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Creation and evaluation of an educational escape room for preclinical training on 3D printing in dentistry

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Abstract

Introduction: The benefit of pedagogical escape rooms for dental students' stimulation, interest and knowledge strengthening has been suggested by several studies. However, in previous studies, only a few students were evaluated. This study aims to confirm the purpose of this innovative pedagogical tool in terms of learning consolidation and team building from students' perceptions. We directly incorporated an educational escape game into the fundamental academic formation as a practical-work course for fifth-year dental students.

Materials and Methods: The present escape game focused on 3D printing, whose implementation fit the different steps of an escape game well. This study was conducted in March 2022. All fifth-year dental students ($n=212$) were divided into 5–6 student groups to match the conditions of an escape game. Before entering the room, each student had to complete a cross-sectional knowledge true/false test of 8 questions to assess their general level. Additionally, an 18-question appreciation survey was completed when leaving the room.

Results: The students perceived the 3D-printing escape game to be relevant and especially expressed the benefit of being part of a team to exchange and build knowledge. These results suggest knowledge strengthening. The instructional benefit of this process seemed to exceed its mere fun and appealing aspect.

Conclusion: Our results with a large number of students showed that, from the students' perception, the educational escape game significantly improved knowledge and team-building. It created a supportive learning environment and increased students' motivation. It can provide a fun and effective way to diversify instruction.

KEYWORDS

3D printing, dentistry, educational game, escape room, serious gaming, teamwork

1 | INTRODUCTION

Times are changing, as are ways of teaching and learning. With the inclusion of e-learning tools or gaming-based learning, medical education methodologies are continuously evolving. In particular, the benefit of pedagogical escape games on dental students' stimulation and knowledge strengthening has been suggested by several studies.¹⁻³ These kinds of games based on active teaching methods are very popular among students and appear to be excellent tools for training and evaluation.⁴ Active teaching is a learner-centred learning method involving active participation, whether through reading, writing, discussion in class, or serious games. Most of the published studies on active learning are done at the medical school level and relate to the effectiveness of this method.⁵ An escape game is defined as a game in which a team of players discovers clues, solves puzzles and accomplishes tasks in one or more rooms to achieve a specific goal (usually escaping the locked gaming area) in a limited amount of time. The game master, a person who conventionally stands outside the gaming room, follows the players' progression through a camera and may provide hints and advice if the team is very late.

Case-based learning and team-based learning, which are part of active learning, are two teaching methods used in escape games that have shown excellent results in medical studies. Case-based learning involves contextualization of the basics through clinical cases, for example, so that they can be learned more effectively.⁶ This motivates students and teachers. In the same way, team-based learning stimulates the development of critical minds.⁷ By using processes such as teams and clinical cases, escape games seem to be an effective way to improve student learning.

Pedagogical escape games have shown benefits in several medical fields, yet only two have been reported in dentistry. Although promising, these studies reported only proofs of concept, and few students were included in each,^{8,9} which could lead to selection bias.

Dentistry, as a surgical specialty, requires considerable equipment manipulation and manual training. It is therefore particularly adapted for learning through an escape game, although the current educational games for dental students are often quizzes or board games.¹⁰⁻¹²

This study aimed to confirm the purpose of this innovative pedagogical tool in terms of learning consolidation and team building. We directly incorporated an escape game into the fundamental academic formation as a practical-work course for fifth-year dental students, so that a large number of participants could be evaluated and significant results obtained.

The present escape game focuses on 3D printing. In addition to knowledge, the 3D printing workflow involves many devices that must be manipulated in a precise sequence. It is therefore wholly compatible with the different stages and puzzles of an escape game. The aim was to provide students with an overview of the 3D printing workflow, from the choice of resin and 3D printer, manipulating some devices, to the postprocessing and legislation of the printed medical device.

2 | MATERIALS AND METHODS

This study was conducted in April 2022, after review and approval. The escape game was directly incorporated into the fundamental academic formation as a practical-work course for fifth-year students ($n=212$) in the biomaterials discipline. Digital dentistry is regularly mentioned in every discipline, but mostly as a tool to achieve a final therapeutic result. The different workflows, protocols, devices and machine manipulations are discussed in the biomaterials discipline. The students were divided into 5–6 student groups to match the real conditions of an escape game. The escape game had to be completed within a maximum of 30 min. The teacher supervising the session played the role of the game master. He followed the team through the escape game and was able to give clues if the team was completely stuck. The goal remained for each student to complete the whole game and to be able to manipulate the 3D-printing workflow.

Each significant mistake by a team led to an additional 3-min penalty with an immediate explanation of the mistake by the game master. The team with the best time won a prize. The theoretical lesson was posted online as e-learning 2 weeks earlier and had to be read and assimilated by the students before participating in the game. The total budget for the entire project was ~\$5000 and included the mechanisms (locks, computers, boxes, beakers, solutions, etc., ~\$3200) and the set (~\$1800).

