times for different groups had an important influence on the final cost because many resources were spent several times to comply with the 12 different groups in the same way.

Despite the sanitary conditions at that time, continuing to teach students with good quality during the pandemic was possible, even with some barriers and limitations. That was only possible because of the commitment of faculties and staff of educational institutions that worked to implement new teaching mechanisms and to use new tools for training the students. Certainly, such strategies are used to ensure minimal impact on education during the pandemic, which demands an investment from an institutional perspective. Given the creativity of the lecturers, this investment was not exorbitant. Considering, according to the Centers for Disease and Control Prevention, a patient with COVID-19 must invest $250, we can consider the investment of approximately $70-$80 acceptable when considering social resource allocation. Evidently, the institution was not who paid for cover medical expenses, but at a wider societal perspective of resource allocation. Investing in these innovative educational resources might compensate for those allocated to staff or students' absenteeism if adaptations had not been made.

We should highlight that these educational adaptations were created empirically and rapidly, given the urgent conditions imposed by the pandemic. Therefore, it was not worth catching up on some details that now we can improve more and more. The adaptations described represent a good starting point for stimulating the development of more realistic and engaging teaching strategies for dental education. They may also use improved tools, such as immersive applications or realistic games, which could be settled for teaching caries detection. Moreover, investigating the educational effects and economic feasibility of those new methods is important to understand their real cost-effectiveness since they represent an economic investment, as stated earlier in this paper.

CONCLUSIONS

The adaptations based on ICT permit the institutions to successfully proceed with their active methodologies, given the barriers imposed by the pandemic. The imposed challenge demanded creativity and a considerable university investment, but the benefits surpassed the pandemic. The experiences lived in that educational context brought valuable insights to elevate the quality of training in caries detection by using game-based elements and innovative ICT approaches that can be applied to our current teaching practices.

Abbreviations

FOUSP - School of Dentistry of the University of São Paulo

IUSD - Indiana University School of Dentistry

PPPs - Purchasing Power Parities

WHO - World Health Organization

IuSTC - Initiatives for undergraduate Students' Training in Cariology

Declarations

- **Ethics approval and consent to participate**

The multicentre study protocol was approved by the Ethics in Research Committee (CAAE 39632614.0.0000.0075). All participants provided informed consent to take part in the research. However, this paper does not comply with participant data, only the experience report.

- **Consent for publication**

The authors obtained explicit consent from the educational institutions involved in the present study and agreed to have the windups published in this journal.

- **Availability of data and materials**

The data presented in the study and also the materials used for the calculations will be accessible and available for review or further research upon request. Prof. Mariana Braga (email: mmbraga@usp.br) can be contacted in those cases in which data access is needed. In the end of the multicenter project (IuSTC-01) to which this report is nested in, all data, including those, will be available in the USP Open Data Repository.

- **Competing interests**

No commercial conflict of interest is present on the part of the authors. Some authors devised the adapted strategies described as an answer to deals imposed by the pandemic. Prof. Mariana M. Braga is a Senior Editor at BMC Oral Health, but she will not be aware of the editorial process related to this publication.

- **Funding**

The study acknowledges the financial support from CNPq (PIBIC scholarships and PVE – Process 400736/2014-4) and PrInt USP/CAPES (The Institutional Program for Internationalization – PrInt – University of São Paulo. PrInt is a program idealized by CAPES, Coordination for the Improvement of Higher Education Personnel, the Brazilian Federal Agency for Improving Higher Education Staff, that aims to promote internationalization strategies within Brazilian universities. Internationalization and contributed to this research (Process number: 8882.376962/2019-01). MMB, DPR, and FMM also receive Productivity Research Scholarships from CNPq.

- **Authors' contributions**

MMB coordinates the IuSTC and conceptualizes the research design, formulating the study's objectives and performing the cost analysis. The implementation of the strategies reported was a collective effort from Brazil (MEV, GMM, KHN, LFC, DPR, FMM, MMB) and the United States (JSLR, AS, MA, NR). Those were responsible for planning and delivering the teaching strategies in their centers. TGO, GO, and JDYV organized cost valuations related to the teaching activities. This last one also wrote the first draft of the manuscript. All authors read and approved the final manuscript before submission.

