Design and evaluation of a new consolidation exercise for students studying cardiac physiology: a digital escape room.

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**Abstract**

The current student body will, by and large, seek online resources to supplement their learning. However, resources that are freely available online vary in accuracy and quality, and the vast majority rely on passive learning. Therefore, there is a need for interactive physiology teaching resources that facilitate application of knowledge, that can be accessed by students in their own time. The aim of this study was to design a digital escape room on the topic of cardiac arrhythmias and evaluate this resource as a consolidation exercise to support learning and enjoyment of physiology. The digital escape room was designed as a series of interactive puzzles and created using a website page builder on a freely accessible WordPress site. To facilitate engagement, the escape room incorporated a countdown timer. Second year medical students were invited to play the digital escape room remotely as a group exercise following delivery of the relevant teaching. Evaluation of the resource took place quantitatively using Google Analytics and Tag Manager software, and qualitatively using a questionnaire (Microsoft Forms). Quantitative evaluation suggested that the puzzles were created across a range of difficulties, but that most groups were able to complete the exercise and remained engaged throughout. Student feedback suggests that the format of the resource was rated positively, and most participants felt that the game helped to consolidate and apply their knowledge of cardiovascular physiology. Future studies will focus on examining whether the cardiovascular-themed digital escape room improves knowledge attainment amongst students studying physiology in higher education.

**New and noteworthy**

This manuscript describes the design and development of a new, freely accessible cardiovascular-themed digital escape room. This web-based resource promotes active learning by facilitating problem-solving and application of physiology knowledge whilst working against a clock.

*Key words: Cardiac physiology; arrhythmias; escape room; educational resource*

**Introduction**

Many undergraduate students (irrespective of their degree) find physiology challenging. Although it is likely that this difficulty is, at least in part, inherent to the field (25, 33), many students attempt to learn physiology using passive techniques that could hinder deep learning if used in isolation. Therefore, it is imperative that active learning strategies are employed by students outside as well as inside the classroom. By increasing student’s participation in their own learning, teachers can promote analysis, evaluation, and synthesis of thought (6). Evidence suggests that active learning encourages student engagement, deep learning, and increases exam performance for both undergraduate medical and basic science students (13, 14), including those studying physiology (26). Conversely, it has been demonstrated that passive learning strategies (e.g. the didactic lecture) can increase boredom and hinder knowledge retainment (13, 23).

The use of educational technology (e.g. videos, discussion boards, quizzes) can be conducive to supporting student learning outside of the classroom, and it is now undeniable that virtual learning has made a significant impact to teaching. Indeed, implementation of technology in teaching is no doubt necessary to meet the modern student’s expectations (37). However, resources that are freely available online vary in accuracy and quality, and the vast majority merely provide an additional means of passive learning (e.g. watching videos). Following the COVID-19 pandemic, many universities adopted a blended approach to teaching, and it is likely that learning technologies and asynchronous teaching will remain relevant following this dramatic shift in educational delivery. Therefore, there is a need for innovative, interactive physiology teaching resources that facilitate active, deep learning and application of physiology knowledge, that can be accessed by students off campus.

In recent times, game-based learning has gained recognition as a useful pedagogical tool to create engaging, interactive learning experiences across the educational spectrum. Game-based learning inherently encourages problem-solving, active engagement and often, collaborative group work. Although not restricted to the virtual learning environment, games have been incorporated in the teaching of the basic sciences within undergraduate healthcare courses with positive outcomes (2, 21). This suggests that games can be used to reinforce and apply knowledge of physiology by creating a fun, interactive learning experience. One such game that holds this potential is the escape room. An escape room is an interactive game involving “locking” players in a room that has a specific theme. To “escape”, players must discover clues and solve a series of puzzles to reveal keys/codes to unlock the room within a specified time. Escape rooms have become somewhat of a global phenomenon in recent years with settings now established across major towns and cities worldwide. They are regarded by most as a recreational activity but, unsurprisingly, have made their way onto the pedagogical scene in both live and digital formats (22, 36). In teaching of both medicine and bioscience, escape rooms have been used to reinforce learning of genetics (8), vascular surgery (18) and patient safety (3). However, live, physical escape rooms are limited to the institutions who implement them and are not conducive to remote learning or for use as an accessible revision exercise. In this way, *digital* escape rooms may provide an engaging and interactive learning experience outside the classroom (15). More recently, digital escape rooms have been designed by educators. However, many utilise web-based apps (e.g. Google Suite; (1, 5, 19)) which can be restrictive in terms of functionality and puzzle diversity. Furthermore, depending on the account which the resource was created, the digital escape room may not be available to students outside the educator’s host institution, therefore limiting dissemination potential. Therefore, there is a lack of bespoke, integrated and freely available physiology-themed digital escape rooms for use in higher education.

