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Activity

Spectroscopy Unlocked: An Escape Room Activity for Introductory Chemistry Courses

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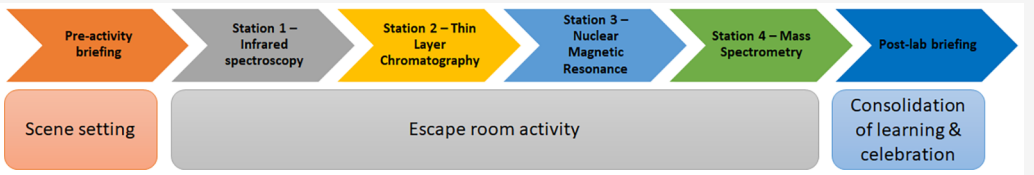

ABSTRACT: *Spectroscopy Unlocked* is an escape room activity cocreated by student and staff authors. The escape room presents students with a series of activities that they must complete in the laboratory in order to reveal a series of codes and clues that can be combined to "unlock" the escape room. Students were highly engaged with the escape room, and evaluation of the activity revealed that students agreed that the format of the activity facilitated their learning and that the activities provided an appropriate level of challenge. The activity can be integrated into introductory chemistry courses, and it may be possible to adapt the activity to change the level or content to meet the specific needs of other courses.

KEYWORDS: *First-Year Undergraduate/General, Laboratory Instruction, Humor/Puzzles/Games, Problem Solving/Decision Making, Laboratory Equipment/Apparatus, Mass Spectrometry, Spectroscopy, Chromatography*

INTRODUCTION

Game-Based Learning

Game-based learning involves the use of games as the basis of formal and informal learning activities. Game-based learning typically facilitates active learning through enjoyable, engaging, and challenging activities[1] that often involve a competitive element (e.g., learners may be competing with their peers to win the game). A large variety of game types have been used in chemistry education, including card games,[2−4] board games,[5] app-based games,[6] and role-playing games.[7] Games have been developed that span a wide range of different topics in chemistry education, including introductory topics such as chemical bonding[8] and organic nomenclature[9] and more advanced topics including quantum mechanics[10] and retrosynthesis.[11]

Reported benefits of using game-based learning approaches in chemistry education include improved student engagement,[12] creating a structure to support peer learning,[13] and positive impacts on student learning of the relevant topics.[14]

Escape Rooms

Escape rooms are team-based activities where players are typically "locked" in a location (either physical or virtual) and must find clues by solving problems or challenges to escape from the room.[15] Escape rooms typically require players to coordinate their efforts in order to solve the challenges set.[16] Escape rooms have increased in popularity since the first recorded example of a public escape room in 2007 and have been designed around various different premises and contexts (e.g., escape rooms based on popular books, movies, or television series).[17]

A number of chemistry-based escape rooms have been developed that require students to engage with challenges based on a variety of different facets of the subject, including laboratory chemistry,[18] models of atomic structure, radioactivity, and the periodic table,[19] and specific topics in inorganic chemistry.[20] During the COVID-19 pandemic there were a number of published examples of remote escape room activities.[19,21]

The majority of published chemistry escape rooms share a number of common features: (i) students work in teams; (ii) teams must solve a series of challenges that provide hints or codes; and (iii) the hints or codes are put together at the end of the activity to escape from the room.

Student−Staff Cocreation

Cocreation of learning materials with undergraduate students is an important approach that can help improve the quality of the educational experiences for students involved in cocreation and those who engage with the materials.[22,23] One of the primary benefits of cocreation is that it allows students to be

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more invested in their learning and may result in their being more likely to take ownership and responsibility of their own learning. This can result in a deeper understanding of the learning material, leading to an impact on academic performance (e.g., better achievement of learning outcomes).[23] A significant advantage of cocreation is the production of more relevant and focused learning materials.[24] Student cocreators can help ensure that the educational materials and activities are relevant to their needs and interest, helping make it more practical and applicable to real-world situations. Cocreation also fosters a more collaborative and inclusive learning environment. This can help build a sense of community and belonging.[25]

Spectroscopy Unlocked: A Laboratory-Based Escape Room

In this submission, we present a student-codeveloped chemistry-laboratory-based escape room called *Spectroscopy Unlocked*. The following sections include a discussion of the design of the puzzles, the incorporation of appropriate safety measures, and the assessment of *Spectroscopy Unlocked* as an effective learning tool.

