

Design and Implementation of Interactive, Remote Online Escape Rooms in Medicinal Chemistry

Aisyah Saad Abdul Rahim¹ and Kee Man Chuah²

¹Faculty of Pharmacy, Universiti Teknologi MARA, UiTM Puncak Alam Campus, Selangor, Malaysia

²Faculty of Education, Language and Communication, Universiti Malaysia Sarawak, Kota Samarahan, Malaysia

aisyahsaad@gmail.com (corresponding author)

kmchuah@unimas.my

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Abstract: This research explores the development, execution, and student feedback on a multi-themed digital escape room (ER) activity, designed for teaching medicinal chemistry during the COVID-19 pandemic. It aimed to examine students' perceptions of the ER activity, focusing on its effectiveness in enriching students' understanding of medicinal chemistry and increasing their engagement level. Implemented in a synchronous online lecture for third-year pharmacy students, this ER activity was designed with the intention of fostering active learning and teamwork. A total of 184 students participated in various medicinal chemistry-themed challenges, using puzzles on a virtual whiteboard and breakout rooms for team discussions. The findings gathered from the post-implementation survey highlight the impactful learning outcomes associated with a replicable ER activity designed for online medicinal chemistry courses. This innovative teaching strategy not only cultivated a deeper understanding of key medicinal topics among students (mean=4.36) but also enhanced their collaborative skills through increased peer interaction (mean=3.73). They also reported higher level of engagement due to the interesting activities (mean=4.53). The quantitative results were affirmed by the qualitative feedback obtained from the open-ended questions, indicating a consistently positive learning experience and student reception towards the ER implementation. Although they encountered obstacles like stress, internet issues, and unfamiliarity with the ER format, more than 70% of the students agreed that the ER activity was a highly effective learning tool. This digital ER activity also demonstrates promise as an educational tool to encourage active learning and enhance students' motivation in learning medicinal chemistry. The study has showcased the potential benefits of integrating digital ERs into traditional teaching methods, especially for catering to the preferences of Generation Z students in a collaborative learning environment. In addition, the research offers valuable insights into the use of ERs in pharmacy education, contributing to the scarce literature on ER applications in medicinal chemistry and opening avenues for further research on ER-based educational strategies.

Keywords: Active learning, Educational games, Escape room, Medicinal chemistry, Gamification

1. Introduction

In the current higher education landscape, undergraduates, primarily from Generation Z (Gen Z), are navigating their studies amidst a digital revolution that has gained momentum in the post-COVID-19 era. This generation is characterised by a seamless integration of digital technologies into their daily lives, effectively erasing the boundaries between physical and digital spaces and embracing what is known as a 'physical' reality (Prensky, 2001 & 2002; Mele et al., 2023; Poliakova et al., 2022 & 2023). Their modes of communication, collaboration, and personal management are deeply entwined with social media, the internet, and various digital devices (World Economic Forum, 2020). Thanks to the internet, they have access to a vast amount of learning materials and resources at their fingertips (Sadjadi, 2023; Tolstikova et al., 2023).

Studies have outlined characteristics of Gen Z for the higher education sector; they are self-starters with the willingness to learn on their own from online courses, goal-oriented, avid virtual gamers, and prefer to design their own studies (Schwieger and Ladwig, 2018; Tolstikova et al., 2022 & 2023). The changing demographics and characteristics of students in the higher education institutions call for innovations that prepare students for uncertain and ambiguous future (Azer, 2008; Eckleberry-Hunt et al., 2018; Sadjadi, 2023; Tolstikova et al., 2023). Crucial are adaptive and dynamic curriculum incorporating teaching practices and innovations that foster active learning and inculcate critical thinking through collaborative learning.

During the COVID-19 pandemic, the abrupt shift to online distance learning in universities, necessitated by the closure of higher education institutions, brought significant changes in teaching methodologies. This period saw a predominant reliance on synchronous lectures and video presentations, often delivered through PowerPoint. Despite their widespread use, these methods, which closely resembled traditional lectures, faced criticism for

their lack of engagement and effectiveness. A study by Baker et al. (2018) highlighted this issue, finding that PowerPoint lectures had no significant impact on improving learning outcomes compared to the conventional chalk-and-talk approach. Doherty (2007) also pointed out that such online instruction methods led to lower student attendance, diminished peer interactions, and fostered a passive learning environment. In large enrolment programs, particularly in disciplines like medicine and pharmacy, traditional lecture formats continued to be the preferred instructional strategy due to their perceived efficiency and cost-effectiveness. However, this approach proved to be especially challenging in courses like organic chemistry, medicinal chemistry, and pharmacy ethics. Studies by Cain (2019) and Abdul Rahim et al. (2022) revealed that students often perceived these courses as lacking immediate practical application or relevance to their future roles as pharmacists.