Therefore, the aims of this study were to: (i), design an innovative, bespoke, cardiovascular-themed digital escape room using a WordPress platform that is freely accessible to students studying human physiology; and (ii), perform a preliminary evaluation of the resource in terms of difficulty, enjoyment/satisfaction, and student perception of effectiveness as a consolidation/revision exercise.

**Materials and methods**

**Escape room design**

The digital escape room “*The Emergency Department*” focuses on the theme of cardiac electrophysiology, arrhythmias and ECGs (the escape room can be accessed here: <https://activephysiology.com/escape-rooms/emergency-department/>). The game was designed for students studying physiology in higher education and was created as a standalone resource hosted on an existing, freely available website (WordPress; <http://activephysiology.com>). Using a sequential puzzle format as described by (29) and illustrated in **Fig. 1**, the digital escape room was built using a website page builder (Elementor). Players access the escape room “door” (a unique webpage) via the escape room landing page or via a direct link. This “door” page provides: (i), a short introductory video detailing the room’s backstory to set-the-scene (see **Fig. 2**); (ii), important information regarding the game’s functionality (e.g. supported browsers); (iii), tips to get the most out of the exercise; and (iv), a button to start the game. Clicking this button redirects the players to the first puzzle page (another unique webpage) and a countdown timer (HurryTimer) is initiated. The countdown timer is identified by a unique shortcode present on each puzzle page, meaning that as players progress through the digital escape room, the time on the countdown timer is carried over. This timer uses cookies so that it is unique to each user and will not re-start if the user refreshes the page (evergreen timer).

Each puzzle page (see **Fig. 3** for an example) consisted of an interactive puzzle created using one or more WordPress plugins from Elementor, H5P (Joubel) and Element Pack for Elementor (BDThemes) or using anexternal resource (Jigsaw Planet) embedded using an iFrame. Players are required to use their problem-solving skills in addition to their knowledge of cardiac electrophysiology to solve the puzzle and work out the code for a lock – the latter created using a protected content WordPress plugin (Passster). This plugin allows the designer to hide (password protect) webpage content, and hidden content is only revealed when the player inputs the correct password (i.e., the code to the lock). Inputting the correct code reveals a button which, when clicked, redirects the player to the next puzzle in the sequence (another unique webpage). Six puzzles were included in “*The Emergency Department*” digital escape room, and completion of the sixth puzzle revealed a button which redirects the players to a “YOU ESCAPED!” page, which consisted of a printable summary of the puzzles and physiology concepts covered by the resource.

As each puzzle was designed on a separate webpage, a unique 8-digit code was included at the end of each page’s URL so that players are unable to skip forward in the game without solving the puzzle.

If at any point through the game the player runs out of time (i.e., the timer reaches 00m:00s), the countdown timer plugin automatically redirects the player to a different, unique “GOOD TRY” webpage. The player would therefore be “locked out” of the escape room and would need to start from the beginning to try again. A summary is also included on this page to give the player hints to how to work out each puzzle, and the physiology topics they may need to revisit to solve it.

As the digital escape room was developed as an educational resource, it was important to design a game that challenges higher achieving students, but also provide enough support for lower-achieving students. To accomplish this, both “Clue” and “Answer” buttons (Lightbox & Modal, Essential Addons for Elementor) were included on each puzzle page which players could access for additional support.

**Protocol**

*“The Emergency Department”* escape room was timetabled as a consolidation activity for second year MBChB students in the final week of the cardiovascular pathophysiology module at Keele University (February 2022). A total of 173 students from 16 problem-based learning (PBL) groups were invited to play the activity remotely, with each PBL group split into 3 sub-groups (totalling 48 groups across the cohort, 3-4 students per group). Each group played the game together using video conferencing software (Microsoft Teams). A link to the “door” starting page was provided, along with instructions for each group to nominate a team leader who would access and interact with the escape room and be responsible for screen-sharing with the rest of the group. Therefore, it was anticipated that 48 unique page views (representing 48 groups of students) would start the activity.

