Analysing the effectiveness of digital escape rooms on enhancing student experience and knowledge acquisition – A microbiology-based case study

Nicola Morgan and Matthew Allan Jones
The University of Salford
Corresponding author: m.a.jones9@salford.ac.uk

Abstract

Active and gamified teaching methods, such as digital escape rooms, effectively enhance student outcomes. However, current work in this area is highly specialised and lacks translational capability across sectors, with limited data associated with key higher education impact measures. This study aimed to design a central platform for developing digital escape rooms and evaluate their pedagogical impact using a microbiology-based example.

A university-wide platform for the design and delivery of digital escape rooms and an exemplar microbiology-based room were developed utilising WordPress with specialist plugins. The study cohort was comprised of 17 students from a range of biology, biomedicine and chemical science programmes. Quantitative surveys were then completed to understand how digital escape rooms impacted key pedagogical metrics with further stratification based on socioeconomic factors.

Overall feedback was positive with students reporting a positive experience (100 %), the escape room was well developed (88.2 %), increased their knowledge (82.4 %) and added value to their degrees (70.6 %). These data show the positive pedagogical impacts of digital escape rooms in higher education.

Keywords: Digital Escape Rooms, Microbiology, Gamification, Digital Learning, Higher Education

Introduction

For centuries games have been a normal part of society, from board games to digital games. Over previous decades, the integration of games into higher education (HE) has become increasingly more frequent by HE practitioners through the concept of gamified education (Landers, 2014; Subhash & Cudney, 2018). Gamified education is a form of teaching utilising elements of games or activities to actively engage students in the learning process. Games can have a profound impact and draw on emotional connections enabling people to reflect on their experiences and facilitate active recall (Huang et al., 2019). This form of teaching has been readily utilised to increase student engagement (Mohamad et al., 2018), provide a simulation of real-life events (Krishnamurthy et al., 2022) and accomplish the overcoming academic challenges (Kaufmann, 2018).

Gamified learning can arise in many forms including interactive quizzes (e.g. Kahoot or Mentimeter), escape rooms, card games, mobile apps, and virtual simulations (Kim et al., 2017; Zainuddin et al., 2020), with their use increasing as supplements to traditional HE delivery methods (lectures, workshops, tutorials) or as alternatives to this style of teaching. Gamified tools such as simulation have now become commonly utilised within medicine and allied health subjects to support development of practical and intellectual competencies in subjects where physical demonstration may be difficult or cause harm to individuals, such as medicine and nursing programmes. Apprentice surgeons routinely use virtual simulations for training, which enables surgeons to perform procedures in a risk-free environment with access to the facilities at times that fit in their work schedules (Cosman et al., 2002). Within a nursing environment games have been used to simulate clinical settings, which has been shown to improve knowledge retention and increase clinical reasoning (Padilha et al., 2019).

Whilst gamification has shown significant promise as a pedagogical tool, the overall success of gamified education is dependent on the quality of gamification, constructive alignment to course content, as well as engagement with gamified learning by participants. Overall, multiple studies have shown that the gamification of learning content increases student engagement and subject knowledge (Chen & Liang, 2022; Kim et al., 2017), both of which are inducive to improved academic

outcomes. Whilst more traditional gamification approaches and simulations are now routinely used within HE, other types of gamified learning have gained significant traction in recent years, including integrating escape room concepts into higher education learning.

Escape rooms are rooms or areas that participants are 'locked' in, with the task to complete a series of puzzles to 'break out' of the room before the time runs out. These rooms typically consist of physical puzzles that will relate to codes that need to be unlocked to leave the room and therefore end the game (Taraldsen et al., 2022). These concepts have been developed in educational games to help students utilise the knowledge and skills developed during their degree programmes. Due to the quick timing and enclosed space, escape rooms have been shown to increase leadership skills, with one study describing increased listening, conflict negotiations, verbal communication and advocating viewpoint (Veldkamp et al., 2020).

In recent years there has been an increasing number of publications highlighting the digital conversion of the escape room concept into learning materials known as digital escape rooms. Digital escape rooms are similar in concept to physical escape rooms, with the end goal of 'breaking out' of the digital room (Makri et al., 2021). However, these rooms are delivered virtually with all puzzles built digitally, with computerised locks that need a code to be unlocked. The interactivity and easy access of digital forms of education are beneficial to both educators and learners allowing learners to participate in these activities at their leisure, with no physical space requirements allowing for delivery at scale. These rooms have been shown to encourage active learning and engagement within the student cohorts, with an observed increased understanding of the topic developed as a result (Makri et al., 2021).

One of the key challenges within HE is to teach students how to apply their knowledge to real-world scenarios, in addition to solving problems either individually or as a part of a team. These escape rooms, both physical and digital, offer valuable tools to allow students to begin to develop these problem-solving competencies and apply them to scenarios which mirror what they would observe in future assessments or in the workplace upon graduation. These benefits of escape rooms in HE have been previously described in numerous subject areas but have been predominantly

utilised across science, technology, engineering and maths (STEM) based subjects including sex education (von Kotzebue et al., 2022), pharmacy (Fraguas-Sánchez et al., 2022), chemistry (Gilbert et al., 2020), mathematics (Fuentes-Cabrera et al., 2020), cardiac physiology (Horn, 2022), renal physiology (Hu et al., 2024), and medical education (Gillespie, 2021).

Nearly all these digital escape rooms are designed for individual academics or subjects to use, limiting the utilisation and wider impact of the resources developed. One area this could be improved upon is through the development of a central platform for the design and delivery of digital escape rooms, allowing academic staff from across an institution to rapidly design and develop digital escape rooms related to their subject area, leveraging the already established technical knowledge. For this case study to assess the pedagogical benefits of digital escape rooms via a central platform, we created a microbiology-focused digital escape room, which has been highlighted as currently lacking from educational digital escape room provision (Brown et al., 2018; Makri et al., 2021).

Therefore, based on these studies, this project sought to design and implement an institution-wide platform for the design and delivery of digital escape rooms to integrate into HE practice and to evaluate the efficacy of digital escape rooms as pedagogical tools to enhance student knowledge and experience utilising a microbiology based exemplar digital escape room.

Methods

Digital escape room platform development

The purpose of the digital escape room platform is to provide a freely available platform for students to access and use as an extra studying tool to complement traditional content delivery methods. The digital escape room platform developed as a part of this project known as UoScape (www.uoscape.co.uk) was hosted through WordPress (Automattic Inc, USA). This was selected due to the ability to develop a wide range of content and to make the content freely available globally. Additionally, WordPress was selected as it allows for the utilisation of built-in software plugins enabling the website to be built using predesigned layouts and content to allow for a rapid design and delivery of escape rooms upon request from academic colleagues.

The UoScape website was built using the plugin Elementor v3.24.6 (Elementor, Israel) which allowed editing and changes to individual web pages, to facilitate the streamlining of escape room development.

Microbiology digital escape room development

The microbiology digital escape room centres on exploring the laboratories located at the University of Salford using 360° images taken from a GoPro Max camera (GoPro, USA). The images were uploaded into the WordPress virtual reality Pro plugin, to navigate and sequence 360° images to mirror the concept of movement around a space. The theme of the digital room focuses on the structure and Gram of bacteria, viral replication, antibiotic disc diffusion and general microbiological knowledge. The games were aimed at students attending their first year of university and have basic knowledge of microbiology.