METHODOLOGY

Cocreation of Activity

Spectroscopy Unlocked was cocreated by a team of two final-year undergraduate chemistry students working as part of a chemistry education research project along with two experienced (in the context of this course) faculty members. The student coauthors took the lead on designing the practical challenges as well as the overall structure of the escape room (e.g., how the different elements of the activity aligned to allow students to "escape" from the room). The faculty members led by ensuring that the developed activities were pitched at a suitable level for students taking the course. The author team met on a weekly basis for a 10 week period leading up to the delivery of the activity. Team meetings lasted 1 hour and focused on alignment of activities with course intended learning outcomes (see Table 1), practical requirements of delivering the activities (i.e., identifying and ordering the required resources), and designing the evaluation tools.

Table 1. Relevant Intended Learning Outcomes for the Course

1	Manipulate simple laboratory equipment and glassware and hence perform a variety of basic synthetic and analytical practical procedures (either individually or as part of a larger team) in a safe manner and following good chemistry laboratory practice.
2	Accurately observe and record experimental details and results and appreciate the different types of errors that may occur and how to deal with them.
3	Employ a range of analytical techniques to determine important thermodynamic, kinetic, and spectroscopic properties of systems, solutions, and reactions.

The activity was deployed as part of the laboratory module in an introductory practical chemistry course. The course was taken by chemistry students completing a foundation year. The foundation year is an alternative entry route for students who do not meet the standard entry requirements for the first year of the University of Leicester's Chemistry or Natural Sciences degree programs.[26]

Promotion of Activity

The success of an escape room often depends on its ability to generate a sense of anticipation and mystery in its participants. Inspired by other work in the literature,[27] this sense of anticipation was fostered through the creation and publication of "teaser" posters to advertise the escape room (Figure 1). The posters were deployed throughout the School of Chemistry's home building some weeks in advance of the escape room being scheduled.

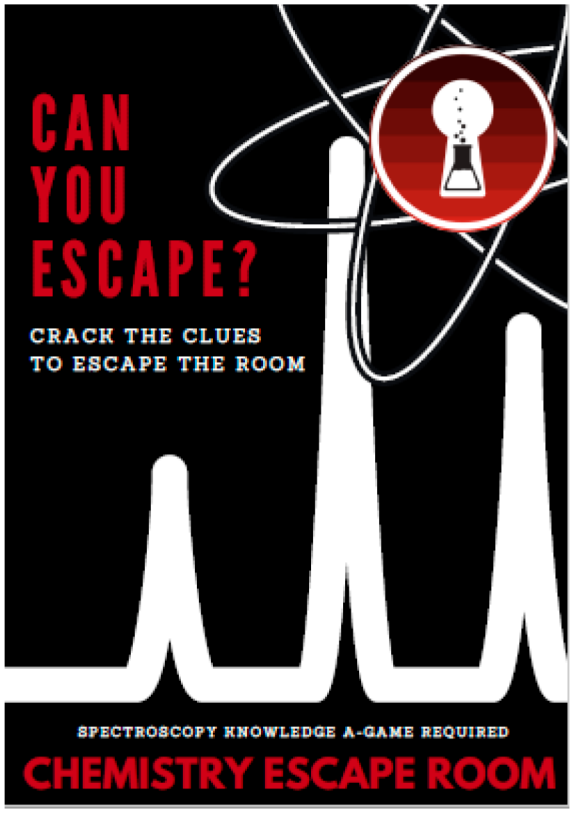

Figure 1. Promotional poster advertising the escape room, designed by the student partners.

Setting the Scene

Before entering the laboratory, students are presented with the front page of a fictional newspaper briefly explaining the problem in the laboratory (see Appendix 4.5 in the Supporting Information). Students also watch two short videos where anonymous villains set the scene for the activity. Both the newspaper article and videos show how two "pranksters" are teasing students about higher education being a waste of time and encouraging them to prove them wrong.