Furthermore, traditional lectures encourage a strong dependency on the lecturer, and not the students. It hardly provides the conditions in learning that would prepare students the autonomy, agency and promotes peer interdependence in dealing with uncertainty in simulated or authentic learning environments. Educational games are a notable innovative pedagogy that has gained widespread attention in the recent years (Kabilan, Annamalai and Chuah, 2023; Zainuddin et al., 2020). It is a type of instructional strategy in which students are the active participant in a competitive learning activity that is governed by a set of rules. Students benefit by learning in a fun and interesting environment in which the repercussions of errors are minimised. An educational game that has become increasingly popular in amongst the younger generations is escape rooms (ERs) (Abdul Rahim et al., 2022; Rawlinson and Whitton, 2023; Veldkamp et al, 2020).

ERs are time-constrained team-based games that are rooted in active and cooperative learning pedagogy, which empowers student teams to problem-solve tasks and puzzles before escaping a locked room (Brown, Darby and Coronel, 2019). At its core, the use of ERs in teaching and learning embodies the principles of Experiential Learning Theory (Kolb and Kolb, 2017), an instructional theory grounded in a four-stage learning cycle: concrete experience, reflective observation, abstract conceptualization, and active experimentation. Through the interactive nature of ERs, learners directly engage with problems (concrete experience), a dimension that serves to transition abstract concepts into tangible challenges (Morris, 2020). This hands-on interaction permits reflective observation, during which learners analyse the outcomes of their actions within ERs and articulate their findings, initiating a dialogue that enhances collaborative learning (Moseley et al., 2020; Kirschner et al., 2018). Subsequently, this reflection stimulates abstract conceptualisation, inviting learners to formulate hypotheses and devise strategies to address the challenges encountered within the escape room environment. The cycle culminates in active experimentation, whereby these newly synthesized theories are applied to novel puzzles and problems, effectively operationalising learned concepts (Kolb and Kolb, 2017).

Building on the established effectiveness of ER activity in educational settings (Abdul Rahim et al., 2022; Abdul Rahim, 2023; Eukel et al., 2017; Veldkamp et al., 2020), this study examines a specific implementation of ER activities in the context of medicinal chemistry education. The ER format, varying from linear to open or path-based structures, has been shown to effectively sequence puzzles in a way that enhances learning (Nicholson, 2015; Veldkamp et al., 2020). Furthermore, the linear game design, closely aligned with specific instructional strategies (Cain, 2014), along with its application in health sciences, demonstrates its capacity to boost confidence and competence in professional practices and as a preparatory tool for problem-based learning (Abdul Rahim, 2023; Manzano-León et al., 2021; Veldkamp et al., 2020).

However, the unique nature of medicinal chemistry, encompassing complex concepts and requiring a deep understanding of chemical and biological interactions, raises questions about the suitability and efficacy of ERs in this domain. The immersive and thematic approaches of ERs, which engage students in scenarios like solving mysteries or undertaking rescue missions, must be examined for their ability to not only engage students but also to effectively convey complex medicinal chemistry concepts (Abdul Rahim, 2023; Veldkamp et al., 2020). This study, therefore, seeks to investigate the implementation of a multi-themed escape room activity for medicinal chemistry education, particularly as an innovative learning method during the COVID-19 pandemic. The research problem centres on understanding the effectiveness of this ER activity in medicinal chemistry education. Specifically, it aims to address the following research questions:

RQ1: What are the students' perceptions of the ER activity in terms of engagement and learning experience? :

RQ2: How do students perceive the usefulness of the ER activity in enhancing their learning in medicinal chemistry?

2. Literature Review

2.1 Student Engagement in Online Learning

Student engagement in learning, particularly in the context of online and blended learning environments, has been a focal point of educational research, especially during the COVID-19 pandemic. Salas-Pilco et al. (2022) synthesised findings on student engagement in Latin American higher education institutions during the pandemic, emphasizing the behavioural, cognitive, and affective dimensions of engagement (Salas-Pilco et al., 2022). This three-way model of engagement underscores the multifaceted nature of student involvement in learning processes, highlighting the importance of addressing all three dimensions to foster effective learning environments. Unlike traditional classroom settings, online learning environments necessitate active participation and self-directed learning, which can be difficult to sustain without effective engagement strategies. A vast body of research has examined this topic, exploring the multifaceted nature of student engagement in online contexts. Czerkowski and Lyman (2016) emphasised the importance of social engagement, highlighting the need for interaction and collaboration among students and instructors. Understanding these various dimensions allows educators to design online learning experiences that cater to the diverse needs and learning styles of their students. On the other hand, in the study by Abou-Khalil et al. (2021) on low-resource settings, they found that student-content engagement strategies to be most preferred by the participants of their study as compared to student-student strategies. This could be largely due to the limitations of real-time online interaction between students. This theme in the literature showed that although engagement is key in online learning, its implementation remains the major factor affecting the learning experience and intended outcomes.

Another key theme in the literature concerns the factors that influence student engagement. Khlaif et al. (2021) investigates the factors that influence student engagement in online learning environments during the COVID-19 crisis. The study, conducted in middle schools, highlights the negative impact of the transition to online learning on student engagement. Cultural factors, such as parental concerns and traditions, are identified as significant contributors to this phenomenon. The quality of the online content is found to be subpar, further hindering student engagement. The authors emphasise the need for further research to improve online learning in the long term, particularly in the context of cultural and infrastructural challenges faced by developing countries. Furthermore, studies in the areas of student engagement in online settings highlighted the need in establishing clear expectations, providing timely feedback, and creating a supportive learning environment (Carroll et al., 2021; Gray and DiLoreto, 2016).