The layout of the website requires a web page to be created and linked to the home page of the site with the use of inbuilt buttons containing hyperlinks to the unique web pages. The timer at the start of the digital escape rooms is created using the plugin HurryTimer with the Evergreen mode, this mode gives users their own unique timer from when they enter the web page. An initial launch page enables the user to get background information on the current digital escape room. A short introductory video was created in Animaker (https://www.animaker.com/) to depict cartoon-style images linking to a locked laboratory. Upon entry to the digital laboratory, the user is started at the entrance of the laboratory and able to freely navigate around to locate the puzzles hidden within the room.

There are four unique puzzles (Gram stain game, viral replication game, crossword, jigsaw) within the digital escape room, each designed using information available to the students throughout the year. The Gram stain (Multiple choice question and Image hotspot), viral replication (Imaging sequencing) and crossword puzzles were created using H5P v1.16.0, with the jigsaw puzzle created using Jigsaw Planet v1.3. To 'escape' the laboratory, the user must type in the correct five-digit code accumulated from the puzzles around the room. The WordPress plugin Passster v4.2.6.6 was used to create a locked section. When the correct code is entered into the password box the user is taken to a unique webpage with congratulatory text and

buttons 'Feedback', which contains a hyperlink to a review survey; 'Home' which contains a hyperlink to the home page; and 'Back to Lab' which restarts the digital escape room.

Microbiology digital escape room participants

The Microbiology escape room was delivered through the digital escape room platform UoScape (www.uoscape.co.uk) and made freely available globally online. For this study, only students enrolled in both author's host institution were eligible to prevent the biasing of the data by non-students who may play escape rooms through this platform. This was confirmed by survey access only being available to participants with a host-institution email address. The escape room was advertised to students via extracurricular groups and through embedding into a first-year microbiology-based module available to all Biomedical Science, Human Biology and Infectious Diseases and Biochemistry students. Over the course of the evaluation period (November 2023 – August 2024), there were 220 visits to the microbiology digital escape room. Of these visitors, a total of 17 participants completed the feedback survey and consented for participation in this project.

Survey design and delivery

To evaluate the pedagogical impact of the digital escape room on student experience and knowledge acquisition, students were requested to complete a quantitative survey following the completion of the microbiology-based digital escape room to allow them the opportunity to rate the practical and technical elements of the digital escape room, in addition to how it impacted their student experience and knowledge acquisition. This approach to data collection was selected to gather key information from participants via the online escape room platform, allowing participants to complete the survey from any location globally, without the need for on-campus attendance. The overall evaluation survey (Appendix 1) was delivered via Microsoft Forms (Microsoft, USA) immediately upon the digital escape room time limit being reached or successful completion of the microbiology digital escape room, with all responses returned anonymously.

All questions were designed as either open-answer questions or based on a 5-point Likert scale with the responses categorised as scores of one or two indicating a negative response, a score of three indicating a neutral response, and scores of four or five indicating a positive response, as previously described in Hussain et al. (2023). The questions used in the survey were distributed into multiple categories to evaluate various aspects of the digital escape room including technical quality, student experience and knowledge acquisition, puzzle design and difficulty and digital escape room participants' backgrounds and demographics.

Utilising participant background data including non-term time postcodes, the likelihood of higher education participation (based on the POLAR 4 scoring system (HEFCfE, 2017)), participant's home area representation in higher education (based on the TUNDRA LOSA scoring system (OfficeforStudents, 2019)), the abundance of higher education qualifications within the participants home area (based on the Adult HE 2011 scoring system (OfficeforStudents, 2020)) and the United Kingdom Government ministry of Housing Communities & Local Government English indices of deprivation (https://imd-by-postcode.opendatacommunities.org/imd/2019) were determined to allow for data stratification based on these metrics.

Statistical analysis

The results of all student surveys are reported as mean ± standard deviation. Data normality was evaluated using the Shapiro-Wilk test or Kolmogorov-Smirnov test for normality dependent on the sample size evaluated. All two group comparisons were conducted using parametric unpaired t-tests, non-parametric Mann-Whitney tests or Wilcoxon matched-pairs signed rank test as described in the associated figure legends. All statistical analysis was performed using GraphPad Prism version 9.5.1 (GraphPad Software, USA). Statistical significance was set at $P \leq 0.05$.

Ethical approval

The studies involving human participants were reviewed and approved by the institutional ethics committee (Ethics Application ID: 14273). All questionnaires and analysis procedures were also approved by this ethics committee. The participants

provided their written informed consent to participate in each stage of the study and were allowed to withdraw at any time before publication.

Results

Microbiology digital escape room design

The microbiology digital escape room was designed to integrate the learning of a first-year undergraduate microbiology module with core concepts for the puzzles constructively aligned to both previously taught content and the upcoming assessment, allowing the room to be utilised as an active revision tool. The digital escape room centres on exploring the laboratories located at the University of Salford using custom-taken 360° images. The theme of the digital room focuses on the structure and Gram of bacteria, viral replication, antibiotic disc diffusion and general microbiological knowledge, all of which are core threshold concepts required to successfully pass the associated microbiology module. These concepts were then split across a series of four puzzles (Appendices 2-5) where students would have to utilise their knowledge of these concepts to deduce a password and successfully escape the room.

Participant demographics

The demographics of the participant cohort are described in Table 1. Demographic analysis revealed that the majority of the participants were female (82.4 %) and from minoritised ethnic backgrounds (64.7 %). Analysis also found that participants were from intermediate higher education access backgrounds based on their POLAR4 (3.3 ± 1.9), TUNDRA LOSA (3.0 ± 1.6) and ADULT HE (3.3 ± 1.6) scores. The majority of the participants (58.8 %) reported no previous experience with any form of escape room with those who had completed an escape room previously stating an average of 1.0 ± 1.7 escape rooms per participant.

**Table 1. Microbiology digital escape room participant demographics.**

Participant demographics	
Gender (% Female)	82.4 %

Minoritised ethnic background (%)	64.7 %
Vocational qualification (%)	47.1%
Average Multiple deprivation decile	3.4 ± 3.1
Average POLAR4 score	3.3 ± 1.9
Average TUNDRA LOSA score	3.0 ± 1.6
Average ADULT HE score	3.3 ± 1.6
Previous experience of escape rooms (%)	41.2 %
Average number of escape rooms previously conducted	1.0 ± 1.7

Digital escape room participant technical feedback

Overall, students who completed the escape room provided positive feedback relating to the technical qualities of the Microbiology digital escape room, as shown in Figure 1. Most students (88.2 %) reported that the escape room was well developed, with 76.5 % of students stating that the escape room worked well on the device they used to complete the digital escape room. However, 5.9 % of participants did report a negative experience using it on their device. The majority of students (58.8 %) found the digital escape room visually appealing, with 17.6 % of participants disagreeing and reporting poor visual appeal of the room. Students reported mixed opinions regarding the navigability of the digital escape room, whilst 52.9 % of students reported a positive ability to navigate the room, 29.4 % did report a negative opinion on navigating through the escape room, highlighting an area of improvement for future iterations of digital escape rooms using this platform.