- **Acknowledgements**

The authors would like to thank members of the IuSTC group who participated in devising and implementing these training activities in both universities during the pandemic.

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Tables

Table 1 – Costs related to the first adapted methodology at FOUSP, in Brazil, and delivered completely online.

FOUSP	SEL-DIRECTED GAME				VIRTUAL LABORATORY				CLOSING SESSION
PHASES	**ASSUMPTIONS**	**TYPE OF RESOURCE**	**($) COST**	**($) COST**	**ASSUMPTIONS**	**TYPE OF RESOURCE**	**($) COST**	**($) COST**	**ASSUMPTIONS**
DEVELOPMENT **$4897.11** **(96%)**	Teaching staff time in elaborating videos and instructional material on digital platforms were estimated	PERSONNEL	2369.19	**2443.88** **(97%)**	For being a completely new method of teaching, tutors' calibration was necessary. It was (performed on-line)	PERSONNEL	2450.63	**2453.23** **(96%)**	N/A
		MATERIAL	74.61			MATERIAL	2.60		
		FACILITIES	0.00			FACILITIES	0.00		
DELIVER **$ 125.81** **(3%)**	No cost was registered for the institution (Asynchronous activity)	PERSONNEL	0.00	**0.00** **(0%)**	In smaller discussions groups. An on-line quiz was performed with students	PERSONNEL	108.58	**108.70** **(4%)**	The lecturer was responsible for the on-line closing session, where it was performed a final gamified quiz competition with the students.
		MATERIAL	0.00			MATERIAL	0.12		
		FACILITIES	0.00			FACILITIES	0.00		
ON-LINE SUPPORT **$ 68.27** **(1%)**	A professor was available on-line to provide feedback and solve students' problems	PERSONNEL	68.15	**68.27** **(3%)**	N/A	PERSONNEL		**0.00** **(0%)**	N/A
		MATERIAL	0.12			MATERIAL			
		FACILITIES	0.00			FACILITIES			
TOTAL COST: **$ 5091 (100%)**		**TOTAL**	**($) 2512.07 (49%)**			**TOTAL**	**($) 2561.93 (50%)**		

Table 2- Costs related to the FOUSP hybrid subsequent offerings, delivered partially on-line and partially in-person.

FOUSP	SEL-DIRECTED GAME				VIRTUAL LABORATORY WITH IMAGES				WORKSHOP LAB T
PHASES	ASSUMPTIONS	TYPE OF RESOURCE	($) COST	($) COST	ASSUMPTIONS	TYPE OF RESOURCE	($) COST	($) COST	ASSUMPTIONS
DEVELOPMENT $5152.20 (91%)	Teaching staff time in elaborating videos and instructional material on digital platforms were estimated	PERSONNEL	2369.19	2443.81 (94%)	Tutors' training and calibration was performed on-line.	PERSONNEL	2450.63	2453.23 (95%)	Teeth are prepared and cleaned. Evaluation sheets are elaborated. Tutors are trained/calibrated.
		MATERIAL	74.61			MATERIAL	2.60		
		FACILITIES	0.00			FACILITIES	0.00		
DELIVER $ 449.98 (8%)	Considering the costs of the use of an informatics lab structure provided by the university for the students' on-line activities.	PERSONNEL	65.47	85.82 (3%)	In smaller discussions groups (break-out rooms) an on-line quiz was performed with the students.	PERSONNEL	125.61	108.70 (5%)	Carried out in a pre-clinical lab equipped with dental lamps and air/water syringes. Students simulate all clinical conditions and perform teeth assessments is small discussion groups with tutors.
		MATERIAL	0.00			MATERIAL	0.46		
		FACILITIES	20.35			FACILITIES	0.00		
ON-LINE SUPPORT $ 68.27 (1%)	A professor was available on-line to provide feedback and solve students' problems	PERSONNEL	68.15	68.27 (3%)	N/A	PERSONNEL		0.00 (0%)	N/A
		MATERIAL	0.12			MATERIAL			
		FACILITIES	0.00			FACILITIES			
TOTAL COST: $ 5670.56 (100%)		TOTAL	($) 2597.90 (46%)			TOTAL	($) 2579.30 (45%)		

Table 3 - Costs related to the IUSD adapted methodology, in USA, delivered in a hybrid teaching modality.