**Evaluation**

*Quantitative evaluation of student engagement and puzzle difficulty*

User interaction with the digital escape room elements was recorded anonymously and in real-time for quantitative evaluation of the resource. Student engagement/enjoyment was measured by comparing the number of puzzle page views/exits (Google Analytics). Puzzle difficulty was quantified using the average time spent on each puzzle page (Google Analytics) as well as the number of “Clue”, “Answer” and “Unlock” button clicks (Google Tag Manager). For all quantitative analysis, data entries were restricted to the date and time that students were timetabled to play the game, to ensure that only page views and button clicks occurring during this session were evaluated.

*Qualitative evaluation of the digital escape room as a consolidation/revision resource*

Qualitative evaluation of the digital escape room formed a study that was approved by The Keele Institute for Innovation and Teaching Excellence Educational Research Ethics Committee (KIITE EREC; Keele University). Students were informed that completion of the feedback questionnaire was entirely voluntary and that all responses would be kept anonymous.

Approximately one-week following the timetabled activity, all second-year medical students were invited to take part in a qualitative study to evaluate the digital escape room. Students were sent a participant information sheet and a consent form (Microsoft Forms) which they were asked to sign (by typing their name) should they have chosen to participate. Upon submission of the consent form, a link was revealed allowing access to a student questionnaire (Microsoft Forms) which was not traceable to the original consent form signed by the student (hence maintaining anonymity). The questionnaire consisted of various question types (e.g. Likert scale, multiple choice, best answer, free-text responses) to assess student’s perception of the digital escape room’s difficulty, functionality and usefulness as a revision/consolidation exercise.

**Results**

**Quantitative evaluation**

*Student engagement/enjoyment*

Student engagement was quantified by the number of groups/individuals who accessed each puzzle page *vs*. the number who exited at different points throughout the game (**Fig. 4**). Although a total of 48 groups of students were invited to play the game, the number of unique page views indicates the actual number of groups (or unique individuals) who accessed each puzzle page. A total of 58 groups/individuals started the game (with Puzzle 1), suggesting that students either split themselves into even smaller groups, or more than one student (individual) per group accessed the game. Of these 58 groups/individuals who started the game with Puzzle 1, a total of 43 (74.1%) accessed the “You escaped!” page and therefore completed the game and remained engaged with the activity throughout. Of the 15 (25.9%) groups/individuals who did not complete the game, 4 were redirected to the “Good Try!” page, suggesting that they ran out of time before completing the game. The remaining 11 individuals exited the game before completing, but without being redirected by the countdown timer. This latter group may therefore represent groups/individuals who were lacking engagement or did not enjoy the activity.

*Puzzle difficulty*

A list of the different puzzle types, the area of cardiovascular physiology each puzzle tested, as well as the Google Analytics/Tag Manager data assessing puzzle difficulty is provided in **Table 1**. Of the 58 groups/individuals who started the game, 4 (6.9%) were redirected to the “Good try!” page – i.e., they ran out of time on the countdown timer before managing to complete the game, suggesting that most groups were able to complete the exercise.

The average amount of time users spent on each puzzle page provides one measure of individual puzzle difficulty – the longer time spent on the page, the longer it took to complete the puzzle. These results suggest that the quickest puzzle took on average 3 mins and 50 s to complete, whereas the longest puzzle took on average 11 mins and 11 sec to complete.

As the number of groups/individuals accessing the game was greater than the original number of groups assigned (58 *vs.* 48), and the number of group/individuals playing changed throughout the game, the percentage of groups/individuals that needed to access either the clue or the answer in order to solve the puzzle was calculated from the number of unique button clicks (either “Clue” button or “Answer” button) divided by the total number of unique page views to each puzzle page. Using these parameters, to complete the easiest puzzle, 32.8% and 29.3% of groups/individuals needed to access the clue and answer, respectively, whereas to complete the most difficult puzzle, 74.4% and 74.5% of groups/individuals needed to access the clue and answer, respectively.