Nevertheless, in recent years, gamification and game-based learning has emerged as a promising strategy to boost engagement in online programs (Krath, Schürmann and Von Korfflesch, 2021). Gamification is the process of incorporating game design elements into non-game contexts to enhance user engagement and motivation. This approach leverages techniques such as point scoring, leaderboards, and rewards to drive participation and improve outcomes in various fields like education, marketing, and workplace productivity (Deterding et al., 2011; Koivisto & Hamari, 2019). Looyestyn et al. (2017) in their systematic review, explore the potential of gamification, dissecting its various features like points, badges, leaderboards, and challenges. It covers the existing research on gamification's efficacy, analysing studies that have employed gamified interventions in online educational settings. The review highlights that gamification can be a powerful tool for enhancing engagement, but further research is necessary to optimise its design and implementation strategies for different contexts and learner populations. One of such gamified strategies in teaching is the use of ERs, which remains largely understudied in higher education especially in the field of medicinal chemistry.

2.2 Escape Rooms for Teaching and Learning

Escape rooms, originally popular as entertainment venues, have recently gained attention in the educational sector as innovative tools for teaching and learning. These immersive, problem-solving environments provide a unique platform for engaging students in active learning, critical thinking, and teamwork. ERs have been regarded as a type of gamification, which incorporates aspects of game design and principles, such as rewards and incentives, to boost user participation and motivation (López Carrillo et al., 2019) Nicholson (2015) explored the educational potential of ERs, highlighting their ability to create a context for learning through play, which can be particularly effective in enhancing student motivation and engagement (Nicholson, 2015). The interactive nature of ERs requires participants to apply knowledge and skills in a practical, hands-on manner, making the learning experience more memorable and impactful. The adaptability of ERs to various educational subjects and levels is another key advantage (Adams et al., 2018). Veldkamp et al. (2020) demonstrated how escape rooms

can be tailored to teach specific subjects, ranging from science and mathematics to history and language arts. This flexibility allows educators to design ER scenarios that align with curriculum objectives and learning outcomes (Veldkamp et al., 2020). By incorporating elements of storytelling and thematic challenges, ERs can transform traditional classroom content into an engaging narrative, fostering deeper understanding and retention of the material.

In addition, ERs promote the development of 21st-century skills such as collaboration, communication, and problem-solving. A study by Clarke et al. (2017) found that participants in educational ERs showed significant improvement in teamwork and communication skills, as the nature of the challenges within the rooms necessitates effective collaboration and information sharing among team members (Clarke et al., 2017). This aspect of ERs is particularly valuable in preparing students for real-world scenarios where teamwork and problem-solving are essential. Kinio et al. (2019) also demonstrated that medical students who participated in an ER as part of their curriculum showed increased engagement and motivation compared to traditional learning methods. The study emphasised that the active participation and problem-solving elements in ERs stimulate student interest and involvement, leading to a more engaging learning experience (Kinio et al., 2019). Thus, ERs offer a multifaceted approach to education, combining knowledge acquisition with the development of essential life skills.

Despite the insightful findings from the literature on student engagement in online learning and the educational potential of escape rooms (ERs), several limitations and research gaps remain evident. One notable limitation is the generalisability of these studies, as many are context-specific, focusing on particular regions, educational levels, or subjects, which may not translate well across different educational settings or cultural contexts. For example, studies on student engagement in online learning, particularly in low-resource settings, may not fully capture the engagement strategies in more technologically advanced environments. Moreover, the effectiveness of engagement strategies, including gamification and ERs, in promoting long-term knowledge retention and transferability to real-world scenarios remains underexplored. While studies like those by Looyestyn et al. (2017) and Kinio et al. (2019) highlight the immediate benefits of such approaches in enhancing engagement and motivation, there are still rooms in examining their impact on learning outcomes and skill development beyond the classroom. Another gap is the integration of technology in engagement strategies. With the rapid advancement of digital tools and platforms, there is a need to explore how emerging technologies can be effectively harnessed to enhance engagement in online learning environments.

3. Methodology

3.1 Context of the Study

During the COVID-19 pandemic, a 2-credit hour PHC525 NSAIDs, Gastrointestinal system and Pharmacotherapeutics course was conducted online via synchronous "live lectures". The course that consists of lectures in physiology, pharmacology, and medicinal chemistry. The integrated course was taught to 184 third-year pharmacy undergraduate students at the Faculty of Pharmacy, Universiti Teknologi MARA (UiTM). Moreover, students were provided with asynchronous teaching materials, e.g., instructional videos, PowerPoint slides, PDF, and end-of-topic assessments throughout the 14-week course.