IUSD	DIDACTIC LECTURE				WORKSHOP LAB TRAINING WITH IMAGES AND TEETH			
PHASES	ASSUMPTIONS	TYPE OF RESOURCE	($) COST	($) COST	ASSUMPTIONS	TYPE OF RESOURCE	($)COST	($) COST
DEVELOPMENT $5100 (62%)	It was already prepared , so no cost was considered	PERSONNEL	0.00	0.00 (0%)	Selection of teeth and development of the evaluation sheets exam keys and individual teeth assessment kits students.	PERSONNEL	2496.19	5100.47 (63%)
		MATERIAL	0.00			MATERIAL	1057.09	
		FACILITIES	0.00			FACILITIES	1547.19	
DELIVER $3109 (38%)	The use of educational platforms provided by the university and lecturer and computer technician´s time was considered	PERSONNEL	154.14	155.43 (100%)	The in-person activity was performed in two phases (discussion with images and assessment of teeth`s models)	PERSONNEL	1565.36	2953.35 (37%)
		MATERIAL	0.00			MATERIAL	1146.97	
		FACILITIES	1.29			FACILITIES	241.03	
ON-LINE SUPPORT $0 (0%)	N/A	PERSONNEL	0.00	0.00 (0%)	N/A	PERSONNEL	0.00	0.00 (0%)
		MATERIAL	0.00			MATERIAL	0.00	
		FACILITIES	0.00			FACILITIES	0.00	
TOTAL COST: $8209 (100%)		TOTAL	($) 155.43 (2%)			TOTAL	($) 8053.83 (98 %)	

Figures

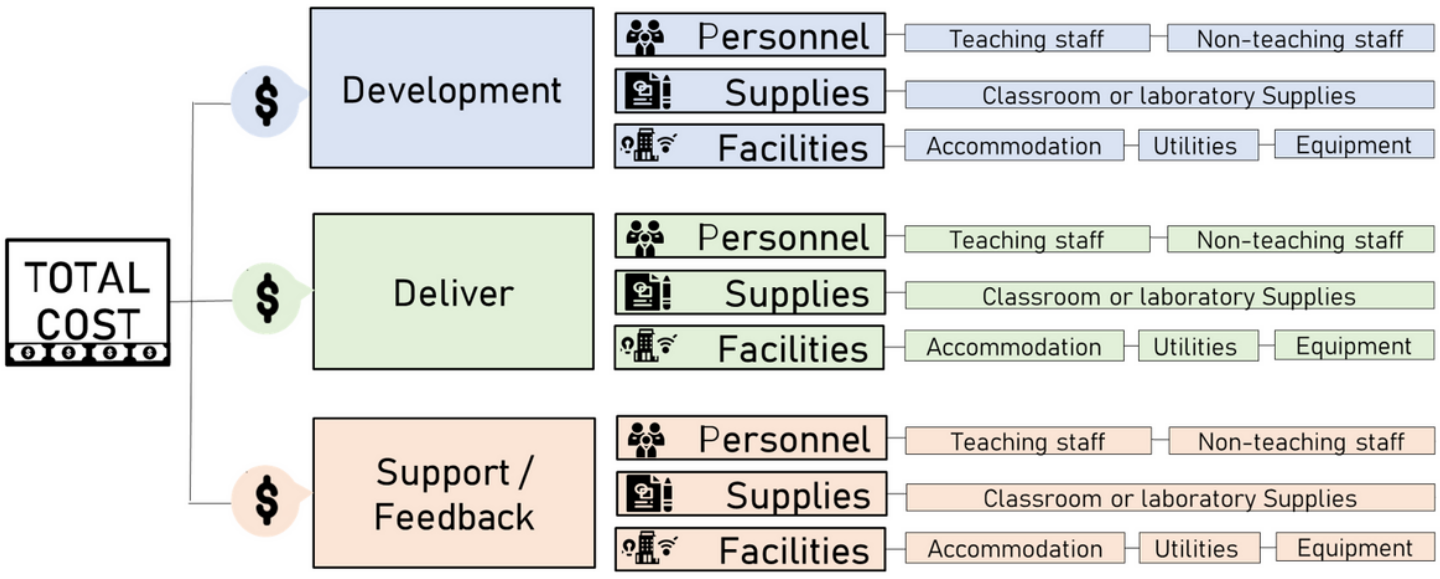

Figure 1

Final cost composition, considering the development and delivering phases of educational strategies.