2.1 | Scenario

Before entering the room, a brief video describing the scenario and main instructions was presented. In this game, the students arrived at the clinic at 8 am to start their day, consulted their planning and determined that they had forgotten an intervention planned in the operating room at 8:30 am: 3 implant placements. For this intervention, a surgical guide was needed. Luckily, this guide had already been designed a week earlier by a teacher. The students entered the laboratory (the escape room) and had 30 min to 3D print the surgical guide and exit the room.

2.2 | The four stages of the escape game

2.2.1 | Stage 1 – Choice of the 3D printer

Material

Station 1 included 3 3D printers (one stereolithography (SLA), one digital light processing (DLP) and one fused deposition modelling (FDM)) with a 3-number code on each, 3 laminated papers with the letters 'SLA', 'DLP' and 'FDM', a box with a lock and a 3-piece torn table to make each letter match a number (Figure 1A).

Sequence

The students entered the room and faced Stage 1. On the table was the following instruction: 'Match the 3D printer to the correct

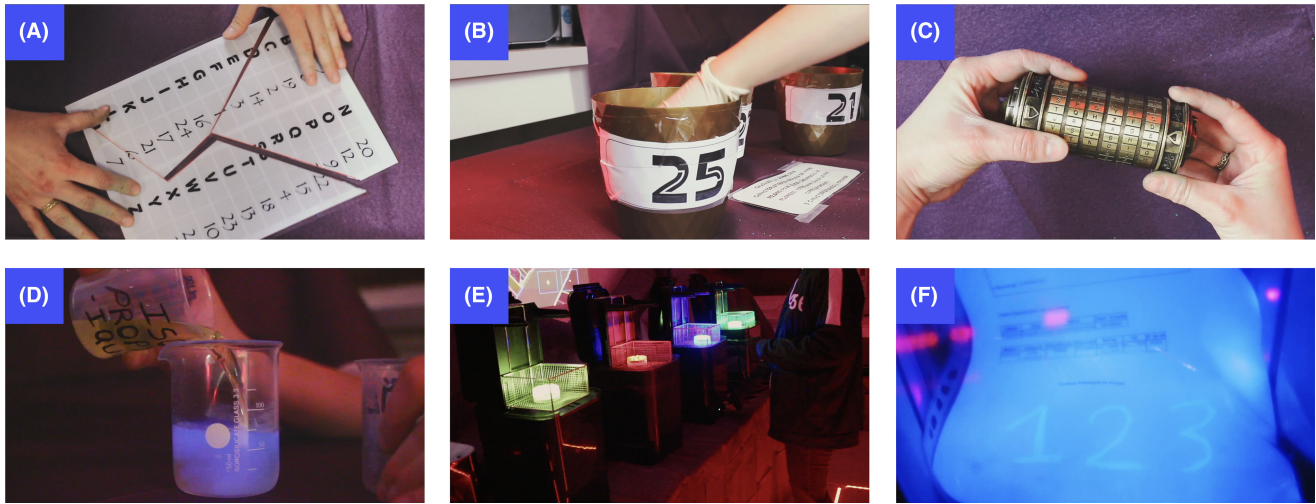


FIGURE 1 Pictures of stations 1, 2, 3 and 4. (A) The 3 pieces of the table put together, (B) dipping a hand into the correct jar, (C) opening the cryptex with a code, (D) mixing the correct solutions to obtain a fluorescent blue solution, (E) 4 washing machines with pool LEDs in the baskets, (F) invisible ink appearing under the UV light on the certificate.

technology'. One piece of the torn table was clearly visible on the station and encouraged students to find the 2 other pieces hidden on the station. Once assembled, the table allowed the students to match a letter to each number (Figure 1A).

The 3 matched number codes on the 3D printers were 465 → SLA, 269 → DLP and 327 → FDM. This allowed the students to match each printer to the correct technology.

If the previous step was completed, the game master gave the team the locked box with the following question: 'Which printer should you choose to print your surgical guide?' The guide had to be printed quickly, but most of all, it had to be precise. Both SLA and DLP were acceptable answers. However, because only one code could be entered into the locker, the game master gave the team an enigma to lead them to the answer SLA. The code for the right answer (SLA → 465) opened the box. Inside was a cryptex and an instruction: 'Head toward Stage 2'.

2.2.2 | Stage 2 – Choice of the resin

Material

Station 2 included 3 jars with numbers filled with magic sand, twelve laminated papers with resin characteristics associated with different numbers, a laminated paper that read 'SURGICAL GUIDE' with 6 letters highlighted in red and the cryptex earned at the previous station (Figure 1C).

Sequence

When students arrived at Station 2, they faced the 3 jars and an instruction on the table: 'Choose the correct 5 characteristics of your resin for the surgical guide and add the associated numbers. Then, dip your hand in the correct jar'. Out of 12 characteristics, 5 had to be chosen. The sum of the correct characteristics was 25.