In week 10, most medicinal topics were delivered asynchronously as short video lectures. The topics were peptic ulcer drugs, anti-emetics, H₁-antagonists, and non-steroidal anti-inflammatory drugs (NSAIDs). Then, in week 13, a 2-hour live lecture session was held for the students. The ER activity was conducted in the first hour of the session, followed by a lecture on the medicinal chemistry of gout. As an educational intervention, the primary purpose of the ER activity was to help students review the earlier topics in medicinal chemistry and improve their understanding of the didactic content presented in the instructional videos (Abdul Rahim et al., 2022; Eukel et al., 2017; Veldkamp et al., 2020). The escape game also served to encourage peer interactions and active learning online with the hope of turning a typical dry synchronous lecture into a more interesting session under the gaming environment.

The study utilised a design-based research methodology to investigate the impact of the ER activity on student engagement and learning experiences. This approach involved a systematic process of analysis, design, and implementation within a practical educational environment (Wang, 2020). This paper primarily reports on the design and development of the educational escape rooms (ER) and the evaluation results following the initial implementation. Central to the research was the development and implementation of an ER challenge named "MedChem," tailored specifically for medicinal chemistry students. This challenge was integrated into synchronous online learning sessions, engaging the students directly in the activity. To assess the effectiveness

of the MedChem ER, the researchers used self-reported questionnaires, which were distributed to the students upon the completion of the ER activity. This instrument measured the students' perceptions of the ER challenge, focusing on how it influenced their engagement levels and enhanced their overall learning experience.

3.2 Design and Development of the MedChem Challenge Escape Room

The MedChem Challenge ER featured a combination of interactive quizzes and escape room templates as puzzles. As shown in Figure 1, these puzzles were created using Genially templates, a web-based tool for creating interactive learning content. The game employed a linear game structure; as such, the puzzles were arranged accordingly on a real-time collaborative platform. In our case, the Miro board was chosen for its ease of use and stability for online collaboration. Students would solve the interactive puzzles sequentially starting from themes: 1) Where in the world is?, 2) MedChem Superheroes, 3) Find C-19X vaccine code, 4) Stop the Alien invasion, and 5) Final challenge: Baek-hyun's First Date.

As shown in Figure 1, the board was visually divided into four sections. From left to right are: 1) the ice-breaking (the yellow circle), 2) the game briefing, 3) four escape room puzzles, and 4) the final challenge. Unlike recreational escape rooms, the design of escape rooms for pharmacy students must align with specific learning objectives (Table 1). The ER game helped students review the video lectures posted in week 10 by assessing their understanding of the topics. Designed for the players to progress from one topic to the next, the game design also helped ensure that students remained focused on a topic before moving to the next one.

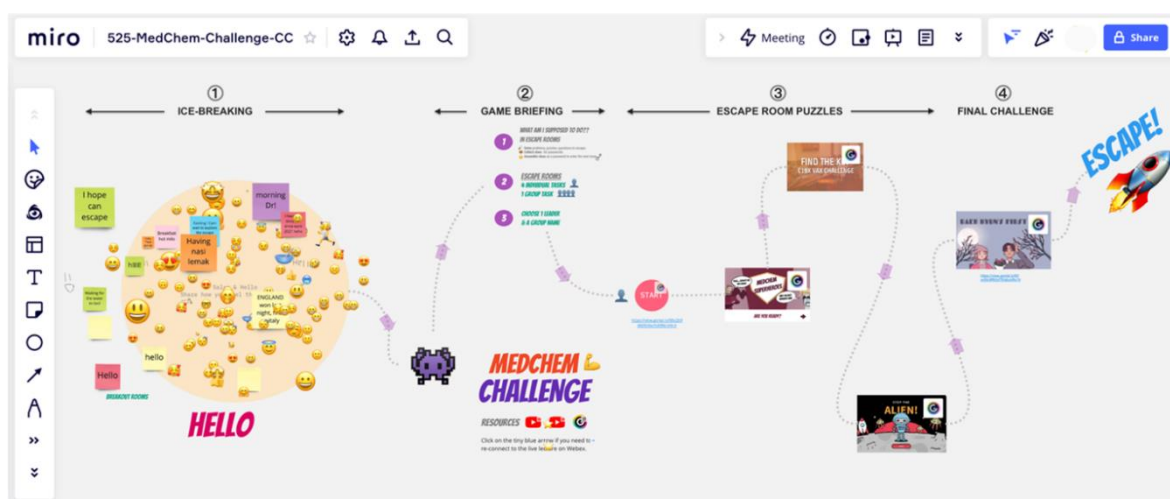


Figure 1: Screenshot of the MedChem Challenge on the Miro Board showing the four sections: 1) ice-breaking area, 2) game briefing, 3) four escape room puzzles, and 4) the final challenge

Furthermore, to keep students engaged with the online tasks, multiple themes were used for each topic, and they were aligned to the course's learning objectives (Table 1). These themes served as the underlying narrative for the challenges. For instance, MedChem Superheroes theme was used for the topic of anti-emetics, whereas Stop the Aliens' invasion theme was created for reviewing peptic ulcer drugs. In the final challenge, Baek-hyun's first date served as a short case-based learning (CBL) for the students to review the medicinal chemistry of H₁ antagonists.