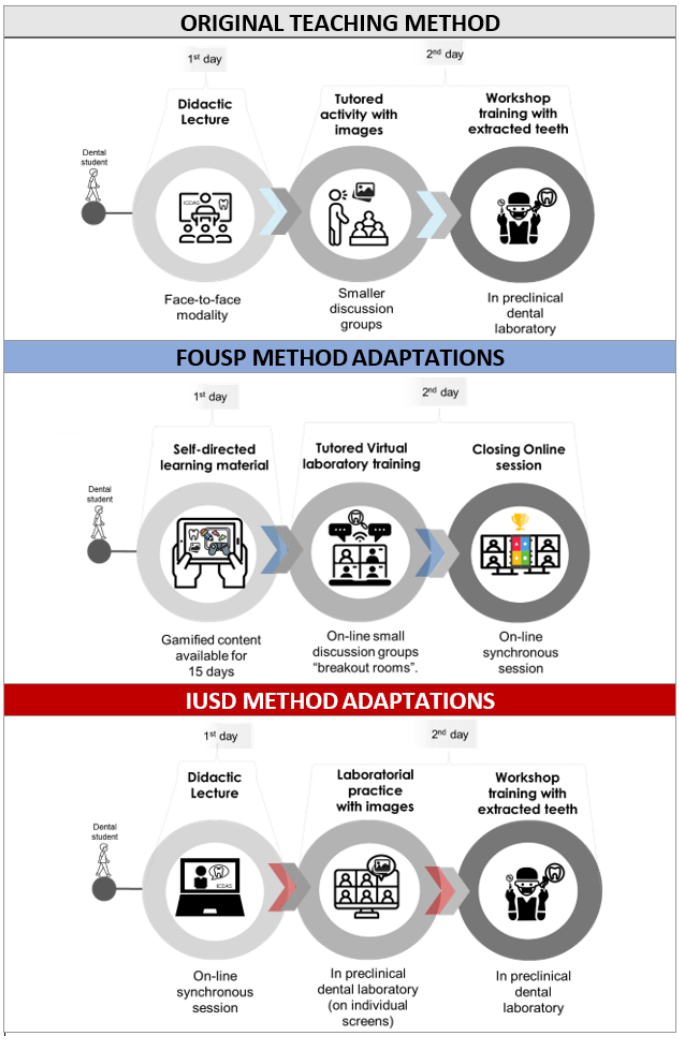

Figure 2

Comparison of the pandemic adapted methodologies to the IuSTC original teaching strategy (pre-pandemic version).

