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Activity

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Do-It-Yourself: Creating and Implementing a Periodic Table of the Elements Chemical Escape Room

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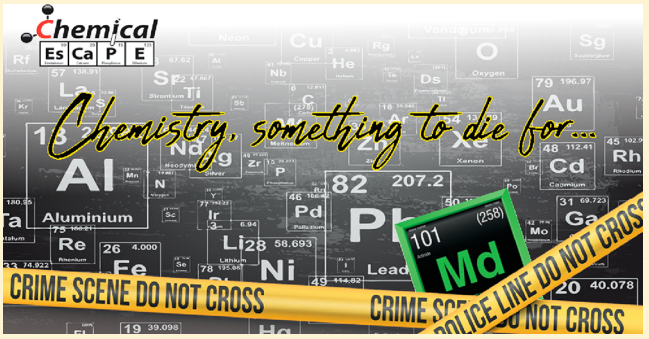
Supporting Information

ABSTRACT: This year (2019) represents the 150th year since the discovery of the periodic table of the elements (PTOE). In honor of this important event, we designed a PTOE chemical escape room (called ChEsRm) that is suitable for middle and high school chemistry students. The main idea behind this ChEsRm is that it is relatively easy and inexpensive for teachers to build in order to introduce the activity into as many chemistry classrooms as possible. The puzzles of ChEsRm include interesting facts regarding the elements, their every day use, and their properties, as well as the subatomic particles. Some involve actual experiments and other nonlaboratory activities. Participants are asked to solve a mystery: finding the cause of a mysterious death. Although most escape rooms use locks and keys, in this case the mechanism used to reveal the solution is different and more flexible. Here we provide a detailed description of all the puzzles and explain how to operate the escape room in a school lab.



KEYWORDS: *Collaborative/Cooperative Learning, Hands-On Learning/Manipulatives, Humor/Puzzles/Games, Problem Solving/Decision Making, Inquiry-Based/Discovery Learning, Student-Centered Learning, Periodicity/Periodic Table, Elementary/Middle School Science, High School/Introductory Chemistry*

INTRODUCTION

Escape rooms (EsRms) are games in which a small group of participants (usually, groups of 2−8 people) work as a team to solve a mystery and escape the room. Since 2007, when the first escape room was built, escape rooms have appeared in the US and all over the world![1] The idea of using this extremely popular genre, in which you use your brain, intuition, and need a bit of luck to escape, via educational scenarios, triggered the imagination of educational developers and led to the development of different types of educational EsRms. These educational EsRms are designed for different school levels, ranging from high school[2] to undergraduate students,[3−6] and include different kinds of puzzles: written puzzles,[3] simple hands-on lab activities,[2,4] or more difficult experiments such as GC or IR analysis.[5,6] The educational EsRms deal differently with the issue of the number of participants: some allow only a few students at a time like in the original EsRms;[3,5,6] some allow a group of 24 students to work, but not simultaneously (once one group leaves a room, another one can enter);[4] and some were planned to fit a group of 24 students simultaneously.[2] Although the background mysteries differ from EsRm to EsRm, most deal with something that occurred at the lab. This includes, for example, Nicolas Leblanc, a young chemist who wants to win a contest and produce industrial soda ash;[3] a murder was committed, and students have to find out who of the four suspects committed the crime, using the forensic laboratory.[5] In another escape room, students have to secretly enter Dr. Devious's lab, while he is at a meeting, and find a virus that can kill humanity[4] or a bomb that was hidden in a school lab which students are asked to find and defuse it.[2] A summary of different ChEsRms that were published in the educational literature is presented in Table 1.

At the Department of Science Teaching we have developed three mobile Chemical Escape Rooms (ChEsRms) that can be loaned to chemistry teachers who implement them in their own school lab. More than 170 classes (2660 students) have experienced the ChEsRm during the past two years. However, borrowing the ChEsRm requires them to pick up and return the equipment from and to the Weizmann Institute of Science. This process also limits the number of teachers who can use ChEsRm every year. The year 2019 was announced as the 150th anniversary since Dmitri Mendeleev created the Periodic Table of Elements, and it has been proclaimed as the "International Year of the Periodic Table of Chemical Elements (PTOE)". In honor of this important event, we designed a PTOE ChEsRm and introduced it to middle school and high school chemistry students. In contrast to the ChEsRms that the teachers have to physically borrow, this ChEsRm is a DIY (do-it-yourself) room, in which all the puzzles can be printed or prepared at school. Therefore, the

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Table 1. Different Educational ChEsRms and Their Characteristics