When the students dipped their hands in the right jar (Figure 1B), they found the 'SURGICAL GUIDE' paper. The 6 highlighted letters U-R-I-A-G-E were the code to open the cryptex.

In the cryptex was a USB stick and the instruction, 'Plug me in on Station 3'.

2.2.3 | Stage 3 – Design and impression

Material

Station 3 included a computer, the USB stick earned at the previous station and the printed surgical guide.

Sequence

The students joined Station 3 with the USB stick from Station 2. They plugged it into the computer and opened the file 'to print'. In this file, there was a first quiz on 3D printing, with 5 files representing 5 different answers. The team had to click on the right file/answer to open a new file with a new quiz and 5 new answers. The team navigated through the files and, if all the answers were correct, found a video in the last file. This 3-minute video explained how to design and place the surgical guide in the slicer and then start the printing.

Once the video was over, the game master gave the team the real surgical guide, as if it had just been printed. The students could then move on to Station 4.

2.2.4 | Stage 4 – Postprocessing

Material

Station 4 included 8 beakers filled with coloured solutions, 1 empty beaker, 4 FormWash (FormLabs) with an LED pool light within each

one (Figure 1E), 5 laminated certificates of medical devices inside a transparent box with a locker and a FormCure (FormLabs).

Sequence

The students arrived at Station 4 and found 8 beakers filled with coloured solutions and the following instruction: 'Mix together the two correct solutions to create the solvent that will remove the unpolymerized resin'. The two beakers to mix were labelled 'Alcohol' and 'Isopropyl' and contained yellow solutions. When the two yellow solutions came into contact in the empty beaker, the solution turned fluorescent blue (Figure 1D). Above the wash machine, this instruction was as follows: 'Be careful to dip the surgical guide in the correct alcohol bath to remove the unpolymerized resin'. The correct bath was the one with the blue LED (the answer was given by the colour obtained when mixing the beakers). Once the wash machine had been turned on (with the help of the game master), the guide slowly drowned in the alcohol bath. The LED lit the whole bath and revealed a code on the side of the tray. If the wrong beakers were mixed, another colour appeared, the guide was dipped in the wrong bath and no code became visible. The code opened the transparent box. Inside it were 5 certificates of medical devices, 4 with mistakes and 1 correct. As indicated, the students put the correct certificate inside the curing machine and turned on the polymerization. The UV light made the last code appear (Figure 1F), which was written with invisible ink. This code allowed the students to escape the room.

A summary film of the different escape game stations can be obtained by using the QR code in Figure 2. Detailed stage sequences are also available in the supporting information section (Figures S1–S4).

2.3 | Data collection and analysis

Before entering the room, each student had to complete a cross-sectional knowledge true/false test of 8 questions (Table 1). When leaving the room, an 18-question appreciation survey had to be filled out, focusing on students' appreciation and personalities and based on a Likert scale (Table 2). For each proposal, five possibilities were given: totally agree, agree, neutral, disagree and strongly disagree. The study data were collected in April 2022.



FIGURE 2 QR code leading to the YouTube video of the entire detailed escape game.

TABLE 1 True/False test questions.

1	3D printing is a technology that can also be designated as 'milling' (False)
2	The SLA (stereolithography) technology uses fused filament (False)
3	A printed implant surgical guide is most likely fabricated in a soft resin in order to facilitate the insertion into the teeth (False)
4	The slicer is used to postprocess the printed elements (False)
5	A 0° angulation of the printed elements is one of the angulations that guarantees the best results for printing precision in stereolithography (True)
6	Isopropyl alcohol is the solvent most commonly used to remove the nonpolymerized resin surrounding the printed elements (True)
7	As the surgical guide spends little time in the oral environment, it does not need to be systematically postpolymerized in the adequate device (False)
8	The dental surgeon degree in itself allows dental prostheses to be fabricated in the dental office (False)

TABLE 2 Appreciation survey Likert scale, 5 answers possible (totally agree, agree, neutral, disagree and strongly disagree).

1	I usually appreciate playing games (video games, board games...)
2	I consider myself a serious student (I'm always prepared for tests, well-focused...)
3	I find it relevant to associate different kinds of learning methods to assimilate knowledge (e-learning, games, class-led instruction...)
4	Being part of a team helps me build new knowledge
5	I consider myself an anxious person
6	I feel capable of using my knowledge in a stressful situation
7	The stress induced by the escape game reproduces the stress I feel in clinic
8	I found the escape game to be a good exercise for learning how to deal with stress
9	I found the escape game relevant to learn new knowledge about 3D printing
10	I found the escape game relevant to consolidate and revise my knowledge about 3D printing
11	I found the escape game hard to complete
12	I understand the 3D-printing workflow better after participating in the escape game
13	The escape game made me understand the sequence of 3D printing step by step more easily than my usual lessons
14	Discussions and deliberations with my team helped me strengthen my knowledge
15	Being part of a competition against other groups motivated me to complete the escape game as quickly as possible
16	The 'game' aspect of the escape game distracted me from the learning purpose
17	I would like to participate in another escape game on another subject
18	After this escape game, it feels easier to use 3D printing in a dental practice

A descriptive analysis of the answers was first completed for the test and the appreciation survey. The results were expressed as percentages (and 95% confidence intervals) or means (and standard deviations [SDs]) when appropriate.