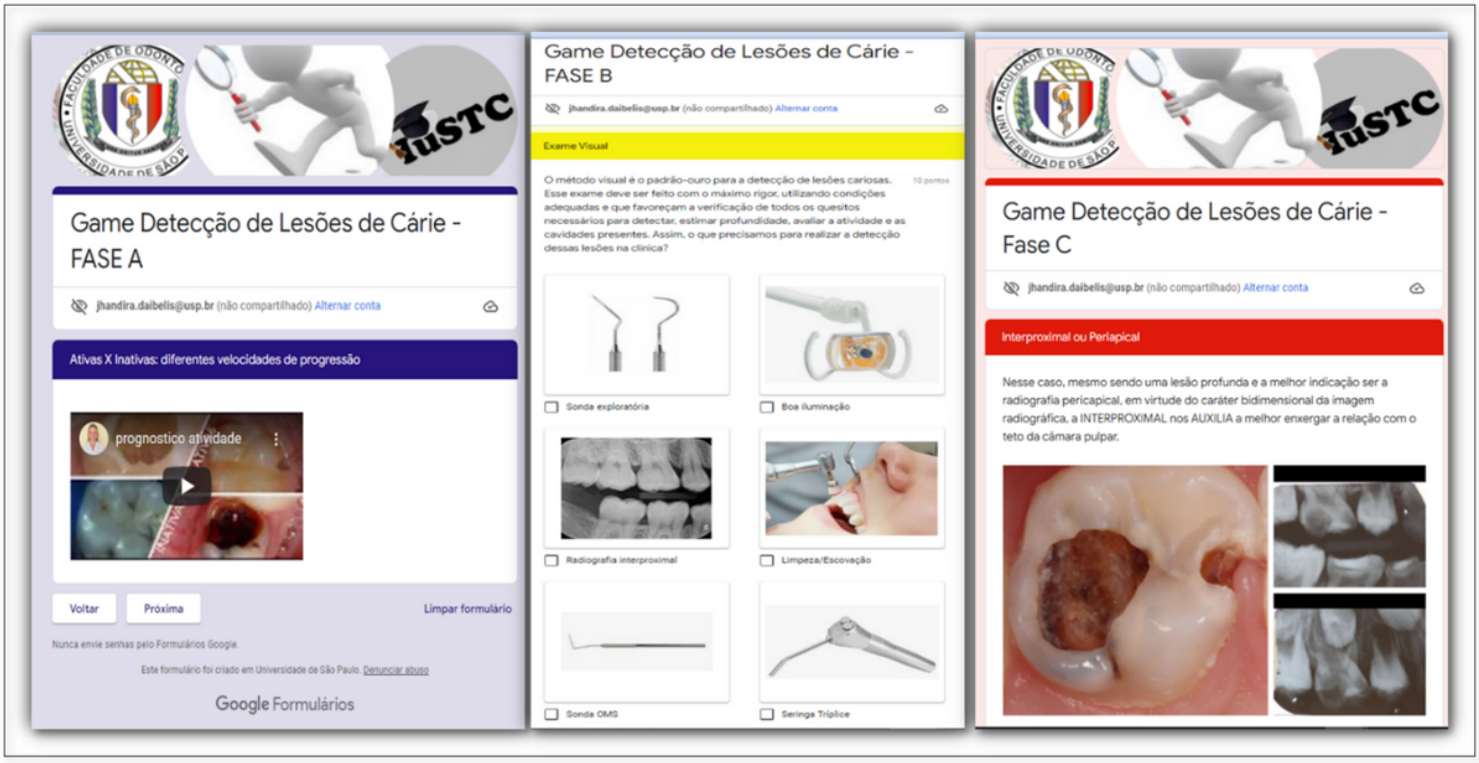

Figure 3

Self-directed game using learning phases that stimulated students to interact with the caries detection contents.