After engaging with the scene-setting activities, students enter the laboratory, where there are four different "stations". Each of the stations is based on a different topic: (i) infrared spectroscopy, (ii) thin-layer chromatography, (iii) NMR spectroscopy, and (iv) mass spectrometry. Each station consists of an experiment or exercise based on that particular topic and a puzzle that must be solved after the completion of the experiment. The activities located at each station are interrelated: the solution for each one provides vital information that must be used in the following activity (see the schematic overview in Figure 2).

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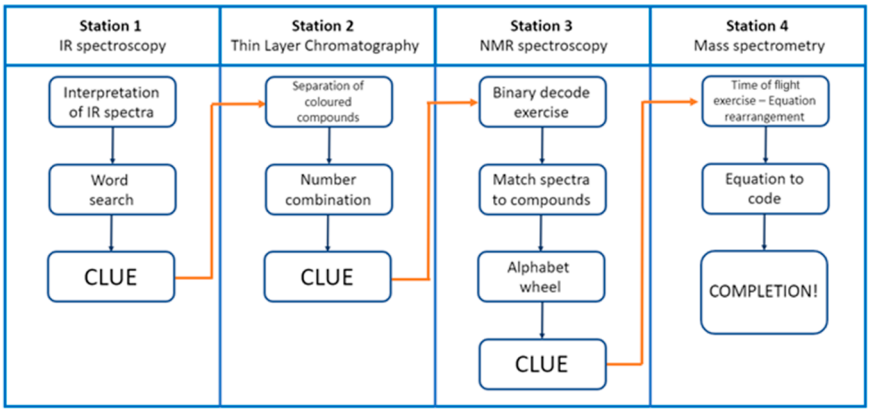

Figure 2. Schematic overview of the structure of the escape room.

Station 1: Infrared Spectroscopy

At this station, students are provided with three unlabeled chemical samples and two names of organic molecules. In order to complete the experimental part of this station, students must record an infrared spectrum for each sample, identify the relevant functional groups in each spectrum, and determine which two of the samples correspond to the names provided. The name of the third sample is obtained by completing a word search game. As students have already recorded an infrared spectrum for this unknown third sample, they will already know which functional groups are present in the molecule (the infrared spectrum shows that the sample is an alcohol; the sample is ethanol).

Once they have successfully determined the names of all three samples, students are told that there is a three-letter word contained in the name ethanol that corresponds to an item placed in the laboratory with information that they need to help them to complete the second station. The three-letter word is "hat", and this is easily identified as hats are not usual items in a laboratory environment.

Station 2: Thin-Layer Chromatography

The hat contains instructions about the second activity station, which is based on thin-layer chromatography (TLC). In this station, students run a series of TLC plates of a mixture of colored compounds under different eluents, calculate the retention factor (R_f) values of the colored compounds, and determine the order of polarity of the given eluents.

Once students correctly identify the correct order of polarity for the set of available eluents, they are provided with a box that contains instructions for the following activity. The following activity is a letter "cross" with a combination code (see Appendix 4.2 in the Supporting Information). Once they decipher the code, it provides them with a clue to find the instructions to enter the next station.

Station 3: NMR Spectroscopy

Students are given an alphabet wheel (see the Supporting Information) where random capital letters link to lower-case letters and a decoding book based on the binary code (i.e., each capital letter of the alphabet is represented as a binary code), three NMR spectra, and the names of the three chemical compounds linked to those spectra. The names of the chemical compounds are doubly encrypted (see Figure 3 for an example; the binary code key and the alphabet wheel can be found in the Supporting Information) First, students must find out the names of the three compounds. The first step is to

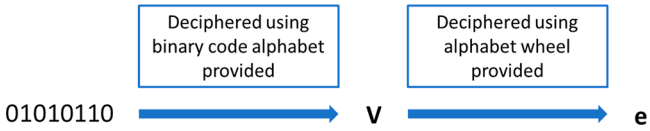

Figure 3. Example of doubly encrypted text to determine the names of the three organic compounds.

decode the binary code into capital letters. These capital letters do not form an actual word. They must then use the alphabet wheel where each capital letter links to a lower-case letter. They then obtained the names of three compounds by using the alphabet wheel. Following this, they need to match the compounds with their correct NMR spectra.