The association between the test results and the students' responses to the appreciation survey was studied. The appreciation survey assessed both the students' appreciation and their personality traits. Satisfaction was divided into four aspects: global satisfaction (questions 9, 10, 13 and 17), learning experience (questions 8, 12 and 18), socializing experience (questions 4 and 14) and difficulty (question 11). Personality traits were anxiety (question 5), seriousness (questions 2 and 16) and playfulness (questions 1, 3 and 15). We estimated correlation coefficients between these dimensions and developed radargrams to explain the test results and global satisfaction according to these features. In these radargrams, we compared the students of the lower interquartile to those of the upper interquartile (for test results and global satisfaction).

The statistics of the test results and appreciation survey were based on the 212 students who completed the escape game. To keep the answers anonymous, students were asked to complete the tests with their initials. Hence, out of 212 students, only 90 tests were paired with the appreciation survey for the other analyses.

3 | RESULTS

3.1 | Assessment of the initial knowledge level

A total of 212 students in 38 groups participated in the escape room. The mean time to escape was 17 min and 18 s (± 3.04 min), and the fastest group escaped in 10 min and 46 s.

The percentage of correct answers on the test was 82.1% ($\pm 9\%$) (Table 3). 24.4% of the students gave 100% correct answers.

3.2 | Student satisfaction

3.2.1 | Pertinence

A total of 199 students completed the satisfaction survey. The results are shown in Table 4. The 212 students were asked to mark their questionnaires with their initials, but no teacher checked that it had been done correctly. Some questionnaires went missing, some others did not present initials, and on the other hand, some initials were the same and could not be differentiated. We were only able to match 90 questionnaires out of the 199. We paired the answers to the test with the appreciation questionnaire to try to identify trends between the improvement in learning and the personalities of the students.

Students appreciated the games in general with a mean (SD) of 4.6 (± 1.3) and found it relevant to associate different ways of learning (including games) to assimilate knowledge (4.7 [± 1.4]). Furthermore, for most of the students, the game aspect did not distract from the learning purpose (3.1 [± 0.2]). The students who felt distracted still found the escape game to be relevant to learning new knowledge and even more relevant to consolidating and revising their knowledge. After participating, the students understood the 3D-printing workflow better (4.3 [± 1.0]), even better than with the usual lessons (4.3 [± 1.0]). Manipulating all the steps of the workflow through the escape game helped the students feel more ready to implement 3D printing in their future dental practice (4.0 [± 0.8]). They wanted to participate in another escape game with other subjects (4.6 [± 1.3]).

TABLE 3 True/False test results (N = 212).

		Test correct answers n = 212
1	3D printing is a technology that can also be designated as 'milling' (False)	85.4%
2	The SLA (stereolithography) technology uses fused filament (False)	81.1%
3	A printed implant surgical guide is most likely fabricated in a soft resin in order to facilitate insertion into the teeth (False)	65.7%
4	The slicer is used to postprocess the printed elements (False)	75.4%
5	A 0° angulation of the printed elements is one of the angulations that guarantees the best results for printing precision in stereolithography (True)	77.8%
6	Isopropyl alcohol is the solvent most commonly used to remove the nonpolymerized resin surrounding the printed elements (True)	87.6%
7	As the surgical guide spends little time in the oral environment, it does not need to be systematically postpolymerized in the adequate device (False)	94.8%
8	The dental surgeon degree in itself allows dental prostheses to be fabricated in the dental office (False)	89.2%
Total		82.1%

TABLE 4 Escape game perception scale results (N = 199).