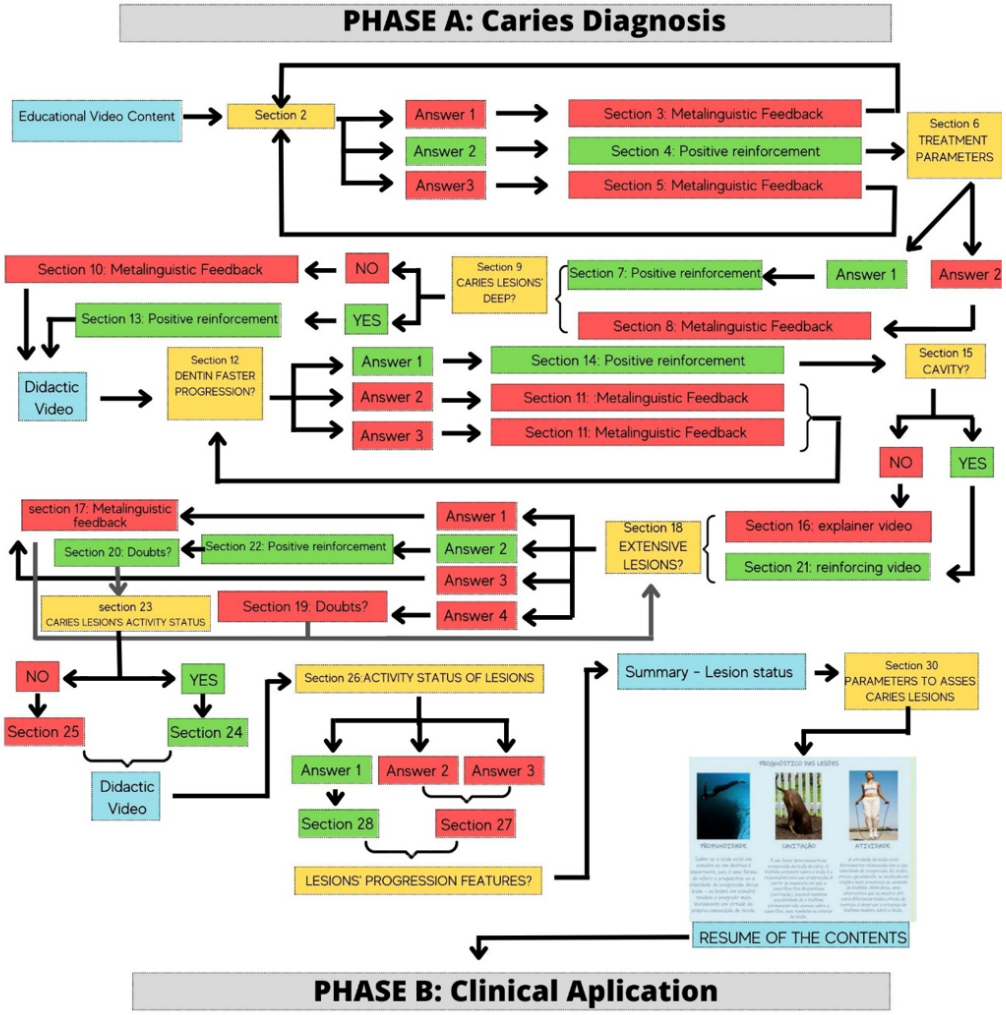

Figure 4

Flowchart represents the different pathways followed according to students' answers, allowing immediate feedback.