Finally, the number of “Unlock” attempts provides another measure of puzzle difficulty. Here, the easiest puzzle required on average 2.3 attempts to unlock the lock, whereas the most difficult puzzle required on average 13.6 attempts.

As just described, four different parameters were used to assess puzzle difficulty. Therefore, to obtain an overall value for puzzle difficulty, for each parameter (average time spent, percentage of groups accessing clue; percentage of groups accessing answer and average number of unlock attempts) puzzles were ranked from 1-6 according to difficulty (1=easy; 6=difficult). These ranks were then summated to calculate an overall “Difficulty rating” (see **Fig. 5**). Here Puzzle 5 (puzzle type = hidden clues/diagnose patient; physiology topic = atrial fibrillation) was rated the most difficult, and Puzzle 6 (puzzle type = diagnose patient; physiology topic = acute coronary syndrome on ECG) was rated the easiest.

**Qualitative evaluation**

*Study participants*

A total of 11 second year MBChB students completed the questionnaire evaluating the cardiovascular-themed digital escape room. Of these participants, 91% of students had not studied physiology as part of a previous degree and 55% of students said that they find physiology as a subject difficult. Participants were also asked whether they had ever played an escape room for educational purposes prior to playing the digital escape room for the current study. With regards to a live escape room, 72.7% of participants responded that they had never played an escape room for educational purposes, whereas 27.3% said they had done so once. However, all participants said that they had never played an online/digital escape room for educational purposes.

*Digital escape room format*

Participants were asked to evaluate the format and useability of the digital escape room (**Fig. 6**). When asked how easy/difficult the physiology topics covered in the digital escape room were, 36% of participants responded “Easy”, 55% responded “Neither easy or difficult” and 9% responded “Difficult”. No participants responded, “Very easy” or “Very difficult”. When asked how easy/difficult the puzzles used in the digital escape room were, 30% of participants responded “Easy”, 40% responded “Neither easy or difficult” and 30% responded “Difficult”. Again, no participants responded, “Very easy” or “Very difficult”. Participants were then asked how easy/difficult the instructions for the digital escape room were to follow, to which 82% responded either “Easy” or “Very easy”. Furthermore, 82% of participants found the digital escape room either “Easy” or “Very easy” to interact with. Finally, participants were asked to rate the digital escape room puzzles, clues, summary pages and the website platform (<http://activephysiology.com>) to which ≥91% of participants rated all elements either “Good” or “Excellent”.

*Suitability of the digital escape room as a consolidation/revision exercise*

Next, the questionnaire was used to assess whether participants found the game engaging, as well as whether they found it useful as a revision/consolidation exercise (**Fig. 7**). All students who took part in the study found the escape room either “Engaging” or “Very engaging” and all students thought the physiology topics covered in the digital escape room were either “Relevant” or “Very relevant” to their degree. Additionally, 64% of participants thought the digital escape room helped to consolidate their knowledge of cardiovascular physiology (the remaining 36% responded “Somewhat”), 82% of participants thought the digital escape room helped them to practice applying their knowledge of cardiovascular physiology (the remaining 18% responded “Somewhat”) and 91% of participants said they enjoyed playing the digital escape room (the remaining 9% responded “Somewhat”). Finally, 100% of participants thought the physiology topics were appropriate for students with a range of abilities, 64% said they would use digital escape rooms as a means of consolidating/revising additional physiology topics in the future and 91% said they would recommend the digital escape room as a consolidation/revision exercise to their peers.

*Participant feedback and suggestions*

As the digital escape room was created as a bespoke educational resource, it was important to gather free-text responses from study participants to gain further insight as to which aspects of the resource worked well, and which areas require improvement. To address these points, participants were asked the following question: *“The intention is to create more of these digital escape rooms to act as consolidation/revision exercises on different physiology topics. What do you think of this idea, and do you have any suggestions?”*. Free-text responses to this question are provided in **Table 2**.

**Discussion**

*Design challenges*

As stated previously, there is a need for high-quality, freely available physiology-themed revision/consolidation exercises that can be accessed by students in their own time. When designing *“The Emergency Department”* digital escape room, the following criteria were borne in mind: (i), the resource should promote active learning; (ii), the resource should facilitate *application* of physiology knowledge (as opposed to rote learning); and (iii), the resource should be engaging and enjoyable.