Figure 1. Participants technical experience of using the UoScape platform and the microbiology digital escape room.
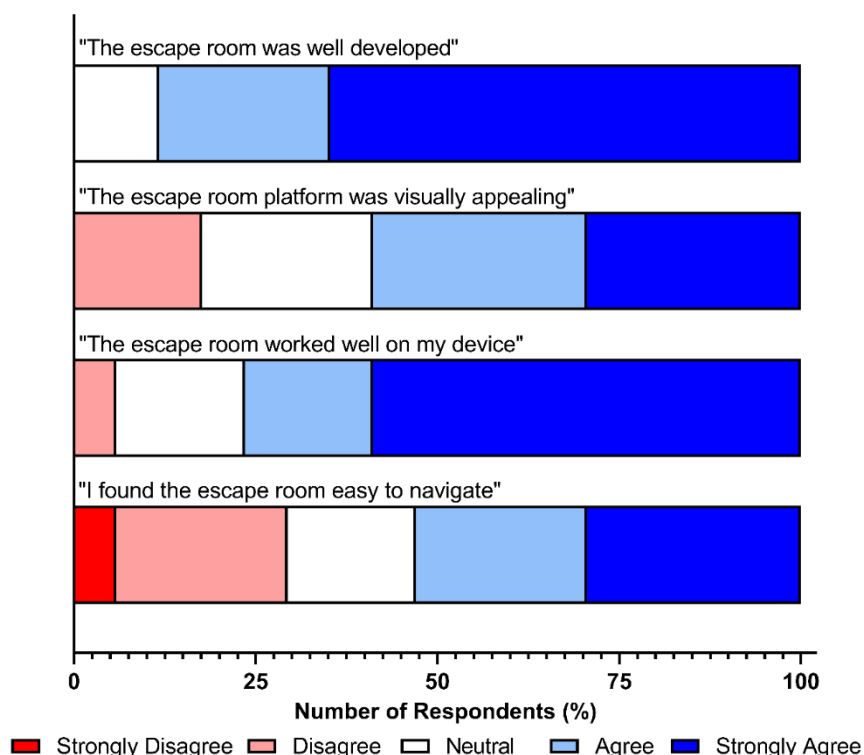

Does the Digital Escape room positively impact student experience?

Analysis of student feedback relating to student experience metrics and enjoyment of gamified learning such as digital escape rooms revealed highly positive feedback to all questions, as visualised in Figure 2. All participants reported an overall positive experience in utilising digital escape rooms as a part of their academic content. Further to this, 82.4 % of participants stated that utilising the digital escape room helped to enhance their knowledge of key microbiology concepts, with 70.6 % of students stating that they thought the addition of the microbiology digital escape room was a valuable tool to support their education. Analysis also revealed that 82.4 % of digital escape room participants enjoyed the gamification of academic content such as that used in the microbiology digital escape room, with 11.8 % of students stating that they did not like this gamified version of learning. These data also identified that the majority of students (70.6 %) thought that the addition of digital escape rooms enhanced the value of their degree programme, with 76.5 % stating

that they would recommend the microbiology digital escape room and digital escape rooms using this platform to their peers.

Figure 2. Participants experience of completing the digital escape room.
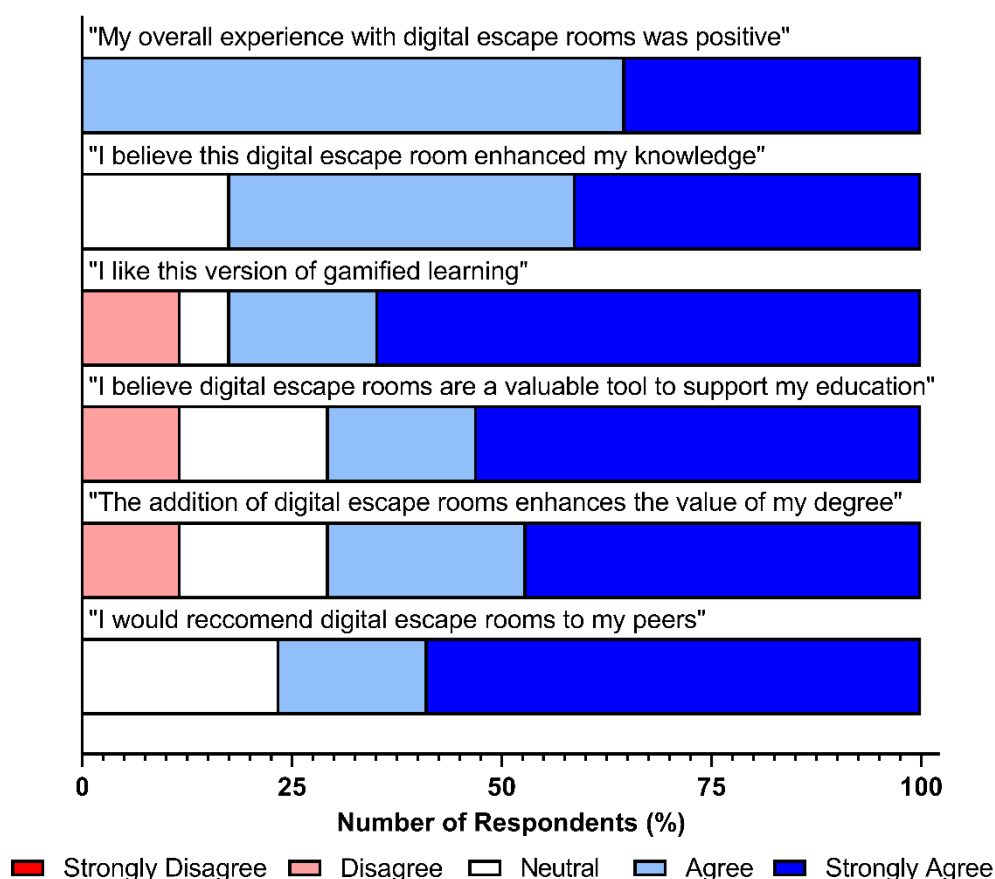
Does puzzle type influence student experience and knowledge acquisition?

We next sought to determine if different puzzle types utilised within the microbiology digital escape room (Gram staining game, Viral replication game, Crossword puzzle and Jigsaw puzzle) influenced student experience and knowledge acquisition. To do this, we surveyed students on their enjoyment of each puzzle in addition to whether they found it challenging, interesting and knowledge-enhancing, the results of which are shown in Figure 3.

Most students (88.2 %) found the Gram staining game enjoyable with only 5.9 % reporting a negative experience with the game (Figure 3A). The majority of students stated that the game was challenging (64.7 %) and interesting (70.6 %) with 17.7 %

of students stating that the game was easy and 5.9 % finding it disinteresting. Most students (76.5 %) also stated that the game enhanced their knowledge relating to Gram staining with only 5.9 % reporting that it did not support their knowledge acquisition.

Figure 3. Participants feedback on puzzle types

The puzzles evaluated include A) Gram staining game, B) viral replication game, C) crossword puzzle, and D) jigsaw puzzle. Response scores of 1 = strongly disagree/not challenging, and scores of 5 = strongly agree/too challenging. n = 17 for all panels.