Table 1: Tasks and Learning Objectives

Puzzle	Puzzle Name	Learning Objective and Topic	Type of assessment, Game structure
1	Where in the world is?	A warm-up activity to familiarise students with Genially and the game format.	Quiz, Linear
2	MedChem Superheroes	To briefly review anti-emetics	Quiz, Linear
3	Find the C-19X vaccine code	To review chemistry of NSAIDs	An interactive graphic adventure, Open structure

Puzzle	Puzzle Name	Learning Objective and Topic	Type of assessment, Game structure
4	Stop the Aliens' invasion	To review peptic ulcer drugs	Quiz, Linear
Final challenge	Baek-hyun's First Date	To review H ₁ antagonists, then apply their knowledge in a fictitious situation.	Case-based learning

The background story of the final puzzle revolves around Baek-hyun, a pharmacy student in UiTM, who went on the first date with Soo-hee (Figure 2). Soo-hee asked Baek-hyun for some drug information; for instance, she wanted to know the differences in antihistamine drugs and which drug is best to take for her conditions. Trying to impress Soo-hee, Baek-hyun realised that he had to revise the topic on antihistamine drugs before he could answer her questions.



Figure 2: The CBL final puzzle on the medicinal chemistry of H₁ antagonists was presented in the form of a comic strip titled “Baek Hyun’s First Date” using a Genially theme

This CBL tapped into the Korean pop (K-pop) culture that is quite popular with Malaysian youth and in Asia. Baek-hyun is a familiar name to the students since it is the name of a South Korean singer-songwriter, an idol to many adoring K-pop fans. Going out on first dates and being asked about drugs are situations that the younger generation of pharmacy students can relate to. Furthermore, the CBL provided an authentic learning context for the students by triggering them to “think like a pharmacist”. The third-year student group would need to review given teaching materials and then apply their knowledge in a clinically-relevant scenario of the CBL before providing an answer to Baek-hyun. Unlike the rest of the puzzles in Table 1, the Baek-hyun puzzle was presented as a comic-strip format. Under the ‘Gamification’ category on the Genially platform, more than 150 interactive templates are available for quizzes, games, and escape rooms. These attractive templates can be easily customised and would save significant time for instructors who are keen on developing a digital ER activity.

In addition to a variety of themes, the puzzles in the MedChem Challenge consisted of quizzes, a graphic adventure (an interactive point and click), and a CBL. These employed a combination of linear and open game structures. As such, the puzzles introduced varying levels of difficulties in the ER activity. For example, puzzle 2 was designed as a sequential multiple-choice quiz. In contrast, an interactive graphic adventure was chosen for puzzle 3 (Find the C-19X vaccine) with an open game structure.

In the open game structure, students have the freedom to search and explore for specific clues hidden in each image. Upon stumbling on a correct area, a question pops up. A correct answer would reveal a clue that could be used to unlock the next puzzle. However, a wrong answer would lead students back to the image and the search for clues starts again. The combination of difficulty levels, elements of surprises and multiple themes in the ER activity was an intentional design element in the digital ER game. It could help maintain students’ interests and engagement online via the varied, unexpected, or surprising activities, thus fostering a sense of curiosity and anticipation which could lead to more satisfactory learning (Benlahcene, Kaur and Awang-Hashim, 2021). Under the time pressure, they are likely to have little choice but to work together to escape. Ideally, the ER activity would foster peer collaboration during the synchronous lecture session.

4. Implementation of the synchronous ‘Escape the MedChem Challenge’ Activity

4.1 The Ice-Breaking Session

The 2-hour synchronous session began with an ice-breaking session. When students joined the online Miro Board, they could view the entire ER game. A short ice-breaking session is recommended in any online interactions or courses. To start an ice-breaking session, the instructor posted a message “Share how do you feel this morning” on a huge yellow circle (Figure 1). Almost immediately, the students filled the yellow circle

with emojis. Some of the emoticons were happy, surprise, smiling, and love. Sticky notes were also used. Several students said 'hello' or 'good morning Dr'. Others shared their feelings or what they were having for breakfasts.

The ice-breaking session in this online lecture served two purposes: firstly, to get students familiarize with the Miro platform and secondly, to create a sense of community in a remote online lab by getting them share individual feelings and experiences with other students and the instructor (Hagedorn, Serth and Meinel, 2022; Garrison, Anderson and Archer, 1999). Current literature is replete with studies that reported student passivity or lack of interactions in synchronous lectures held during the COVID-19 pandemic (Sadjadi, 2023; Pires, 2022). Many contributing factors were highlighted, including costly data, internet connectivity and lack of skills in online facilitation. Nevertheless, this ice-breaking activity demonstrated the importance of a low-stake activity, i.e., using emoji or sticky notes as a potential substitute for verbal or video at the beginning of an online lecture. Previous studies supported the use of emoji as a catalyst to foster social and teaching presence in online learners through communication, rapport, and perceived authenticity (Bai et al., 2019; Kim et al., 2022).