	Mean (SD)	Strongly disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Strongly agree (%)	Answer	No answer
I usually appreciate playing games (video games, board games...)	4.5 (1.3)	1.0	1.5	7.1	23.9	66.5	197	2
I consider myself a serious student (I'm always prepared for tests, well-focused...)	3.6 (0.7)	2.1	8.7	26.2	50.3	12.8	195	4
I find it relevant to associate different kinds of learning methods to assimilate knowledge (e-learning, games, class-led instruction...)	4.7 (1.4)	0.0	0.5	2.1	23.6	73.8	195	4
Being part of a team helps me build new knowledge	4.2 (1.0)	0.5	5.6	7.7	32.8	51.3	195	4
I consider myself an anxious person	3.3 (0.4)	12.1	13.6	24.7	26.8	22.7	198	1
I feel capable of using my knowledge in a stressful situation	3.3 (0.4)	3.6	22.4	26.0	35.2	12.8	196	3
The stress induced by the escape game reproduces the stress I feel in clinic	2.6 (0.3)	20.6	27.3	24.2	22.7	5.2	194	5
I found the escape game to be a good exercise for learning how to deal with stress	3.7 (0.6)	2.6	9.5	24.9	41.8	21.2	189	10
I found the escape game relevant to learn new knowledge about 3D printing	4.6 (1.3)	0.5	1.5	5.0	25.6	67.3	199	
I found the escape game relevant to consolidate and revise my knowledge about 3D printing	4.6 (1.3)	0.0	0.5	2.0	31.2	66.3	199	0
I found the escape game hard to complete	1.8 (0.3)	38.9	43.9	14.1	2.0	1.0	198	1
I understand the 3D-printing workflow better after participating in the escape game	4.3 (1.0)	0.0	0.5	9.1	47.5	42.9	198	1
The escape game made me understand the sequence of 3D printing step by step more easily than my usual lessons	4.3 (1.0)	0.5	1.1	10.4	39.6	47.8	182	17
Discussions and deliberations with my team helped me strengthen my knowledge	4.2 (0.9)	1.5	2.6	10.7	49.0	36.2	196	3
Being part of a competition against other groups motivated me to complete the escape game as quickly as possible	3.9 (0.8)	6.1	9.6	13.1	28.3	42.9	198	1
The 'game' aspect of the escape game distracted me from the learning purpose	1.9 (0.2)	41.5	38.3	12.8	4.3	3.2	188	11
I would like to participate in another escape game on another subject	4.6 (1.3)	0.5	1.6	5.2	25.7	67.0	191	8
After this escape game, it feels easier to use 3D-printing in a dental practice	4.0 (0.8)	2.6	4.2	15.3	41.8	36.0	189	10

3.2.2 | Stress management

A total of 49.5% of the students considered themselves anxious persons. Moreover, 26% did not feel able to use their knowledge in a stressful situation. With a mean (SD) of 3.7 (± 0.6) out of 5 on the Likert scale, students agreed that the escape game was a good exercise to learn how to deal with stress, even though it did not reproduce the stress felt in the clinic ($2.6 [\pm 0.3]$).

3.2.3 | Team

With a mean of 4.2 (± 1.0), the students felt that being part of a team helped them build and strengthen new knowledge, especially through discussion and deliberation ($4.2 [\pm 0.9]$). Being part of a competition motivated the students to complete the escape game as quickly as possible ($3.9 [\pm 0.8]$).

3.2.4 | Correlation between escape game satisfaction and personality traits

Figure 3A illustrates the correlation between the students' satisfaction and their personality traits. There was a significant positive correlation between satisfaction, the learning experience, the socializing experience and playfulness ($p < .01$). We found no significant correlation between satisfaction and either anxiety or seriousness. Satisfaction with the escape game was significantly associated with playfulness, learning and socializing experiences (Figure 3B).

3.3 | Association with test results, personality traits and students' perspectives

We studied the test results and found that these results were better for students with anxious personality traits ($p = .02$) and slightly lower for students with playful personality traits, although this last result was not significant ($p = .26$) (Figure 4).

4 | DISCUSSION

Dental students experience many new technologies and digitalization. Ways of teaching should follow this evolution to provide the most appropriate instruction and raise real interest in the dental curriculum, which remains long. However, serious games, which have been proven to improve learner satisfaction,^{2,13} remain underutilized. Over the past few years, escape games have become very popular and have been introduced in the medical and dental curricula to develop teamwork, which is critical for quality patient care, according to the Accreditation Council for Graduate Medical Education (ACGME).¹⁴ Thus far, no consensus has been reached on how to teach these skills effectively while strengthening knowledge. Escape games that recreate a life-like environment and contextualization while rewarding players for working together could be an interesting option.

Previous studies^{8,9} showed the effectiveness of these games for dental students, but with a small sample of students ($n = 18$ and $n = 24$, respectively). The aim of this study was to confirm the value of escape games with a larger number of students, minimize bias and