Name	Education Level	Kinds of Puzzles	Number of Participants: Small 24 not Simultaneously	Purpose of ChEsRm
Escape Classroom: The Leblanc Process: An Educational Escape Game[a]	General public with PTOE, balancing equations knowledge	Written puzzles	Class is divided into groups of 5−7	Complementary teaching of basic concepts
Escape Class Room: Can You Solve a Crime Using the Analytical Process?[b]	Analytical chemistry upper-division undergraduate	Experiments such as GC or toxicology analysis	Small groups (no more than 6 people)	An interactive analytical chemistry exercise for evaluating undergraduate students at the end of the subject
A Lab-Based Chemical Escape Toom: Educational, Mobile, and Fun![c]	High school/chemist with knowledge of acids and bases	Written puzzles and hands-on lab simple activities	24 students simultaneously, four groups	A fun motivating activity
Escaping Boredom in First Semester General Chemistry[d]	First-semester general chemistry students	Written puzzles and hands-on simple activities	12 students (3 groups of 4) simultaneously while the class works traditionally	Review topics to prepare for the final exam
Escape the Lab: An Interactive Escape-Room Game as a Laboratory Experiment[e]	Second-year undergraduate students	Experiments such as GC−MS or UV−vis spec	4−6 students	Reinforce prior lab techniques in analytical chemistry, laboratory instruction; a student-directed approach
Do-It-Yourself: Creating and Implementing a Periodic Table of the Elements Chemical Escape Room (current paper)	Middle school and above and the general public	Written puzzles and hands-on lab simple activities	24 participants	A fun motivating activity for the PTOE year

[a]See ref 3. [b]See ref 5. [c]See ref 2. [d]See ref 4. [e]See ref 6.

number of teachers who can use the PTOE ChEsRm is not limited, and many students will be able to experience it during the 150 year celebration.

The developmental process was initiated during a summer course (summer 2018) for chemistry teachers who designed the first version of ChEsRm. Then, the puzzles were modified by the ChEsRm educational team that first introduced it to chemistry teacher−leaders in the Professional Learning Community who implemented it in other chemistry teachers' communities. The activity was tested and implemented in selected classes. During these events where the PTOE ChEsRm was introduced to teachers, we collected feedback and conducted several improved revisions of ChEsRm. In the current paper, we present the improved version of the activity; we also present feedback from teachers who participated in the activity.

Usually ChEsRm is built in a sequential way: each puzzle leads to another. This means that if the teacher changes one of the puzzles, this will consequently cause changes in other puzzles in ChEsRm. In the version of ChEsRm presented here, each of the puzzles is stand-alone. If a teacher makes a change in one of them (or even wishes not to use it), this will not affect the ChEsRm scenario. This principle was applied when we introduced PTOE ChEsRm in two informal events: ECSITE 2019, and in the "Science on Tap" event,[7] which enabled us to adapt ChEsRm to the general public.[7]

■ DESCRIPTION OF THE ACTIVITY

Background Story of the Escape Room

The background story of ChEsRm is told to the participating students by the teacher before entering the room: "This morning I came to the lab and I was horrified... I am so sorry for allowing my students to throw a party here!! They made a big mess, all the lights were on, and music was playing, as you can hear... but the worst part is that I found a corpse in the corner of the room!" (See Figure 1.) "The police arrived, and

Figure 1. Opening scene of PTOE ChEsRm, inside the school lab.

they are certain that you, the students can help determine what happened here. Please help! Let us take Sherlock Holmes' advice; he always claimed: It is Elementary, my dear Watson!" Inside the lab, the music is loud and in the corner of the room there's a silhouette of a body marked with black duct tape as can be seen in Figure 1. There is also a "Do not cross" sign.

The students are divided into 4 groups (red, yellow, green, and purple). Each group receives an inspector's forensic kit (Figure 2) and a periodic table (PT) printed on a transparency.

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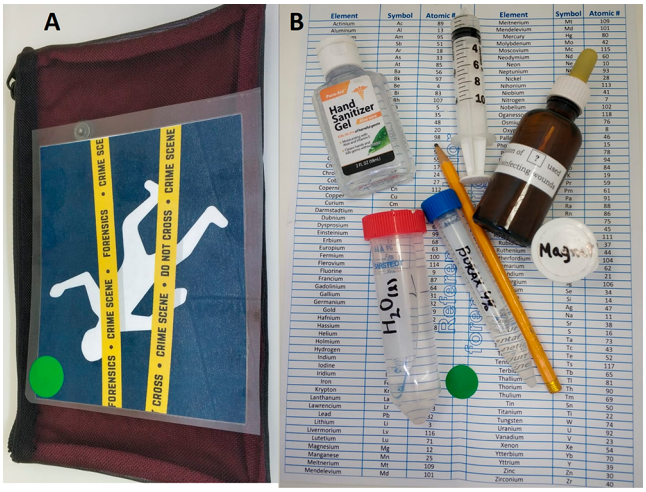


Figure 2. Forensic kit that each group receives at the beginning of the activity: (A) the closed kit and (B) the content of the kit. A detailed description of the kit is provided in the Supporting Information.