4.2 The Escape Room Gameplay

Right after the ice-breaking session, a 10-minute briefing was conducted to inform students about the rules and gameplay. The third-year students joined their own groups of 5-6 members, then went into their group breakout rooms in Cisco Webex. They were instructed to begin with the first puzzle (Figure 3). The questions in puzzle 1 were intentionally created to be as simple and straightforward; they served as warm-up questions to get students to familiarise with the Genially platform. When all questions were correctly answered, students would collect the password 'Belladonna' and use it to access puzzle 2 (Table 1). Google Forms, in quiz mode, was embedded at the end of each Genially puzzle for students to check-in. The forms captured students' progression as they moved in and out of the digital Genially puzzles during the online ER activity. To escape the MedChem Challenge, the time allocation for the teams was 40 minutes.



Figure 3: The warm-up questions of Puzzle 1 tested students on the origins of certain drugs or compounds with medicinal properties. If they answer all correctly, they would be able to obtain the password (e.g., Belladonna) to unlock the next task (Puzzle 2)

The instructor served as the game master and facilitated the ER game online. In a physical ER, the game master can directly monitor students' dynamics and interactions with puzzles by observing their behaviours in person or via webcams (Abdul Rahim et al., 2022). On the contrary, in an online environment, monitoring students is not possible unless the platform is equipped with a tracking feature. Available on the Miro board, the user cursor tracking feature enabled the game master to monitor students' movements in real time. Since a student's cursor is colour-coded and bears the student's name, it was easy to identify students and locate their whereabouts on the platform. Students could also see their group members' cursors which may facilitate online peer collaboration. This is one main advantage of using the Miro board during the remote online ER activity.

Another advantage of the cursor tracking feature in the Miro board is that it allows the game master to anticipate potential issues. Technical issues with the platforms, internet connectivity, or ER puzzles are some potential issues that could arise during an online ER activity. A case in point: about halfway through the game, the game master noticed that an estimate of twenty students' cursors remained stationary for some time around puzzle 3 compared to puzzles 1 and 2. Based on this observation, the game master quickly identified some students from different groups and joined their breakout rooms to make some enquiries. Apparently, they were stuck and unable to find the correct clues in the interactive graphic adventure puzzle 3. The instructor provided hints to facilitate the students' progression through the puzzle as listed in Table 1.

5. Results and Discussion

Of 184 students, only 100 could attend the synchronous lecture session and participate in the ER activity. Eighty students responded to the survey on a voluntary basis. Seventy-one respondents (89%) were female students, and 9 (11%) were male. This imbalance in gender representation is notable. However, it is important to clarify that the researchers did not influence the enrolment process or the allocation of students to this course. The selection and enrolment at the programme level were conducted centrally by the educational institution. Therefore, the gender distribution observed in this study's participant group reflects broader enrolment trends, rather than any selection bias on the part of the research team. Figure 4 shows the devices used by students during the ER game; 83% of the students used laptop computers to play the game. A small percentage of students (3%) used two devices for the activity.

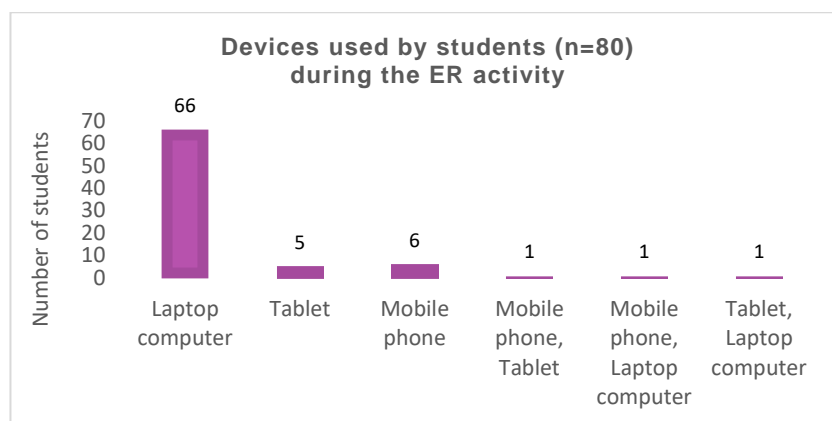


Figure 4: Types of devices used by students during the ER game

5.1 Contribution of the Escape Room Activity in Learning Medicinal Chemistry

Table 2 summarises the results of the student perception of the ER activity. The 15-item questionnaire was adapted from Eukel et al. (2017). It used a five-point Likert scale for each item (1=strongly disagree, 2= disagree, 3=neutral, 4=agree, and 5=strongly agree). Towards the end of the questionnaire, blank spaces were included for students to write further comments and suggest improvements.

Students perceived the ER activity as fun and interesting (4.53), which is consistent with previous studies employing ER games (Abdul Rahim, 2023; Brady and Andersen, 2021; Eukel et al., 2017; Veldkamp et al., 2020). Moreover, they found the ER game relevant to medicinal chemistry topics (4.44). Mostly agreed that the ER activity seemed to be an effective way to learn new information related to medicinal chemistry (4.36), despite having difficulty to focus due to feeling stressed or overwhelmed (3.00). The mixed responses suggested that the ER activity could prove challenging to students, yet they enjoyed it (see Table 4, entry 1). Besides, they thought could learn better in the game format than in a live lecture (3.83) or a video lecture (3.70), and they felt engaged with their group mates to learn new materials (3.73). Fostering teamwork is one advantage of the ER activity and would certainly help them develop the skills as future pharmacists working in multi-disciplinary healthcare teams.