Active learning can be defined as the involvement of students in their own learning by creating meaningful activities to enable learners to think about what they are doing (6, 31). Active learning is therefore an inherent feature of an escape room, where players must problem-solve their way out of a metaphorically locked room. Previous studies suggest that use of puzzle-based activities improve exam performance and enhance student’s perception of their learning (4, 9, 32, 34). *“The Emergency Department”* digital escape room consisted of interactive puzzles with cardiac physiology concepts “embedded” within, meaning students needed to apply their knowledge of cardiac physiology *and* solve the interactive puzzle to progress through the game. Therefore, one of the first challenges to designing the digital escape room was to create interactive puzzles that require students to apply their knowledge of cardiac physiology to work out the code for the lock. For example, Puzzle 1 of *“The Emergency Department”* featured an interactive jigsaw puzzle. Once completed, the puzzle picture revealed the image of a 12-lead ECG with a hidden message overlain – the latter acting as a clue to what the student needed to work out to find the code for the puzzle lock, in this case, the heart rate. Therefore, in this example, the student would need to do the following to complete the puzzle: (i), complete the interactive element (i.e. complete the jigsaw); (ii), identify “what they need to do” (i.e. calculate the heart rate); and (iii) apply their knowledge of cardiac physiology (i.e. actually calculate the heart rate from the ECG).

The second challenge encountered in the digital escape room’s design was to ensure that the resource was suitable for students with a wide range of abilities. In other words, the consolidation exercise should sufficiently challenge higher-achieving students, whilst also supporting those with a lack of knowledge. In this respect it was important that the concepts included in the resource were core knowledge for students studying cardiac physiology at an advanced level (in this case second year medical students). **Table 1** summarises the topics tested in *“The Emergency Department”*, all of which fall within the recommended physiology learning objectives for medical students (guidance from The Physiological Society (35) and The American Physiological Society (10)). With regards to providing additional support to those students who might find the digital escape room challenging, two additional buttons were included on each puzzle page (see **Figs. 1** and **3**). The first was a “Clue” button that when clicked, triggered a popup providing a clue to help work out the physiological component of the puzzle. Ideally, only students who struggle to solve the puzzle would access the clue, and at the start of the game, players are advised to try and solve the puzzle to the best of their ability before using the clue. In this respect, the clue buttons can be likened to a form of student-directed scaffolded learning (38). Similarly, inclusion of an “Answer” button, which provided the answer to the puzzle and hence the code for the lock, meant that if a student could not work out a particular puzzle, they would still be able to progress through the game. Although players were advised to spend at least 10 minutes attempting a puzzle before clicking this button, it is likely that many students would have difficulty refraining from accessing the answer. Unfortunately, prior attempts to time-release the answer button (e.g. 10 minutes after puzzle page entry) were unsuccessful, meaning to some degree, the game relies on students taking responsibility for their own learning (24).

As a freely available online resource, it is possible to play the digital escape room alone, or as part of a group activity. For the latter, a single user accesses the escape room on their device and then shares screens using a video conferencing platform. Therefore, an additional challenge was to decide the format for the study protocol – i.e., whether the students should be given access to the digital escape room to play on their own, or whether they should be assigned to groups to play collaboratively. To address this, third year MBChB students were invited to beta-test a preliminary version of the digital escape room. This earlier iteration of the game did not have “Answer” buttons on puzzle pages, so if a student was unable to work out the puzzle, they would be unable to progress through the game. Two students agreed to take part, and, although feedback was largely positive, some comments suggested that the game was too difficult (data not shown). It was for this reason that the study was designed as a group activity. It is now well accepted that collaborative learning (both in person and online) improves knowledge attainment, communication skills and student satisfaction (12, 26, 31). By working as a group, it was anticipated that lower achieving students would benefit from the knowledge of higher achieving students making the game less difficult overall (20). At the same time, additional features (e.g. “Answer” button; see above) were added to puzzle pages to support those students who, in the future, wish to play the game alone.

Possibly the greatest challenge in the digital escape room design, was ensuring that the resource is a fully functional, interactive online game that would be of the calibre expected from a cohort of digital natives. As explained previously, the decision to build the digital escape room on WordPress was to make the resource freely available to all, but additionally, it allowed the freedom to create realistic escape room/puzzle elements not achievable using other, more popular app-based platforms (e.g. Google suite). However, with this freedom brought further challenges. Throughout the digital escape room’s development, the resource needed to be tested on different screen sizes and on different browsers to ensure functionality was maintained. Indeed, some of the original plugins chosen were changed partway through the project because of browser incompatibility.