When the viral replication game (Figure 3B) was evaluated, it was observed that the
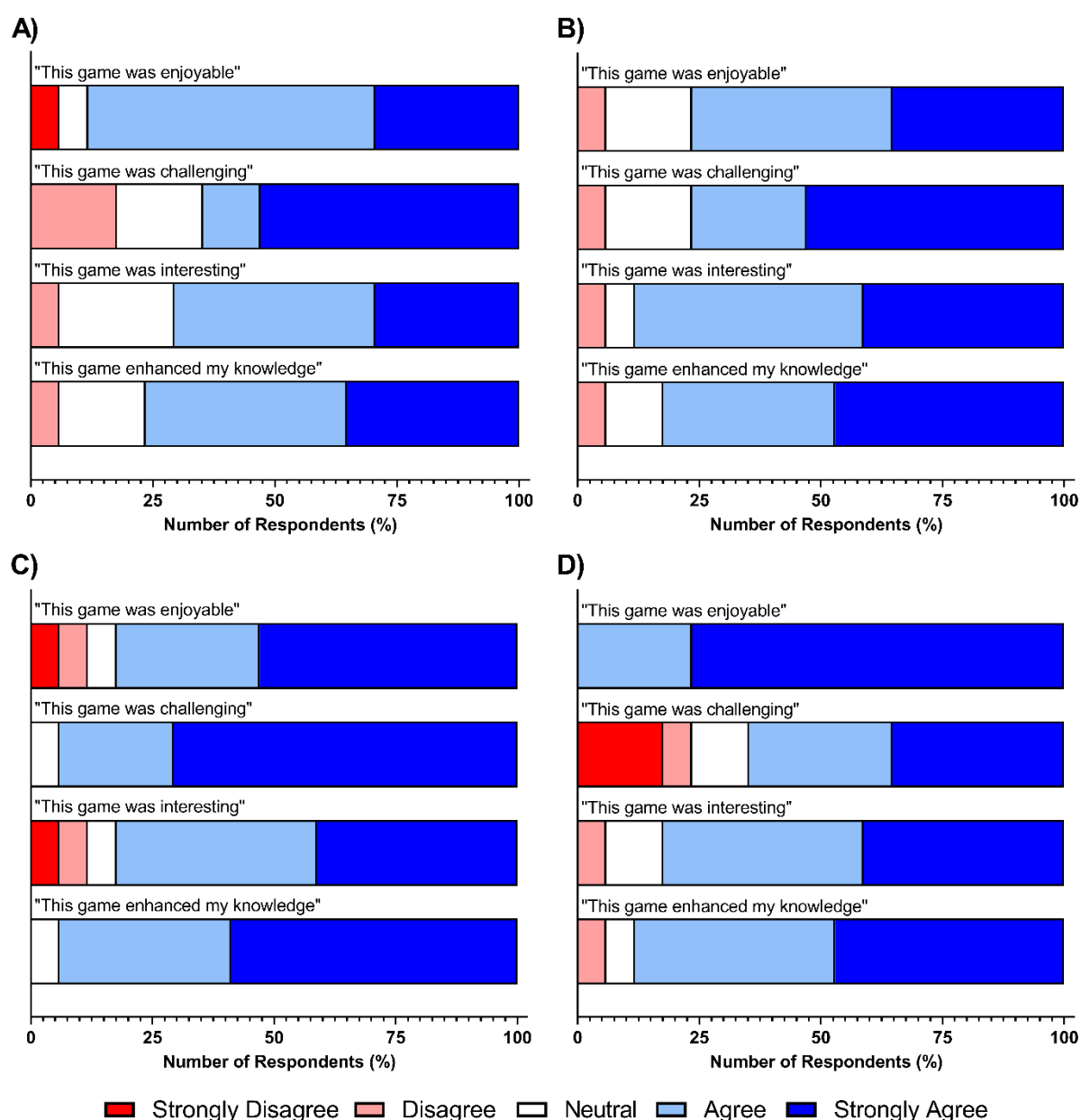
majority of the participants reported positive feedback relating to its enjoyability with

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76.5% of students stating they enjoyed the game. Most students found this game challenging (76.5 %) however, the majority found the game interesting (88.2 %) and knowledge-enhancing (82.4 %).

The third game of the escape room was a crossword puzzle, similar to the previous puzzles most students (82.4 %) found the crossword puzzle enjoyable and interesting to complete (Figure 3C). The majority of students did state that the crossword puzzle was challenging (94.1 %), however, the same number of students (94.1 %) did identify that this puzzle enhanced their knowledge of microbiology. The final puzzle of the escape room was the jigsaw puzzle (Figure 3D), student feedback revealed all students enjoyed completing this type of puzzle. The majority of students also stated that they found the game interesting (82.4 %) and enhanced their knowledge (88.2 %). Students reported a mixed response when the puzzle level of challenge was evaluated with most students reporting the puzzle to be challenging (64.7 %), however, 23.5 % of students found the puzzle easy to complete.

**Socio-economic backgrounds and university entry qualification?**

To determine if digital escape room preferences differed between students' socio-economic backgrounds or university entry qualifications, which are known to be associated with disparity in HE outcomes, students were stratified based on their minoritised ethnic status, completion of a vocational qualification, social deprivation index, in addition to POLAR 4, TUNDRA LOSA and ADULT HE scores.

When student's overall experience was stratified based on socio-economic and university entry qualifications (Figure 4) we observed a significantly higher average response score from students who studied vocational entry qualifications (BTEC and Access courses) compared to non-vocational qualifications (such as A-levels) (Non-vocational: 4.1 ± 0.3, n = 9 versus Vocational: 4.6 ± 0.5, n = 8, P = 0.026, Figure 4B). Student overall escape room experience was found not to significantly differ when stratified based on the other socioeconomic parameters evaluated.

Stratification revealed no significant differences in participant average response scores when students were asked about whether their microbiology knowledge was

enhanced (Appendix 6), their enjoyment of gamified learning (Appendix 7), degree value enhancement (Appendix 8), supported their education (Appendix 9), and if they would recommend this to their peers (Appendix 10).