Table 2: Student perceptions on the contribution of the escape room activity in learning medicinal chemistry

Items	<i>m</i>	<i>SD</i>
The activity was fun and interesting!	4.53	0.94
The escape rooms were relevant to the topics in medicinal chemistry.	4.44	0.95
The escape room was an effective way to learn new information related to medicinal chemistry.	4.36	0.97
I learn better in a game format than in a live lecture.	3.83	1.11
I learn better in a game format than in a video lecture.	3.70	1.05
It was difficult for me to focus on learning because I was feeling stressed or overwhelmed.	3.00	1.20
I feel I was able to engage with my group mates to learn new material.	3.73	1.09

m mean, *SD* standard deviation

5.2 Escape Room Game Design

In terms of the ER game design, getting instant feedback after making mistakes appeared to be well-received by the students (4.50, 0.95) as shown in Table 3. This game feature informed them of their level of understanding of the topics. Students seemed hesitant about the statement on the ER activity being too difficult (2.58, 1.05). Concerning the time frame of the ER game, they gave mixed responses (2.41) on having insufficient time to complete the game. Though the students seemed fairly distracted by the non-educational parts, i.e., the multiple Genially themes in learning medicinal chemistry (3.11, 1.41), the variety of the escape room activities was perceived as an effective way to review the topics in medicinal chemistry (4.36).

Table 3: Student perceptions on the escape room game design

Items	<i>m</i>	<i>SD</i>
Getting instant feedback after making mistakes makes my learning better.	4.50	0.95
The variety of escape rooms was an effective way to review the topics in medicinal chemistry.	4.36	0.97
Not enough time...	2.41	1.19
The escape rooms were too difficult!	2.58	1.05
The non-educational portions (e.g., the superhero, the alien themes) distracted me from learning about medicinal chemistry.	3.11	1.41

m mean, *SD* standard deviation

5.3 Students' Learning Experiences and Overall Student Perception on the Activity

Table 4 shows an overall student perception of the escape room activity. The third-year student found the ER game challenging yet seemed to enjoy the challenges (4.40, 0.99). It could correspond to the utilisation of a variety of features employed in the ER game in which challenging puzzles serve as a source of enjoyment and excitement in learning. Furthermore, students perceived that the activity would make them more confident in learning medicinal chemistry (3.99, 0.97). They would recommend the ER activity to other students (4.31, 0.98).

Table 4: Overall student perceptions of the escape room activity

Items	<i>m</i>	<i>SD</i>
Challenging games, but I enjoyed them.	4.40	0.99
The escape room helped me feel more confident learning medicinal chemistry.	3.99	0.97
I would recommend this activity to other students.	4.31	0.98

m mean, *SD* standard deviation

Table 5 lists representative positive and negative students' comments in the open-ended questions. Most students positively perceived the game, and described it as "fun", "interesting" and "exciting" for learning medicinal chemistry topics. A student's comment that illustrates the ER learning experience: "It's exciting way to learn! First time doing this activity and it definitely wake me up from feeling sleepy in the morning." They also found that the game was helpful for learning the Medicinal Chemistry topics since it provided an assessment on their level of understanding and gave instant feedback on their mistakes.

Table 5: Representative students' comments on the ER activity

Positive comments	Negative comments
It's exciting way to learn! First time doing this activity and it definitely wake me up from feeling sleepy in the morning.	More time. before starting the game, ice-breaking with teammates because we did not start together and lost communication :D
This is much interesting to learn! Since we know on what level of understanding we have in Med Chem and we can improve in the future.	It would be better if lecturer could ask students to form group beforehand so we can form group with people that we are comfortable with.
I love this escape room because it gives me better understanding because of feedback given after make mistakes. It would be nice if every after lecture, we play this game to improve understanding.	The activity was fun. But sometimes disrupted with internet connection problem. Because of this problem, certain students might lost and didn't know how to participate in the game. Students need to ensure to have strong internet connection before playing the game.

Positive comments	Negative comments
This is a very interesting way of learning, I can see that lecturer really put a lot of effort for this learning session. I would prefer picture along side with the questions so I can see the chemical structure mentioned.	Actually for me with slow line Internet connection, it was kind of lagging (need to open Webex and Miro in one).
Overall is awesome. Its actually interesting and fun!!!! Thank you Dr.	This way is good since i know what my mistake are however using Miro made my laptop kind of slow.

Negative comments on the game design highlighted two inter-related technical aspects which were not apparent during the gameplay: 1) the use of the Miro Board, and 2) internet connections. According to some students, the use of the Miro Board caused their computers to slow down. They also reported that the use of multiple platforms (Genially, Cisco Webex and Miro board) caused noticeable delays during the gameplay, thus underscored the need for a good and stable internet connection for such online activity. Another consequence of frequent internet disconnections during the gameplay was that some students could not follow the pre-game briefing. This led to them feeling lost and unable to fully participate in the game. Apart from the technicalities, students also expressed their need for more time before starting the game. They felt their lack of familiarity with the ER activity and their teammates hindered smooth participation and game progression.