A fundamental feature of the digital escape room is the countdown timer, providing a sense of urgency and a more realistic escape-room experience. To ensure that the countdown timer would not reset when the webpage is refreshed, an “evergreen” timer WordPress plugin was chosen that adds cookies to the browser to track the user’s session. However, if the user decided to open the page in “incognito” mode, the timer would reset. Here again, the game relies on students taking ownership of their own learning (24). The evergreen timer plugin does have a feature to track IP addresses, meaning the timer would not restart in incognito mode. However, the consequence of this is anyone trying to access the game at the same time from the same IP address (i.e. students living in shared accommodation), would see the same time on the countdown timer.

Another example is confliction between different WordPress plugins that would impact game functionality. For example, a password-protected content plugin was used for the digital escape room “locks”. During beta-testing of the preliminary resource, it was identified that when the “Unlock” button was clicked, the entire puzzle page would refresh, resulting in the player’s interactions with the puzzle (e.g. the H5P plugin or iFrame content) being cleared. Therefore, if the player typed an incorrect code into the lock, they would have to re-start the puzzle before trying the lock again. For this reason, a different password-protect plugin that didn’t cause the page to refresh was needed. Similarly, testing of the resource identified a “bug”, whereby some users are unable to use mouse scrolling on the puzzle pages, and will instead have to use either the scroll bar on the screen or the keyboard arrow keys. Despite extensive investigation, this issue has not been resolved, but may be a website-wide issue.

*Puzzle difficulty – data vs. student feedback*

As stated previously, the digital escape room was designed as an educational game, so it is important that the resource challenges students without being so difficult that engagement/enjoyment is hindered. Therefore, a key element to both quantitative and qualitative evaluation of this new resource was assessment of puzzle difficulty, and there are several ways that this could be evaluated (see **Table 1**).

As the game is played under time constraints, the length of time taken to complete the puzzle (quantified as average length of time spent on each puzzle page) will impact whether the user is able to complete the game. For example, the puzzle which took the longest to complete (Puzzle 2) incorporates a crossword. Although it is clear what the player must do to solve a crossword, the number of questions and their inherent difficulty would impact how long it takes to complete. The puzzle that took the shortest amount of time to complete (Puzzle 6; diagnose the patient), focused predominantly on knowledge (acute coronary syndromes on ECG). This leads onto the second measure of puzzle difficulty – the percentage of groups who needed to access the “Clue” or “Answer” buttons on the puzzle page. This provides the best indication of difficulty of knowledge tested. For example, the topic of focus for Puzzle 3 is electrophysiology (afterdepolarizations), and to solve this puzzle, 72.3% and 74.5% if groups needed to access the “Clue” or “Answer” button, respectively. This suggests that electrophysiology is a topic that students find more challenging. When this is compared to Puzzle 1 (Jigsaw puzzle, measurement of heart rate from ECG), only 32.8% and 29.3% of groups needed to access the “Clue” and “Answer” buttons, respectively, suggesting that students are more comfortable with this topic/skill. The final measure used to evaluate puzzle difficulty is the average number of attempts to unlock a puzzle lock. For example, although a group may be able to solve a puzzle, if the code has multiple, plausible iterations (e.g., differences in spelling, units *vs.* no units, uppercase *vs.* lowercase, acronyms *vs*. in full, etc.), multiple unlock attempts may be needed. A good example of this is the answer to Puzzle 3 – “dad”. However other, sensible answers which groups may have tried include “DAD”, “delayed afterdepolarisation”, “delayed afterdepolarization”, etc. This is evidenced by the free-text responses in **Table 2** (see “Criticisms”). To mitigate this, specific guidance was provided in the “Tips” sections on the escape room starting page (e.g. codes could be letters or numbers, but all lowercase and spaces should be included where appropriate). That said, players may not have read these instructions, or they may have forgotten them once they progressed through the game. The puzzle clue was also written in a way to direct the player towards use of the acronym, but again, this may have been missed. Unfortunately, these problems are likely inherent to any escape room based on physiology topics, as the language of physiology is complicated and non-unified which has been suggested to hinder some student’s learning (28, 30, 33).