Figure 4. The impact of socioeconomic and university entry qualifications
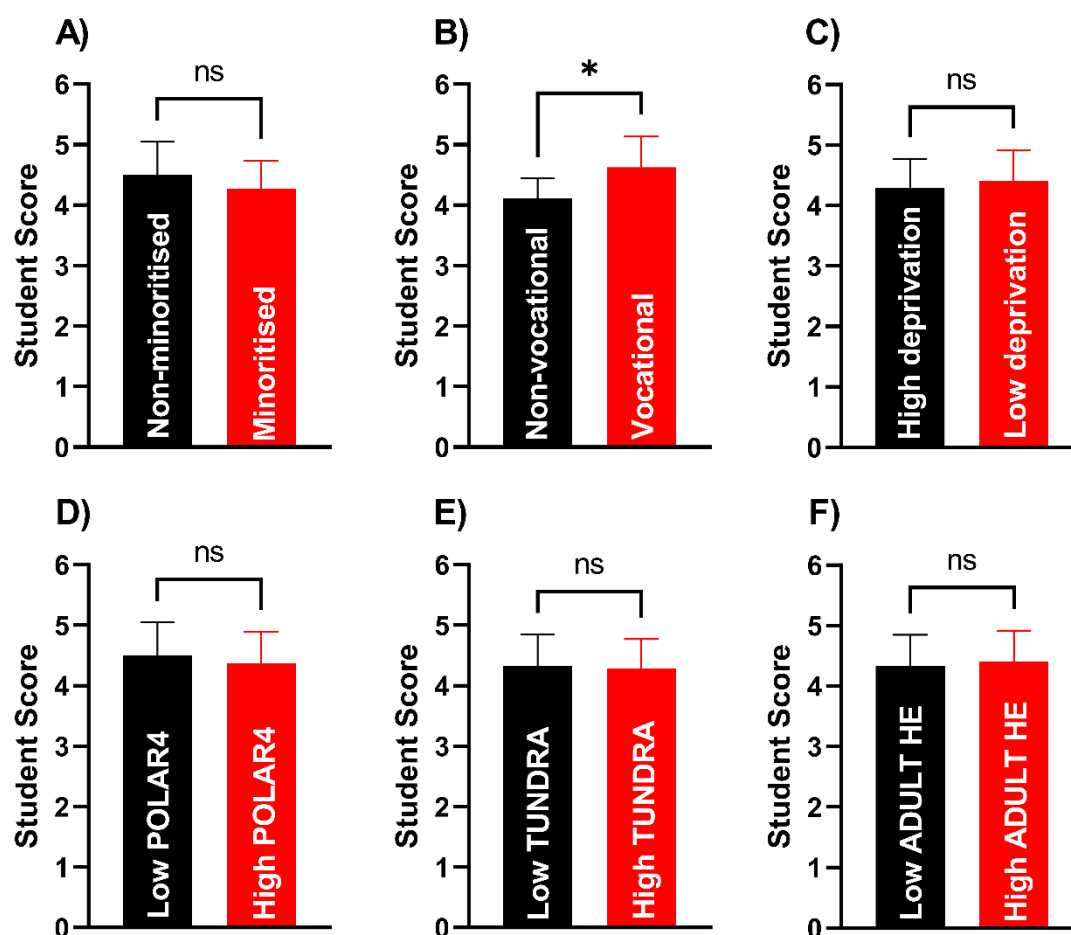
Participants were stratified based on their A) minoritised ethnic status, B) university entry qualification, C) social deprivation decile, D) likelihood to participate in higher education (POLAR4 score), E) area representation in higher education (TUNDRA LOSA), and F) participants areas abundance of higher education qualifications (ADULT HE). Data expressed as Mean ± Standard deviation. Statistical analysis was conducted using Mann-Whitney analysis. * indicates $P < 0.05$, ns = not significant. n = 17 for all panels.

Discussion

Over the previous decades, higher education has progressed through a digital transition, where many students now access all their learning materials via digital means. In addition, the increasing costs of participating in higher education mean that more students are having to take on additional paid employment alongside their studies, thus decreasing the amount of time they can spend on their studies outside

of timetabled sessions, supporting the increased need for a digital transition to support students from non-traditional higher education entry backgrounds. Whilst the integration of physical escape rooms into HE have been shown to be excellent for developing key transferable skills, they are time-consuming to set up and deliver and low throughput for large student cohorts putting increased demand on academic staff. Therefore, the development and design of digital alternatives may mitigate these factors, whilst still supporting knowledge acquisition and enhancing student experience.

Our study has shown that it is feasible to develop a centralised platform for the design and delivery of digital escape room content within higher education utilising finite resources and additional technical expertise to produce a valuable pedagogical tool which can be utilised across departments and institutions. Through the design and development of a microbiology-based digital escape room, we describe the positive impacts of digital escape room integration on student experience and perceived knowledge acquisition (Figure 2).

These findings corroborate those of Antón-Solanas et al. (2022) and Vidergor (2021) who found substantially greater student experience, enjoyment and knowledge absorption through the utilisation of digital escape room content within their curricula. Whilst the later of these studies was conducted within elementary level education rather than higher education, it supports the idea that digital escape rooms such as the one developed as a part of this study can be adapted for all levels of education to facilitate the enhancement of student experience whilst supporting their knowledge acquisition and application. This further highlights the benefits of the gamification of learning to maintain student engagement but also support their learning through the concept of "learning through stealth", where students are unknowingly utilising knowledge or skills that they have acquired through their degree programmes within fun or interactive gamified teaching and learning tools such as escape rooms (Sharp, 2012; Shute et al., 2021).

We also found that the types of puzzles used in the digital escape room had no significant impact on changes in enjoyment (Figure 3), with all puzzles being positively enjoyed by students. When compared to the perceived level of challenge, we did find a loss of enjoyment based on average score, however, this was marginal compared to the other puzzles evaluated, with the exception of the jigsaw puzzle

(Figure 3D) where it was perceived by students to be the least challenging and received a 100 % positive score for puzzle enjoyment. Despite this, the majority of students reported highly positive responses to whether the digital escape room puzzles enhanced their subject knowledge in the area of microbiology.

Previous studies have shown digital escape rooms to enhance knowledge aquation in their respective fields (Bezençon et al., 2023; Gillespie, 2021; Horn, 2022) corroborating our observations. However, a study by Buchner et al. (2022) added to this by describing that the timing of the delivery of digital escape rooms (before or after instruction) can play an important role in the promotion of learning and thus knowledge acquisition, with after the completion of instruction being found to promote learning in their study cohort. In our study, the microbiology digital escape room was provided as a revision tool after instruction, and therefore it may be the case that the highly positive knowledge enhancement scores observed in both Figures 2 and 3 may be partially due to students already possessing the initial knowledge with the digital escape room providing a platform through which to apply it, allowing them to reaffirm their knowledge and increasing their perception of knowledge acquisition. One potential theory for this is that the process of completing the digital escape room increases their independence via scaffolding in line with Vygotsky's zone of proximal development concept (Vygotsky, 1978).

Within this study, we also sought to examine if the experience of utilising digital escape rooms varied depending upon various socioeconomic and demographic factors, which are commonly associated with HE awarding gaps, such as minoritised ethnic status and degree programme entry qualification type (Arday et al., 2022; Baker, 2020). When the study cohort was stratified based on these factors, we only observed a statistically significant difference in the student experience between students who studied non-vocational (A-levels) vs vocational (BTEC or Access courses) (Figure 4B). All other stratifications were found to be non-significant, highlighting overall equity in experience (Figure 4), perceived enhancement of degree value (Appendix 8) and perceived knowledge enhancement (Appendix 6) across the cohort in all other characteristics used for stratification.

With an observed widening of awarding gaps generally across HE based on numerous socioeconomic factors, the inclusive design of curriculum content is paramount to addressing these award gaps in the long term. The findings from our stratifications highlight the potential of digital escape rooms as a teaching and

learning tool, which is both inclusive to students irrespective of background and achieving equitable outcomes when evaluated on student experience and degree value, factors which have been associated with poor engagement and outcomes within higher education (Boero et al., 2024; WONKHE, 2024). Whilst these findings are promising, the authors must acknowledge that stratification groups are likely underpowered and therefore may not be representative of the wider demographic and socioeconomic groups. Subsequent further evaluation will be conducted to better understand if these observations are maintained in a larger sample size.