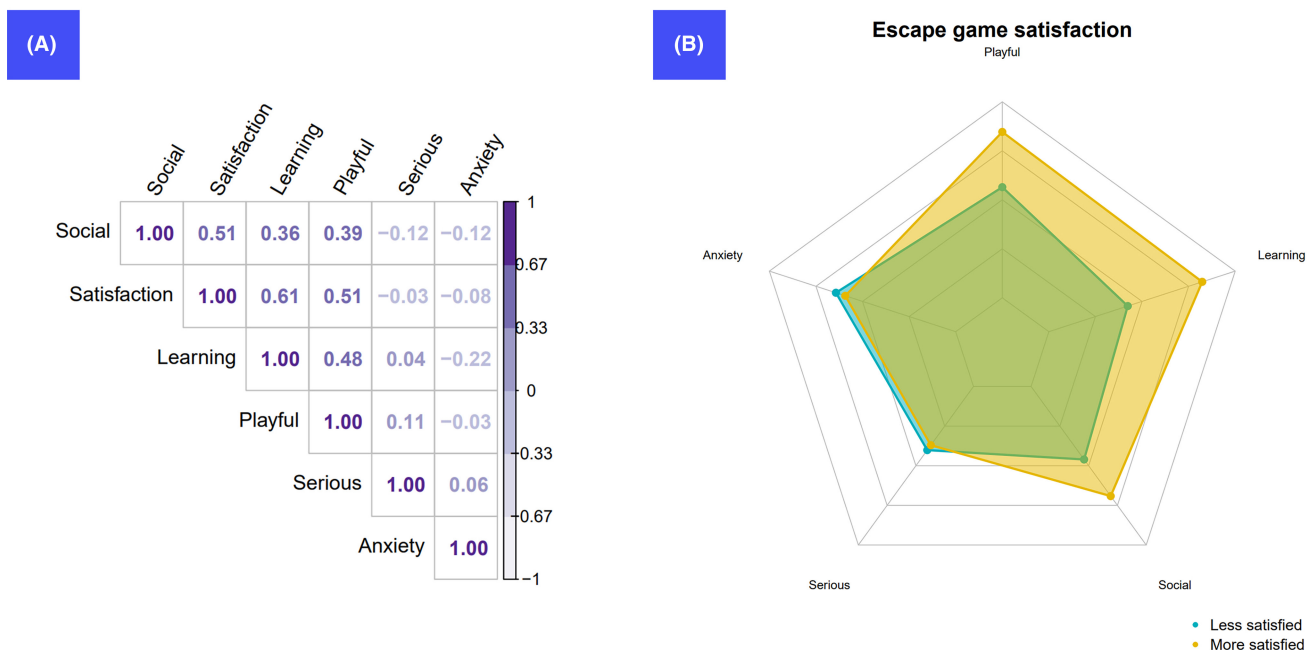


FIGURE 3 (A) Left: correlation matrix of the appreciation survey questionnaire. (B) Right: Evaluation of escape game satisfaction according to students' personality traits and perspectives.