Once they match the correct chemical names to the NMR spectra, a key is provided to them to open the mass spectrometry activity box. The box contains the instructions on what to do in the fourth and final station.

Station 4: Mass Spectrometry

The final area of activity is based on mass spectrometry. Students are provided with a question and four sealed envelopes. The question provides an equation (see Figure 4)

$$\text{KE (Kinetic Energy)} = \frac{1}{2}mv^2 \; ; \; t = \frac{d}{v}$$

Figure 4. Equations provided for the mass spectrometry station.

and asks students to rearrange it in order to calculate the time of flight (t). Each envelope has a rearrangement of the equation written on the cover, and only one of them is correct. They must choose an envelope, and the other three are then taken by the facilitator once they open the first envelope. When they open the envelope, they find a four-digit code. The winning envelope contains the correct digit code to open the mystery box placed in the middle of the activity area.

The mystery box contains a 20-piece jigsaw. They must solve the puzzle, as it contains the magic word. Once they solve it, they shout the magic word, and the laboratory door is unlocked immediately (this is done by a facilitator behind the scenes).

Logistics of Running the Activity

Spectroscopy Unlocked was designed to run in a 2 hour long laboratory session for students in an introductory laboratory course (see Figure 5).

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Figure 5. *Spectroscopy Unlocked* laboratory session timeline.

The introductory briefing was used to prepare students for the laboratory activity by discussing the relevant aspects of health and safety of which the students needed to be aware. This opening session was also used to present the session aims and learning outcomes and to run the scene-setting activities described earlier.

The closing briefing was used as an opportunity to consolidate student learning. This was achieved through reflective discussions of the problem-solving processes used by students along with a consideration of how students used their subject understanding in the activity. Examples of questions used include "What did you learn from the experience?", "How did the escape room support your learning?", and "Did the escape room help consolidate your learning of the key topics from the module?". This part of the session was also used to celebrate student achievements, with prizes being awarded for the team who successfully completed the escape room in the shortest time.

The key aim of *Spectroscopy Unlocked* is to provide a learning environment that allows students to apply their subject understanding and experience of laboratory chemistry to solving problems. The activity also aims to provide a means for students to gain experience working in teams in laboratory-based activities. The key skills that the activity aims to address are summarized in Table 2.

Table 2. Overview of Skills Developed by the *Spectroscopy Unlocked* Activity

Type of Skill	Description
Time management	Teams work against the clock. Problems must be solved within the time available.
Problem solving	Students must apply their subject knowledge to solve nonobvious problems.
Working in teams	Students gain experience of working as part of a team in a laboratory environment.
Communication skills	Effective communication between team members is essential in order to solve problems.
Laboratory techniques	Students must successfully complete a number of activities in the laboratory to solve the problems.
Subject understanding	Students must apply their subject understanding in new contexts to solve the problems.

EVALUATION

Pilot Activity

In order to verify that the problems and laboratory activities functioned as intended and took an appropriate length of time, a pilot group was recruited to test out the activity. A team of faculty members was recruited to pilot the game in order to ensure that information about the gameplay was not "leaked" to undergraduate students. The pilot group found that the game could be completed in the allocated time frame and that the problems could also be solved in the ways intended by the authors.

Instructor Observation of Full Implementation

Throughout the escape room activity, instructors discreetly observed teams as they worked through the individual problems. Teams worked very effectively together, which was not surprising, as the cohort size was small (n = 24) and this activity took place at the end of the year, so students were already familiar with their peers. Different team members proposed different approaches to solving the problems, leading to a discussion of agreed team strategy (followed by continuous reflection on the success of the agreed approach throughout the problem-solving process).

Students were clearly very engaged and motivated in solving the problems. It is clear that the format of the activity was effective at motivating students and helping them to enjoy the time they spent in the laboratory. One of the facilitators of the session commented: "It was fantastic to see how each student contributed to solve the problem and how their knowledge complemented each other's."