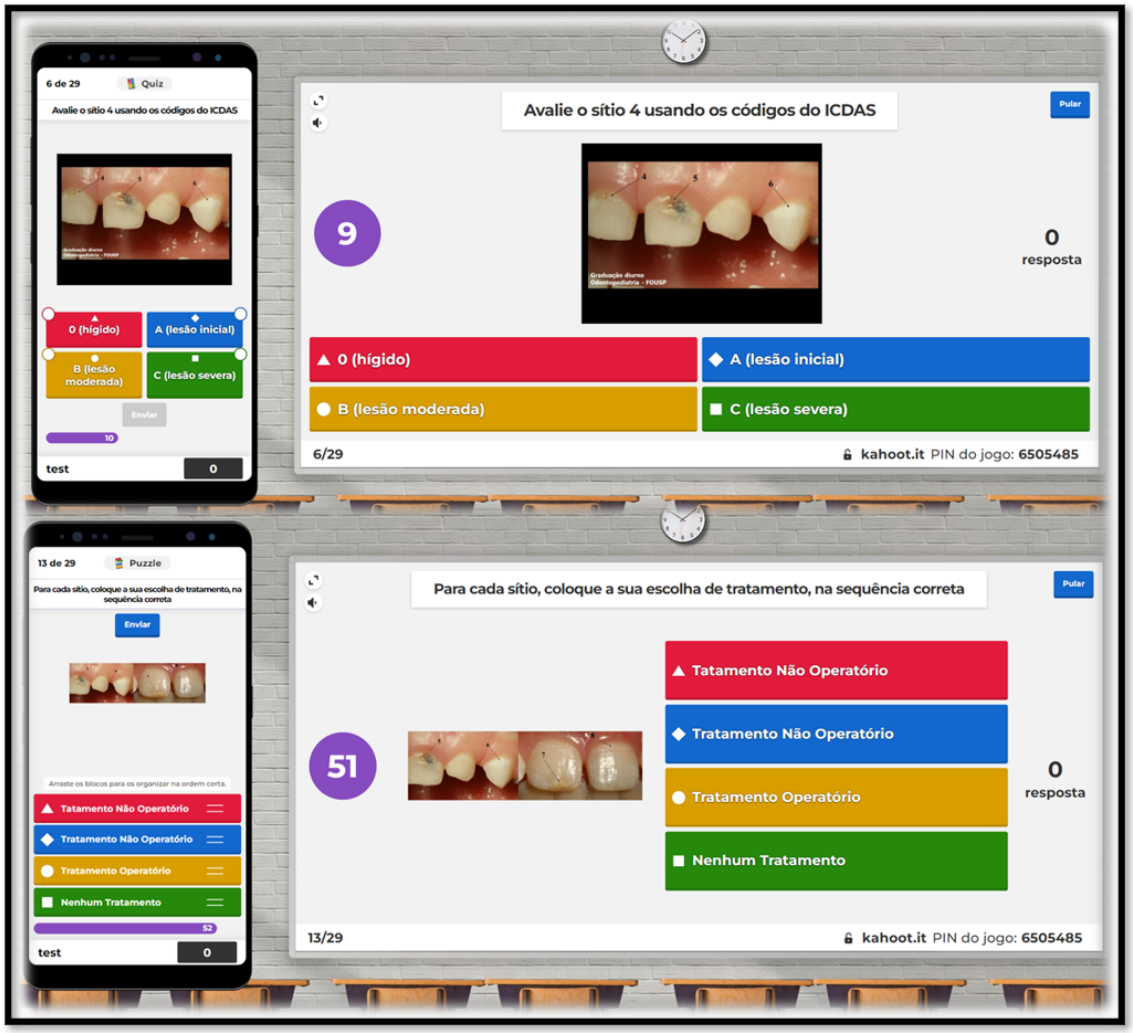

Figure 5

Different types of questions used for summing up the main lessons learned by students (kahoot).