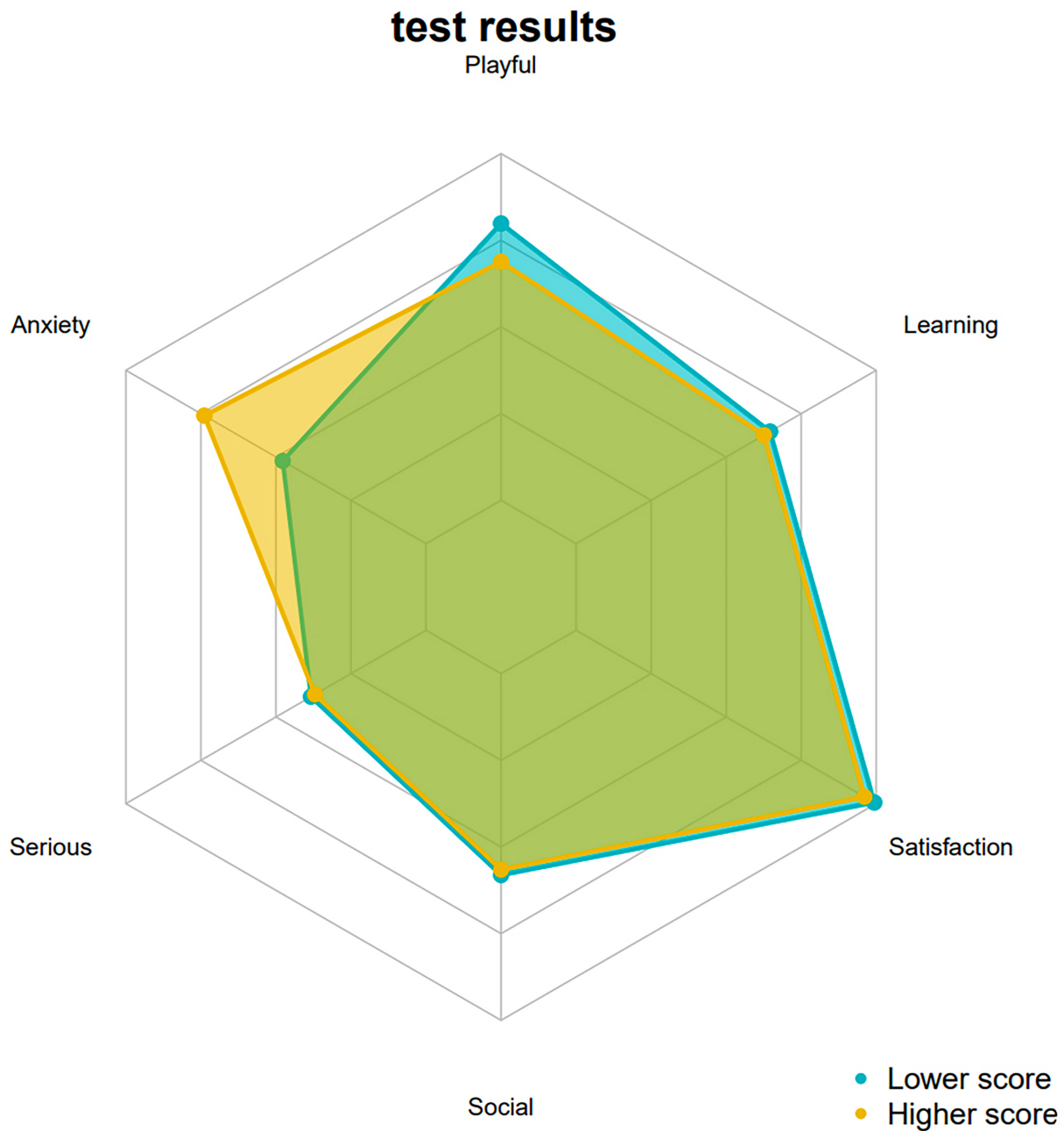


FIGURE 4 Test results according to students' personality traits and perspectives.

raise the statistical power. Our appreciation test related to personality traits was inspired by Aubeux et al.'s.⁹

The percentage of correct answers to the initial knowledge was 82.1%. This percentage is very high. Because the students were notified that the escape game was part of the curriculum and that a prize could be won, they maximized their chances by solidly learning the e-learning related to 3D printing. 72.1% said they were stimulated by the competition to win prizes. Zaug et al.⁸ found similar results (80%). It has been reported that students become intrinsically motivated to learn by playing escape rooms.^{15,16} The test results were better for the students who considered themselves anxious, suggesting a better implication for upstream

e-learning. Afzal et al.¹⁷ suggest that revision is a frequent way for anxious medical students to deal with their stress. We did not objectively assess improvement in knowledge with a subsequent test, but Aubeux et al.⁹ found significant improvement (from 67.33% to 75.33%) and Eukel et al.¹⁸ even greater improvement (from 56% to 81%) on a similar format.

It is known that dental students experience stress and anxiety during the curriculum.¹⁹ Smolana et al.,²⁰ in their meta-analysis, found that the major stressors were the study conditions and performance pressure. According to them, the didactic role of the university seems to be essential in identifying the potential sources of stress to be able to effectively eliminate or minimize them. With a

mean (SD) of 3.7 (± 0.6) out of 5 on the Likert scale, our students agreed that the escape game was a good exercise to learn how to deal with stress. Nevertheless, as they think it does not reproduce the stress felt in clinic (2.6 [± 0.3]), other methods should be used to help them manage the stress in their clinical practice.

Most of the students who did not consider themselves serious were also likely to be motivated to complete the escape game as quickly as possible. To do so, strong knowledge was needed. Once they completed the game, it is likely that in a hypothetically forthcoming escape game, these students would ensure that they had learned the lessons sufficiently to complete the escape game as quickly as possible. This is suggested by Nicholson's RECIPE²¹: if the reward can be detrimental to creating a long-term change in the subject's behaviour, it is suitable in some situations. Reward-based gamification systems create an immediate spike in engagement as users strive to explore the new system. Therefore, these escape games should remain one-time events to maintain enthusiasm and the benefits of reward-based gamification.

The level of satisfaction was correlated with playfulness, learning and socializing experience. Most of the students considered themselves playful (4.5 [± 1.3]). Barnett²² cites fifteen qualities to describe a playful individual, one of which is 'gregarious'. The playful students might have appreciated the experience even more because they were surrounded by fellow students.

Each group was composed of 5 to 6 students. This group size has been described as most effective so that every student can access the different hints and games.^{18,23} Loss of communication and organization in teams with higher numbers than 6 were observed by Eukel et al.¹⁸ The students appreciated the deliberation and discussion with their team to build knowledge together (4.2 [± 0.9]), which might be more complicated with a larger group size. Similarly, Aubeux et al.⁹ found that 66.6% of the students agreed that working as part of a team helped them to assimilate new knowledge. The shyest students might be intimidated to share their opinions in front of the whole class or a larger group, and they may feel more comfortable and not judged by approximately 5 or 6 fellow students.

The level of difficulty is an important parameter to consider.^{24,25} If it is too simple, students will be bored, and if it is too difficult, it might lead to frustration and anxiety.²⁶ To make the difficulty adjustable to the team level, the game master was told to give precise clues at some points during the timer only if the team was too late. With a mean (SD) of 1.8 (± 0.3), the students did not find the game too difficult.