The *Spectroscopy Unlocked* problems worked effectively in a 1 hour time frame. All teams were able to successfully complete the problems within 1 hour. An overall winning team was determined through successful completion of the escape room in the shortest time. The activity could potentially be run on a slightly shorter time scale, but instructors should note that this may result in some teams not completing all activities, which may impact the students' ability to achieve all of the intended learning outcomes.

Student Evaluation of Full Implementation

A postactivity evaluation was run using a survey based on a series of Likert-style statements (see Table 3) along with a small number of free text-response questions. 100% of survey respondents (n = 24) either agreed or strongly agreed with the statement "The *Spectroscopy Unlocked* Escape Room was enjoyable", which is consistent with instructor observations (see above).

Table 3. Percentages of Respondents (n = 24) Agreeing with Likert-Type Statements on *Spectroscopy Unlocked*

Statement	% Agreement
The *Spectroscopy Unlocked* escape room was enjoyable	100
Engaging with spectroscopy topics in an informal, interactive session supported my learning	92
Working in a team helped me learn about spectroscopy topics	88
The activities provided an appropriate level of challenge	75

Student responses to the evaluation questionnaire suggest that they perceive the escape room activity to be of value to their learning. While there was no formal comparison of student knowledge of the topic before and after the activity, student conversations with peers and staff indicated that many students had benefited from the peer-learning experience and were better able to apply the theoretical principles of spectroscopy to explain their approaches to the problems.

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The free-text responses suggest that some students believed that the timed element of the game enriched the learning experience by contributing to the "pressure and excitement" of the activity. A number of free-text comments focused on the challenging nature of the problems as being a highlight of the activity. Some students also stated that the scenario presented at the start of the session (i.e., the "scene setting") helped to create tension among students. When asked how the activity could be improved, some students suggested decreasing the size of each team (four or five students per team in this implementation) to ensure that everyone was kept busy throughout the session. Some students also suggested that prizes should be awarded to the winner of each part of the activity. This is a suggestion that we would advise other academic institutions adopting the activity to consider. There were also a small number of suggestions for additional problems that could enhance future runs of the activity, including a simple synthesis followed by spectroscopic analysis of the product. The authors considered these suggestions as the basis of a follow-up escape room.

Instructors (i.e., the student and staff coauthors) observed a high level of engagement throughout the session and also noticed that teams quickly discussed and chose problem-solving strategies to help them complete each of the individual challenges. Instructors commented on the fact that students engaged well with pre- and postactivity briefings and felt that these were good opportunities to support consolidation of learning. Instructors also felt that the level of the individual problems could be modified to make the activity suitable for courses of different levels of difficulty.

Evaluation of Impact on Cocreators

As part of their final-year B.Sc. research project, the student cocreators wrote reflective notes on their experience designing and delivering the escape room and related activities. A focus on skills development was present in both reflective notes. One of the cocreators commented: "Crafting the activity required meticulous planning, organization, and creative problem-solving. Designing puzzles and challenges that effectively conveyed complex spectroscopy concepts demanded a deep understanding of the subject matter, enhancing my own knowledge and proficiency in the field. Moreover, leading the escape room activity and delivering the accompanying lecture honed my communication skills." A similar view was shared by the other cocreator, who highlighted that "It (the design of the escape room) aided in interpreting data, deciphering spectra, simple calculations, as well as working collaboratively within a team...It changed my perspective on Spectroscopy as a whole, from a topic that I seldom enjoyed studying, to a topic that was more engaging, immersive and enjoyable."

CONCLUSION

Spectroscopy Unlocked is an engaging and fun team laboratory activity suitable for introductory courses on spectroscopy. As found with other chemistry escape rooms,[20] the approach appears to be effective at providing an active learning experience for students. Student responses to a postactivity questionnaire revealed that all respondents found the activity to be enjoyable, and a substantial majority of respondents agreed that the activity was a productive learning experience and provided an appropriate level of challenge for the course. It is worth noting that similar studies have also reported the importance of student enjoyment in terms of promoting engagement with educational escape rooms.[18] Instructors observed that students were highly engaged in the activity and were able to successfully complete the activities. The introductory and closing briefings appeared to be important elements for helping students understand and consolidate their learning and relate the activities back to other learning activities.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.3c01320.

Notes for Instructors (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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