Our results corroborated with prior research and lent support to introducing the ER activity as an educational intervention *in lieu* of a live lecture (Abdul Rahim et al., 2022; Eukel et al., 2017; Veldkamp et al., 2020). Students positively perceived the ER activity and indicated that it was relevant and effective in enhancing their understanding of medicinal chemistry topics. According to them, the ER game was fun and interesting. The students perceived that they learned better in the game format than in a live lecture or a video lecture. It is reasonable to assume that the use of multiple themes in a gaming environment may appeal to Gen Z students. Though the puzzles were challenging, they seemed to enjoy the challenges during the gameplay. The overall results indicated the online ER activity promoted engagement, persistence on task and collaboration. These are critical conditions for deep learning (Eukel et al., 2017; Benlahcene, Kaur and Awang-Hashim, 2021). Nevertheless, some aspects of the game can be improved; for instance, a pre-game briefing will include a live briefing with written instructions, and a longer ice-breaking session for student teams with an increased time for the gameplay in the next iteration.

Based on the results, several recommendations can be made to enhance the effectiveness and enjoyment of the educational ER activity. Firstly, addressing the technical issues is crucial. Simplifying the platform use by either integrating the tools more seamlessly or reducing the number of platforms can minimise computer slowdowns and delays. Additionally, incorporating a more comprehensive pre-game briefing, possibly with written instructions alongside a live session, would ensure all participants are well-informed and prepared, especially those who might face disconnections. Extending the ice-breaking session would allow students to become more comfortable with their teammates and the ER environment, promoting better teamwork and engagement. Finally, increasing the overall gameplay time would not only accommodate students' need for familiarization but also allow them to delve deeper into the medicinal chemistry topics, thereby enhancing their learning experience. These improvements, centred around student needs and technical efficiency, can maximise the educational impact of the ER activity while maintaining its fun and interactive nature.

6. Limitations

While the study provides valuable insights, several limitations have to be acknowledged. The data, exclusively derived from a single cohort at one institution, could potentially limit the broader generalisability of the findings. In addition, the unfamiliarity of some students with the ER activity format resulted in comprehension difficulties, which may limit the applicability of the findings. For future research, expanding the study to include multiple institutions could diversify the data, potentially leading to more comprehensive results. In terms of future implementations, consideration could be given to the provision of initial training sessions on the usage of digital ERs. This could possibly lead to greater student engagement and enrich the overall learning experience. By addressing these areas, the potential for improved generalisability and relevance of the findings in the broader educational landscape could be increased.

With regards to the design-based research methodology adopted in this study, it is worth noting that the study only reported the first iteration of the ER design. There are several steps in the actual design-based research methodology that had to be improvised to suit the situation at that time, which was affected by the constraints imposed by the educational institution's timetable and resources. This resulted in a condensed design cycle that

may not fully capture the iterative nature of design-based research, where multiple iterations of design, testing, and refinement are typically employed to optimize educational interventions. Future iterations of the ER design could benefit from a more extended timeline and access to greater resources, which allows for a more thorough refinement of the educational tool. Engaging in a collaborative design process with stakeholders such as educators, students, and technical staff could also enhance the relevance and usability of the ER activity.

7. Conclusion

This paper describes the design and implementation of a multi-themed, interactive ER activity in lieu of a synchronous Medicinal Chemistry lecture. In answering the research questions, the responses from the third-year pharmacy students have clearly indicated a positive perception of the multi-themed digital escape room (ER) activity, particularly in terms of engagement and learning experience. They have reported that the ER activity not only made the learning process more interactive and enjoyable but also significantly enhanced their understanding of medicinal chemistry topics. Furthermore, the study's findings suggest that the ER activity's innovative approach to teaching medicinal chemistry has been effective in making complex concepts more accessible and memorable, thereby underlining its usefulness as an educational tool in this field.

Recent studies on escape rooms in pharmacy education or chemistry were mainly based on only one theme (Abdul Rahim, 2023; Eukel et al., 2017). Existing literature reveals a dearth of research on the use of escape rooms to promote active learning in medicinal chemistry. Thus, to the best of our knowledge, this is the first digital escape room (DER) that focuses only on medicinal chemistry topics and employs multiple themes. For educators, the multi-themed DER activity, offers considerable flexibility and adaptability. The themes are versatile and can be effortlessly integrated and replicated in diverse educational contexts beyond Medicinal Chemistry.

Apart from the aspect of novelty, this study has also contributed to the pool of studies pertaining to ERs by highlighting the design structure and its corresponding tools. These could be a valuable point of reference in future research. The digital ER activity has demonstrated its value as a potential educational intervention to escape passive learning during didactic lectures, as supported by the findings of a systematic literature review on Digital Educational Escape Rooms (Makri et al., 2021). The ownership of learning the medicinal chemistry topics during the ER game challenges had shifted from the lecturer to Gen Z students. This provided invaluable opportunity for peer collaboration in the acquisition of 21st-century skills, aligning with the outcomes observed in the application of digital escape rooms in STEM education.

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