The fact that 24% of the students had 100% correct answers on the test could be the result of many things: too easy questions, too few questions or good preparation from the students with e-learning. However, we designed these questionnaires to cover the essential notions that should be assimilated by the students in 3D printing. Therefore, if they might not be discriminatory regarding the role of the escape room itself, they emphasize that by the end of the experiment, the essential concepts had been acquired. Similarly, Veldkamp et al.²⁷ related that as the prospect of an escape game with a competitive character might have stimulated students to study the

content knowledge in the meantime, the knowledge increase cannot be solely attributed to the game. Among these 24% of students, 59% considered themselves serious (36% neutral). 91% said they understood the 3D-printing workflow better after the escape game, although they had 100% correct answers at the beginning.

In general, among all students, our results showed that the pedagogical escape game was a more valuable learning experience than traditional forms of teaching (4.3 ± 1.0).^{18,28} Zaug et al.⁸ found with a mean (SD) perception (3.8 ± 1.0) that students preferred assembling information from a variety of sources when learning new material. Given this assessment, the escape room could have been associated with classic practical or simulation sessions, but it seems nevertheless that it has its own utility.

The developers of other educational escape rooms have suggested that the logistics of the activity are time-consuming and need rigorous organization.^{28,29} Our escape game was created and set up by an 8-person team in approximately 35 h. A 3-person team was needed to supervise each session with each group. The fact that supervisors were in the room with the student has not been reported as problematic regarding the immersion in the game.²⁷ A 45-min session was booked for each team and included 5 min to complete the test, 30 min to escape the room and 10 min for the supervisors to tidy the room for the next team while students completed the appreciation survey in another room. With an average time of 17 min for escaping, the students came close to the time of our β -testers team (12 min), yet they were comprised of graduated dentists with expertise in 3D printing. Playtests to define a realistic playtime are crucial in an escape room design.^{30,31} We definitely overestimated the time within which the students would escape the room. Nevertheless, it once again shows how the subject was well known and understood by the students. In their studies, Aubeux et al.⁹ had a mean time of 55 min to escape, and Zaug et al.⁸ approximately 60 min. These durations were closer to a real escape game but not compatible with our 212-student promotion. As an educational escape room cannot follow every code of recreational escape game²⁷ because it must help to achieve learning goals, we prioritized small groups over a shorter duration so that everyone could fully immerse themselves in the experience, rather than a very long game with larger groups. The 38 groups were evaluated over 4 days, with approximately 5 groups per half-day. The escape game was planned to fit into the usual timeslot allocated for practical lessons. Nonetheless, due to the investment of time and effort in creation and organization, this activity cannot be generalized to the whole dentistry curriculum. Escape games should be an additional tool to promote teamwork and boost students' learning and motivation.⁹

Although the results are promising, there are some limitations to this study. A longitudinal study to assess the long-term effect of this method could provide interesting results. Only one study assessed reported that the degree of knowledge acquired and retained persisted for 3 months.²⁶ As we already assessed the appreciation and knowledge strengthening in the present, the use of Kirkpatrick's model based on four-level training evaluation (reaction, learning, behaviour and results) could be a good way to subsequently evaluate

the students, especially on their application of acquired knowledge in clinic.³² A knowledge test with more questions would be more selective and would provide more accurate data. This same test could have been filled out again at the end of the game to objectively assess knowledge improvement compared with another teaching method. It would be interesting to evaluate the same students on another escape game to see how they prepare knowing the game.

Assessment of the teacher's perception and how they experienced the process would also be relevant. Indeed, the teacher's role during collaborative learning is indeed crucial, as they must remain a central figure in supporting collaborative learning without taking control of the moments in which opportunities to learn arise for students.³³ This position might be tricky to find. Also, for a teacher, participating in active learning allows them to engage with learners at a more personal level by being motivators and listeners themselves.⁵

Pairing the questionnaires with the initials was hazardous, and we were able to pair less than half the test questionnaires with the appreciation survey. Therefore, for further studies, we should find another way to pair the quiz, for example, by randomly attributing a number to each student.

Given the promising results and upon request from the students (4.6 [1.3]), we are about to create a new escape game for 3rd-year students, which is also included in the curriculum. A multidisciplinary escape game could be interesting to add even more contextualization because patient care always involves a multidisciplinary dimension.³⁴⁻³⁶

5 | CONCLUSION

Our results with a large number of students showed that the educational escape game significantly improved knowledge and team-building, from students' perception. The instructional benefit of this process seemed to exceed the merely fun and appealing aspect. It created a supportive learning environment and increased students' motivation. The main drawback was the time spent to create and set up the escape game, but with a budget, helpful new devices are available on the market, such as premade portable escape rooms, that are completely configurable and would accelerate the creation process. The goal, of course, is not to replace all teachings with this type of format, but it can provide a fun and effective way to diversify the instruction.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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