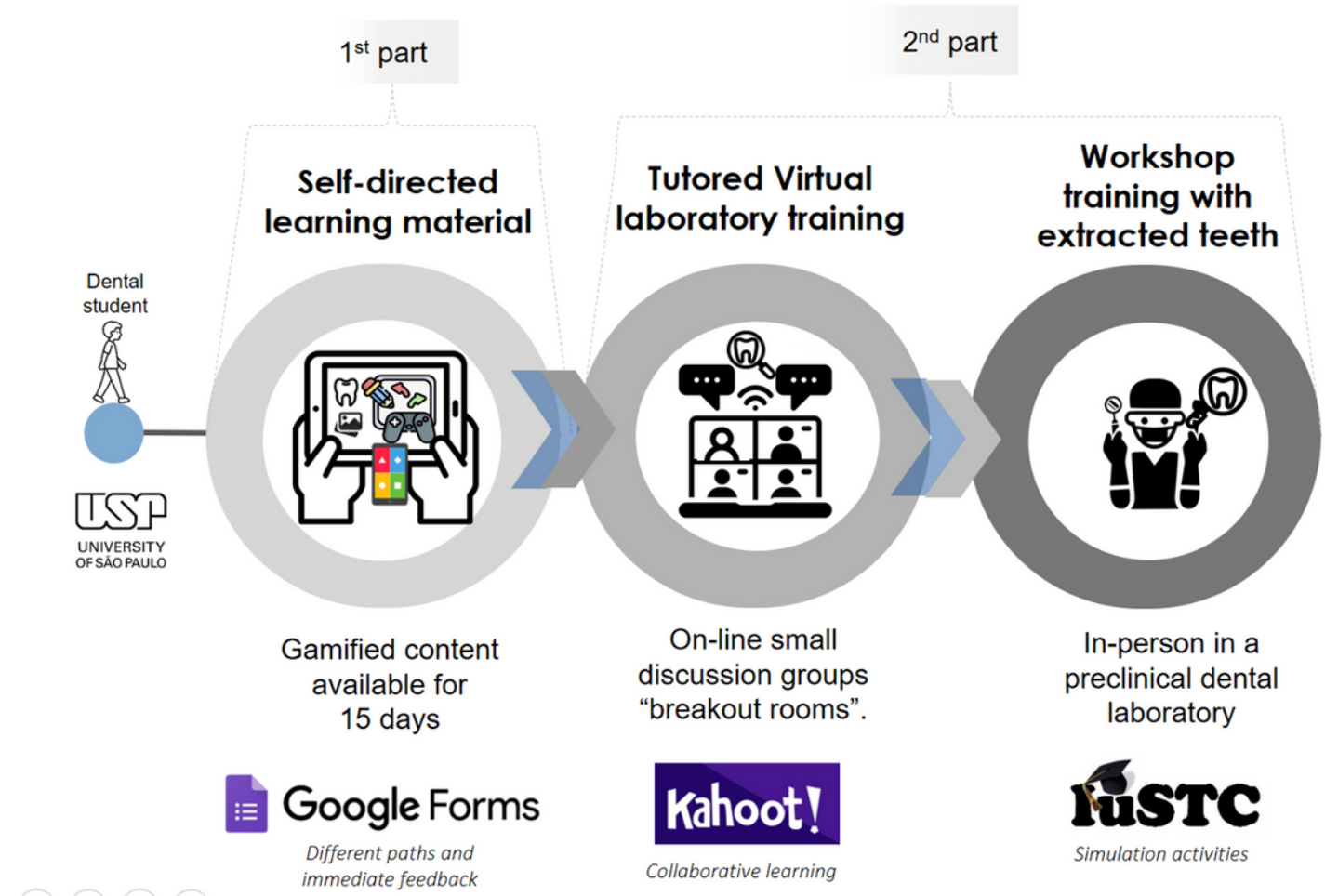

Figure 6

FOUSP Hybrid adaptation for the classes that were able to receive in-person training

Figure 7

The image training was performed in the preclinical laboratories with fixed workstations.

Figure 8

Models of teeth prepared for the laboratorial training. After each evaluation, students must disinfect them.

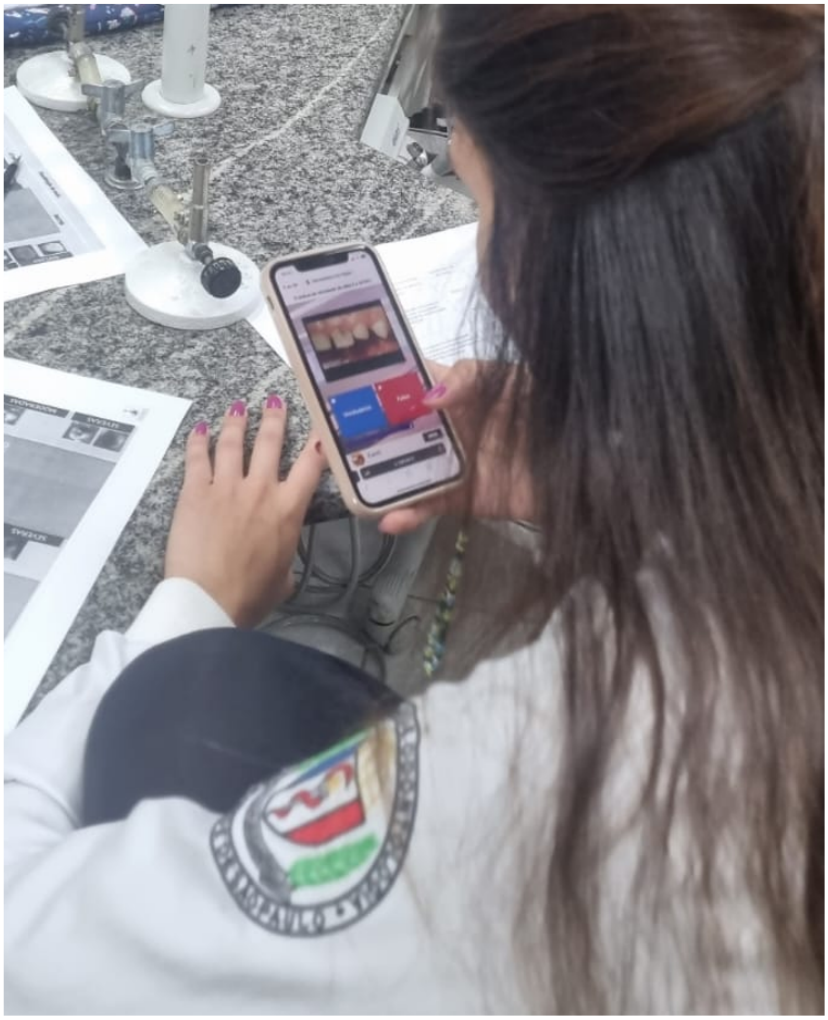

Figure 9

Students in 2023 (after pandemic) using the gamified contents in the laboratory workshop training activity.