This study further highlights that the development of a central platform for the design and dissemination of digital escape rooms is feasible and deliverable on a worldwide scale with a modest budget for establishment. This ensures that is cost-effective for HE institutions to maintain and allow for further future development. The design and development using a single central platform allows a consistency of approach to be maintained across the institution, and allow for the more efficient leveraging of skills and knowledge used in the development of the initial platform. It also allows for optimised utilisation of academic time, as using pre-set but customisable puzzle types allows academics to focus on the constructive alignment of the escape room puzzles to the academic content rather than constructing the room itself, decreasing the time required to develop a viable product. Whilst some technical coding knowledge is required for the establishment of the central digital escape room platform, this can be readily acquired via built-in WordPress tutorials and online video guides thus allowing for the knowledge acquisition curve to be minimised.

The ability to custom design the content of the digital escape rooms allows for a high level of flexibility in the aesthetic of the escape rooms, whether they be designed using three-dimensional virtual environments or custom-taken 360-degree images to allow for the integration of real-world environments linked to the institution or even professional environments to allow for exposure to these environments ahead of graduation. The incorporation of campus spaces may support students in their academic transition to higher education by helping them to visualise key teaching and learning environments before joining the HE institution. Therefore, digital escape rooms utilising real-world spaces may be of significant value for incorporation into induction or pre-induction activities to help support students through the "prepare" and "encounter" phases of the academic transition, thus improving student experience, sense of belonging and outcomes during their first year of study (Jones et al., 2020; Van Herpen et al., 2020).

One of the known benefits of escape rooms is the ability to develop teamwork and team-based problem-solving skills (Makri et al., 2021; Veldkamp et al., 2020). However, with the digital escape room delivered via integration into the virtual learning environment of a taught module, it is likely that students will have been conducting the digital escape room individually rather than as a team, thus eliminating the development of these transferable skills. Whilst we have shown that students still see value in the use of digital escape rooms for their learning, it may be that to propagate the development of these team-based skills, the digital escape room is delivered in person to allow for student interaction and collaborative completion of the puzzles. A significant proportion of students (29.4 %) who utilised the UoScape platform reported some issues with navigating the space within the microbiology escape room to locate the puzzles within the room (Figure 2). Upon review of verbatim student feedback (Data not shown), it highlighted that this could be improved by clearer instructions upon the launch of the digital escape room to allow students to understand what each button in the room means to increase overall navigability. However, despite this concern, the majority of students who completed the microbiology digital escape room (52.9 %) did find the navigability of the digital escape room to be positive.

Conclusion

Overall, this study demonstrates an effective approach for the design and delivery of digital escape rooms using a central unified system, and through the exemplar microbiology-based room, that digital escape rooms are valuable pedagogical tools for supporting students' knowledge acquisition and overall experience within higher education.

Acknowledgements

Disclosure Statement

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Appendices

Appendix 1. Survey questions provided to participants following the completion of the microbiology digital escape room.

Question 1	**Do you agree to participate in the project?**
	Yes or No
Personal Information	
Question 2	**Please provide your gender:**
	Open answer
Question 3	**Please provide your ethnic background:**
	Open answer
Question 4	**Are you a home or international student?**
	Home
	International
Question 5	**Please provide your home postcode:**
	Open answer
Question 6	**Please provide your programme of study**
	Open answer
Question 7	**Please provide your Level of study:**
	Level 3

	Level 4
	Level 5
	Level 6
	Level 7
Question 8	**What qualification did you complete before coming to university for your undergraduate degree?**
	A level
	BTEC
	Access to Higher Education
	T level
	Employment
	International qualification
	Other (Please state)
Question 9	**Where do you normally review your learning materials?**
	Phone
	Laptop
	Tablet
	Other (please state)
Question 10	**Have you ever participated in an escape room of any type before?**
	Yes
	No
	If yes, how many have you previously completed.
Technical questions	
Please indicate how much you agree with the following statements:	
Question 11	**"The escape room was well developed"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 12	**"I found the escape room platform easy to navigate"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 13	**"The escape room platform worked well on my device"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 14	**"I found the Escape room platform visually appealing"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Individual puzzle evaluations	
Please indicate how much you agree with the following statements:	

| Gram Staining Game	
Question 15	**"I found this puzzle enjoyable"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 16	**I found this puzzle challenging"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 17	**"I found this puzzle interesting"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 18	**"This puzzle enhanced my knowledge on this subject"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Viral replication game	
Question 19	**"I found this puzzle enjoyable"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 20	**I found this puzzle challenging"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 21	**"I found this puzzle interesting"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 22	**"This puzzle enhanced my knowledge on this subject"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Crossword puzzle	
Question 23	**"I found this puzzle enjoyable"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 24	**I found this puzzle challenging"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 25	**"I found this puzzle interesting"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 26	**"This puzzle enhanced my knowledge on this subject"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Jigsaw puzzle	
Question 27	**"I found this puzzle enjoyable"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 28	**I found this puzzle challenging"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 29	**"I found this puzzle interesting"**

	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 30	**"This puzzle enhanced my knowledge on this subject"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Overall Digital escape room experience	
Question 31	**"My overall experience with the escape room was positive"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 32	**"I like this gamified version of learning"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 33	**"I believe that access to digital escape rooms would enhance the value of my degree"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 34	**"I believe that digital escape rooms would be a valuable tool to support my education"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 35	**"I believe that this digital escape room enhanced my knowledge"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 36	**"I would recommend digital escape rooms to my colleagues/peers"**
	1 (Strongly Disagree) – 5 (Strongly Agree) Likert scale
Question 37	**Please use this box to provide any further feedback/comments regarding the digital escape room.**
	Open Answer Question