How does this quantitative assessment of escape room/puzzle difficulty compare to [qualitative] student feedback? When asked how easy/difficult the participants found the puzzles and the physiology topics covered in the digital escape room, most responded “Neither easy or difficult” or “Easy”. This finding is supported by free-text responses to evaluation of the resource (see “Criticisms” and “Suggestions” in **Table 2**). This is despite a large proportion of groups accessing the clues and/or answers during the game. It is possible that the small group of students who agreed to participate in the study were predominantly high-achieving, and therefore may or may not have needed the extra support to progress through the game. However, another likely scenario is that students accessed the clue/answer buttons even if they did not need them – i.e., because they couldn’t resist accessing additional support that was readily and easily provided.

*Engagement/enjoyment – data vs. student feedback*

Perhaps unsurprisingly, several studies suggest that enjoyment and satisfaction in game-based learning correlate positively with student engagement (3, 7, 17), and this is important because student engagement may improve knowledge attainment (16, 26). Indeed, this was the primary reason for choosing a game-based approach when developing a new revision/consolidation resource. Both quantitative and qualitative evaluation suggests that students engaged with and enjoyed playing the digital escape room. Google Analytics data suggests that the digital escape room had a relatively low drop-off rate (approximately 19% left before finishing the game). However, it is not clear whether these individuals stopped playing the game altogether, or whether users who exited the game were part of a group where more than one individual accessed the resource (despite being instructed otherwise). Questionnaire data further supports this finding, where 100% of respondents said that they found the format of the digital escape room either “Very engaging” or “Engaging”, and 91% of participants said they enjoyed playing the digital escape room. Finally, free-text responses provide further insight – e.g. *“…The format made it engaging and the sense of competition also made me eager to engage with it”*.

It is possible that engagement with the digital escape room was facilitated by the fact that it was set as a timetabled activity at the end of the relevant teaching module. Whether the same degree of engagement would be found amongst students who use the resource of their own accord is beyond the scope of this study. However, most questionnaire respondents did say that they would use digital escape rooms as a means of consolidating/revising physiology in the future and that they would recommend the digital escape room to their peers.

*Usefulness as a revision/consolidation exercise*

Revision of knowledge can be an important process in allowing students to gain a deeper understanding of core physiology concepts through repetition and consolidation. However, it has been suggested that ineffectiveness in teaching is reflected in many students’ inability to accomplish deep understanding of physiology (11). In other words, students tend to focus on memorizing facts (27) rather than understanding concepts, which hinders their ability to apply their knowledge. Again, game-based learning has the potential to facilitate deep learning, both by improving engagement (as described previously) and forcing students to think about how the physiology they have learned applies to a game-based scenario. Specifically, the aim of the digital escape room was to enable students to apply their knowledge of cardiac electrophysiology to solve the puzzles against the clock and win the game. Although the effectiveness of the digital escape room at improving knowledge was not directly measured in this study, it was important to assess student’s perception of this new resource’s usefulness as a revision/consolidation exercise – importantly, whether the students felt the resource helped them to apply their knowledge of cardiovascular physiology. Here, evaluation was focused on the questionnaire responses. Overall, the format of the digital escape room was rated highly (e.g. instructions, ease of interaction, puzzles, clues, etc.; see **Fig. 6**). All questionnaire respondents felt that the topics covered were relevant to their degree, and most respondents said the digital escape room helped them consolidate and practice applying their knowledge of cardiovascular physiology. Again, free-text responses seem to support this finding – e.g. *“…a fun way to consolidate knowledge and work as a team…”* and *“I think they're a fun and interactive way to consolidate learning without feeling like you are doing work”*.

*Conclusion and future directions*

The aim of the present study was to design and implement a freely accessible, cardiovascular-themed digital escape room for use as revision/consolidation exercise that promotes application of knowledge as opposed to rote learning. Preliminary evaluation of *“The Emergency Department”* suggests that this new resource is functional and suitable for a range of abilities. As evidenced by questionnaire feedback, students find the resource enjoyable, engaging and a useful exercise for consolidation and application of cardiovascular physiology knowledge. However, this study does not directly assess whether the digital escape room improves knowledge attainment. Therefore, a future study should determine the effectiveness of the digital escape room in this respect, for example by comparing knowledge attainment in a group of students who have used the digital escape room, *vs.* a control group. Data analysis in this subsequent study could therefore incorporate statistics to strengthen evaluation of the resource compared to more traditional revision/consolidation activities.