Appendix 2. The Gram staining puzzle used within the UoScape microbiology digital escape room.
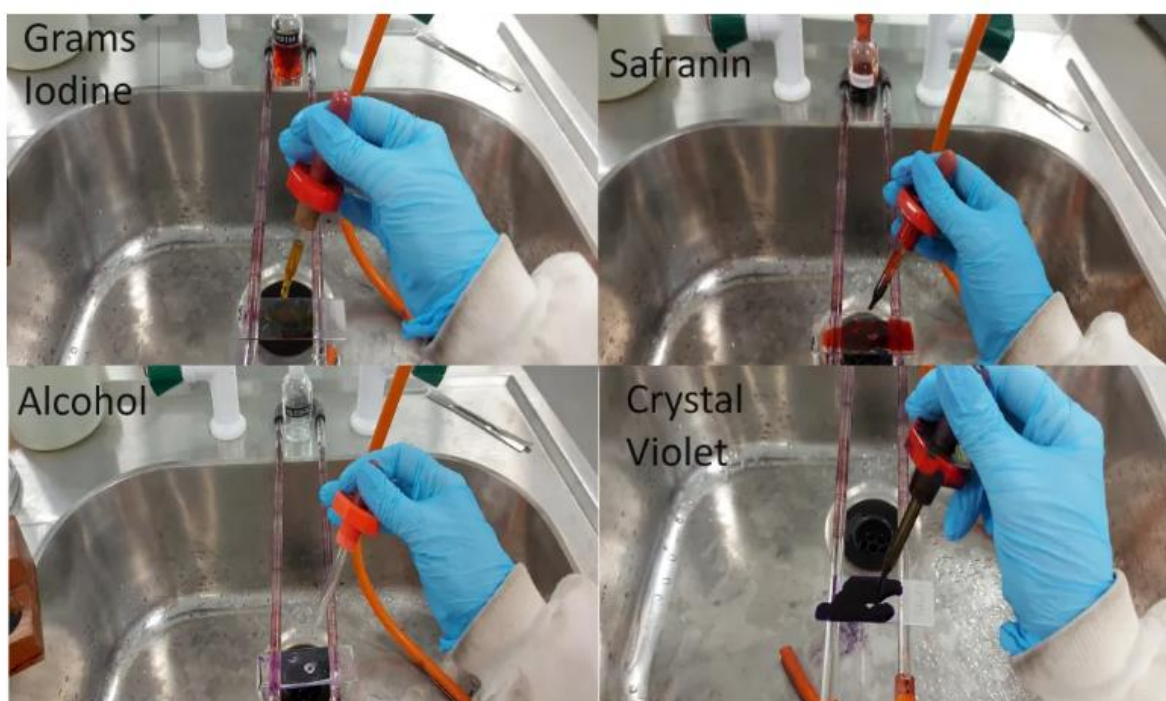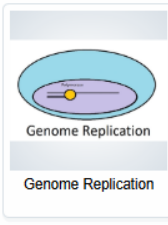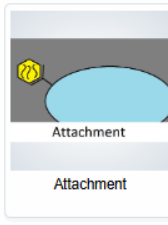
Appendix 3. The viral replication puzzle used within the UoScape microbiology digital escape room.
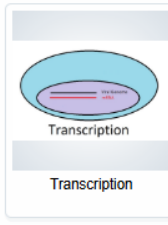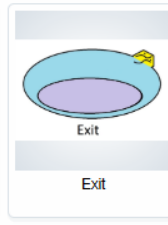
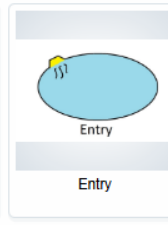Drag to arrange the images in the correct sequence
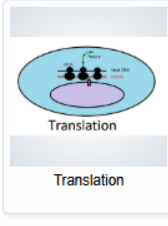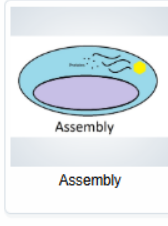
Genome Replication	Attachment	Transcription	Exit	Entry
Genome Replication	Attachment	Transcription	Exit	Entry
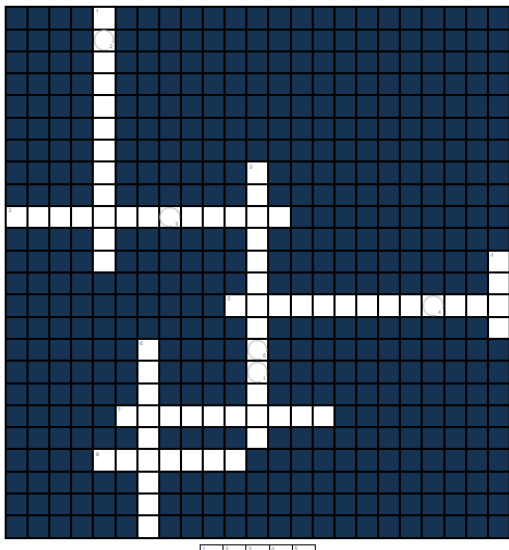
Translation	Assembly
Translation	Assembly

Time spent
0:00
Total Moves
0

✔ Check

↻ Reuse   <> Embed   H-P

Appendix 4. The crossword puzzle used within the UoScape microbiology digital escape room.

Correctly figure out each answer to the crossword to find a number clue

Across

3 NAG and NAM are components of what? *(13)* ⓘ

5 Virus that infects bacterial cells *(13)* ⓘ

7 The viral family HIV belongs to *(10)*

8 Molecule capable of producing an immune response *(7)*
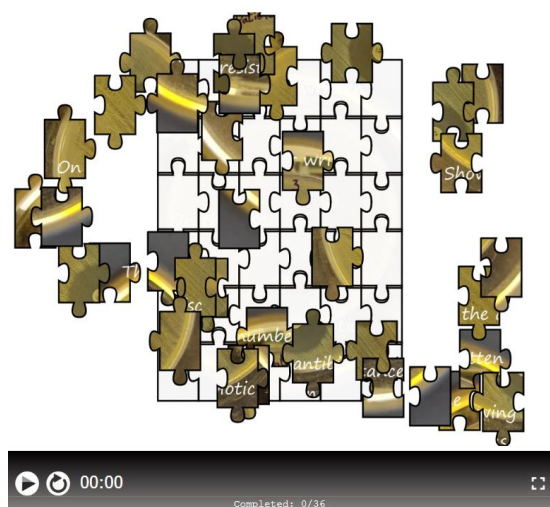
Down

1 Term used for the process of eliminating bacteria from surfaces or objects *(12)* ⓘ

2 Bacteria that play a role in oxygenating the planet *(13)*

4 Enteropathogenic Escherichia coli is also known as *(4)* ⓘ

6 Media used to allow specific bacteria to grow *(9)*

✔ Check   ↻ Retry

↻ Reuse   <> Embed   H-P

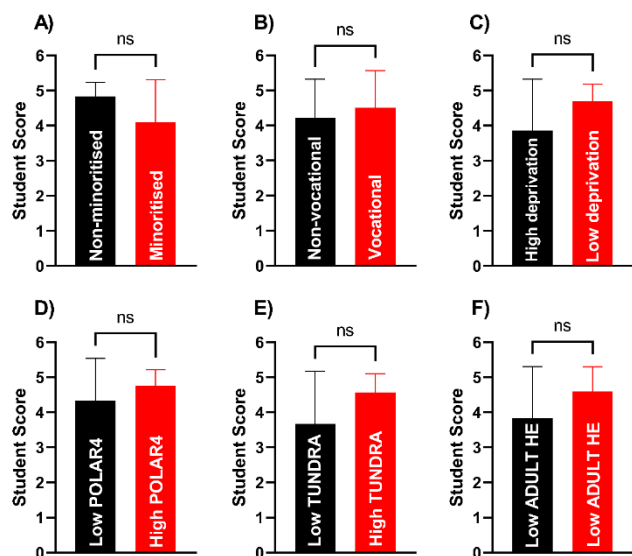**Appendix 5. The jigsaw puzzle used within the UoScape microbiology digital escape room.**