It is also anticipated that future evaluation will incorporate a focus group to gain insight into specific areas of the resource that the students may have struggled with. For example, whether those student’s who accessed the “Clue” and/or “Answer” buttons did so because they struggled with the physiology content, or whether it was the puzzle element that hindered their progression.

Although the WordPress platform is less restrictive in terms of design and development, as well as allowing for accessibility and dissemination, plugin conflicts and ever-changing technology means it is likely that the resource will need to evolve over time. As new plugins are developed, further opportunity may arise to improve the resource further. One example of this would be identifying a way to make the “Answer” button not accessible immediately.

It is anticipated that new digital escape rooms will be created using *“The Emergency Department”* as a template. Comments and suggestions from free-text responses will be incorporated into new projects. For example, inclusion of puzzles that involve more application to medicine (perhaps as a separate room pitched to medical students). Rooms will be created with different levels of difficulty and guidance provided so users can choose which room is best suited to their ability and degree course.

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**Author contribution**

M.A.H. conceived, designed and implemented the resource, performed the study, analyzed the data, prepared the figures and drafted, edited, revised and approved the final manuscript.

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**Figure legends**

**Figure 1. Escape room format.** The escape “room” was designed as a sequence of webpages hosted on an existing Wordpress site (http://activephysiology.com). Players access the room via the escape room landing page, or via a direct link to the escape room “door” page (A). This door page provides an introduction to the resource, directs the players to a short introductory video as well as providing important information regarding functionality and some useful tips. When players are ready to start the game they select the “START!” button. This will redirect the player to the first puzzle page (B) where a countdown timer will start. The puzzle pages consists of a progress bar so players can track their progress through the game. Players use their problem-solving skills as well as their knowledge of physiology to solve a puzzle and work out the code to the lock. Both a “Clue” button and an “Answer” button are available for each puzzle if the player is unable to work out the code. When the correct code is entered into the lock, a previously-hidden “NEXT PUZZLE” button is revealed. Clicking this button redirects the player to the next puzzle page (C). When the final puzzle in the game is solved, players are redirected to the “You escaped!” page (D), where a summary is available to print. If, at any point during the game the player runs out of time on the countdown timer, they are automatically redirected to a different page (E) and “locked out” of the room and they will have to start from the beginning if they wish to play again. They are provided with a brief summary of the physiology topics they should revise before their next attempt.

**Figure 2. Escape room introductory video.** The “door” to the escape room features a short video that sets the scene for “The Emergency Department”.

**Figure 3. Example escape room interactive puzzle page.**

**Figure 4. Student engagement with digital escape room activity.** Grey boxes represent unique pages (URLs) of the digital escape room with the number of groups/individuals who accessed the page (number in grey box). Red arrows and corresponding values represent the number of groups/individuals that exited the game from that page (bracketed number represents the number of groups/individuals who exited as a percentage of number of page views). Of the 15 groups/individuals who did not complete the game, 4 were redirected to the “Good try!” page, suggesting that they ran out of time before completing the game.

**Figure 5 – Puzzle difficulty.** Google Analytics and Tag Manager software was used to quantify the following to assess puzzle difficulty: (i), average time spent on each puzzle; (ii), number of groups/individuals needing the puzzle clue; (iii), number of groups/individuals needing the puzzle answer; and (iv), average number of code attempts to unlock the lock. The puzzles were then ranked 1-6 for each parameter (1=easy; 6=difficult) and the four rankings added together to give a difficulty rating for each puzzle.

**Figure 6. Questionnaire results – format of the digital escape room.**

**Figure 7 – Questionnaire results – Engagement and usefulness as a revision/consolidation exercise**.

**Table 1.** Summary of Google Analytics and Tag Manager data assessing puzzle difficulty.

**Table 2.** Free-text responses to the following question: *“The intention is to create more of these digital escape rooms to act as consolidation/revision exercises on different physiology topics. What do you think of this idea and do you have any suggestions?*