Appendix 6. Awarding gap and socioeconomic factors did not influence participant microbiology knowledge enhancement following participating in the microbiology digital escape room.
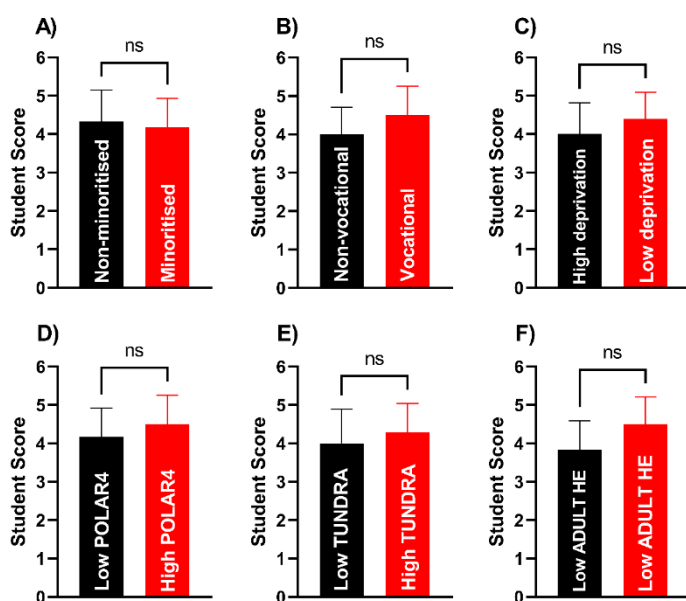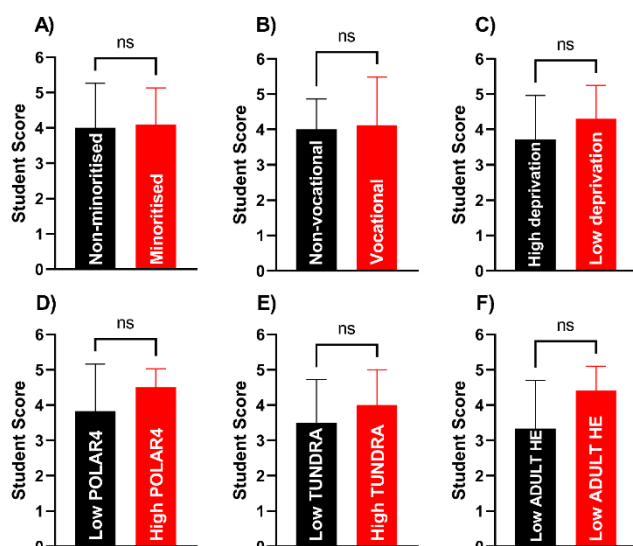

Participants were stratified based on their A) minoritised ethnic status, B) university entry qualification, C) social deprivation decile, D) likelihood to participate in Higher education (POLAR4 score), E) area representation in higher education (TUNDRA LOSA), and F) participants areas abundance of higher education qualifications (ADULT HE). Data expressed as Mean ± Standard deviation. Statistical analysis was conducted using Mann-Whitney analysis. ns = not significant. n = 17 for all panels.

Appendix 7. Awarding gap and socioeconomic factors did not influence participant enjoyment of gamified learning
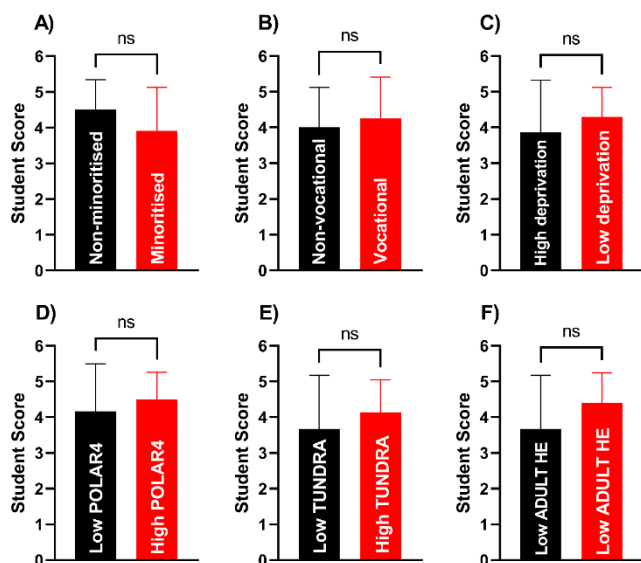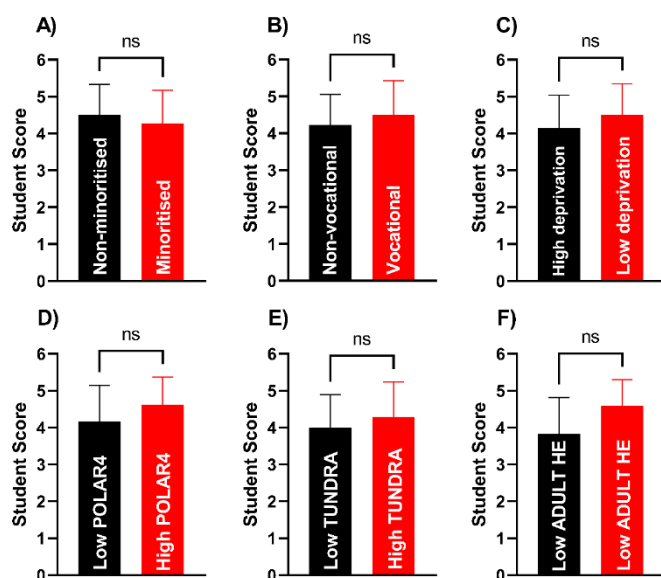

Participants were stratified based on their A) minoritised ethnic status, B) university entry qualification, C) social deprivation decile, D) likelihood to participate in Higher education (POLAR4 score), E) area representation in higher education (TUNDRA LOSA), and F) participants areas abundance of higher education qualifications (ADULT HE). Data expressed as Mean ± Standard deviation. Statistical analysis was conducted using Mann-Whitney analysis. ns = not significant. n = 17 for all panels.

Appendix 8. Awarding gap and socioeconomic factors did not influence participants perceived increase in degree value following the addition of a microbiology digital escape room

Participants were stratified based on their **A)** minoritised ethnic status, **B)** university entry qualification, **C)** social deprivation decile, **D)** likelihood to participate in Higher education (POLAR4 score), **E)** area representation in higher education (TUNDRA LOSA), and **F)** participants areas abundance of higher education qualifications (ADULT HE). Data expressed as Mean ± Standard deviation. Statistical analysis was conducted using Mann-Whitney analysis. ns = not significant. n = 17 for all panels.

Appendix 9. Awarding gap and socioeconomic factors did not influence participants value of the digital escape room to support their education

Participants were stratified based on their **A)** minoritised ethnic status, **B)** university entry qualification, **C)** social deprivation decile**, D)** likelihood to participate in Higher education (POLAR4 score), **E)** area representation in higher education (TUNDRA LOSA), and **F)** participants areas abundance of higher education qualifications (ADULT HE). Data expressed as Mean ± Standard deviation. Statistical analysis was conducted using Mann-Whitney analysis. ns = not significant. n = 17 for all panels.

Appendix 10. Awarding gap and socioeconomic factors do not influence participants likelihood to recommend the digital escape room to their peers

Participants were stratified based on their A) minoritised ethnic status, B) university entry qualification, C) social deprivation decile, D) likelihood to participate in Higher education (POLAR4 score), E) area representation in higher education (TUNDRA LOSA), and F) participants areas abundance of higher education qualifications (ADULT HE). Data expressed as Mean ± Standard deviation. Statistical analysis was conducted using Mann-Whitney analysis. ns = not significant. n = 17 for all panels.