Description of the Puzzles

Every group must find 19 elements that are concealed in different puzzles; most of the puzzles have a sign with a question mark ([?]) that highlights the elements hidden in the puzzle. All groups are provided with the same mechanisms to solve the puzzles (e.g., chromatography, preparing slime, and others that are presented in Table 2), but each group discovers different elements in their puzzles.

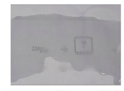
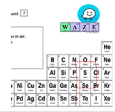
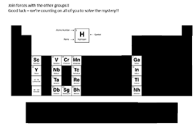
The puzzles of the ChEsRm are based on puzzles designed by chemistry teachers during the teachers' workshop, and they were designed to be fun to solve. They include interesting facts regarding the elements, their everyday use, and their properties, as well as the subatomic particles. Some involve conducting simple experiments, and the others involve nonlaboratory activities. The 13 puzzles and their mechanisms are shown in Table 2. The details of all the puzzles and lab activities as well as the related chemistry content can be found in the Supporting Information.

Each group is provided with a transparency of the PTOE; they blacken the squares of the elements they find on the transparency. After the four groups succeed solving the puzzles and blacken all the elements they revealed, they are instructed to place the 4 transparencies of the 4 groups together, so that they overlap. As a result, the number 101 is revealed, as seen in Figure 3. The number 101 represents the atomic number of the element mendelevium, named after the scientist Dmitri Mendeleev, father of the periodic table of chemical elements.

Number 101 opens a combination lock on a wallet that contains a UV flashlight and a note that says: "Illuminate me!" Once the students shine the light on the note, the following words are revealed: "Chemistry—Something to die for". With this revelation, the students have collectively succeeded in solving the death mystery (and also learn about and practice using the period table of elements).

In total the activity is done during two lessons (45 min each): the gathering to tell the story and give instructions, 10–15 min; the activity of the ChEsRm, 40–55 min; and the closure meeting in which students reflect on the activity and ask questions regarding the puzzles, 10–15 min.

Table 2. Summary of the Puzzles and Their Mechanisms

Name	*Mechanism*	*Photo of the puzzle*
1. The domino puzzle	Match photos in the domino cards, revealing four elements. The letters written on the cards when they are in the correct order, reveal the name of the fifth element.	
2. The iodine puzzle	Add an iodine solution to reveal the symbol of an element cut in paper that can be distinguished from the plastic letters.	
3a. The balloon	Squirt the juice from an orange peel on a full balloon in order to pop the balloon.	
3b. Connect the dots puzzle	Connect dots **only** between elements with a sequential atomic number; the name of the element is revealed.	
4. The hydrogel puzzle	Centrifuge test tubes containing hydrogel balls are hidden in the room. When adding water to the tube; the hydrogel balls which are now surrounded by water, become invisible, revealing a sentence related to an element.	
5. Treasure map with coins puzzle	Add up the value of the coins that are attracted to the magnet, revealing the atomic number of the element.	
6. The envelope puzzle	Smear alcohol on the envelope; the paper will become transparent. A puzzle reveals an element.	
7. Message in a bottle puzzle	A map with a sign on a place that has an element named after a country.	
8. The slime puzzle	Add borax solution to a cup with glue to form slime. A symbol of an element is revealed when the slime is removed from the cup.	
9. The WAZE puzzle	Mark the route on the periodic table and reveal a symbol of an element.	
10. The chromatography puzzle	Add water; the paper absorbs it and part of the drawing is smeared, revealing an alchemy symbol (chromatography).	
11. The songs puzzle	Music is played during the activity; 3 elements are "hidden" in the words of the songs.	
12. The Md-101 puzzle	Place all the transparencies together, so that they overlap - Number 101 is revealed. The 101st element is Mendelevium, named after Dmitri Mendeleev. This is the code used to open a locked wallet containing a UV light and a note.	
13. Solving the mystery	Shine a UV light on the corpse; the following words are revealed: **"Chemistry - Something to die for!"**	

HAZARDS

All puzzles can be solved in a regular class; the chemicals that are included in some puzzles do not require being handled with gloves and the use of goggles. Still, it is always safer to provide gloves and goggles for students.

EVALUATION

The first trial of ChEsRm was held in March 2019 in a community of chemistry teacher–leaders. After the pilot

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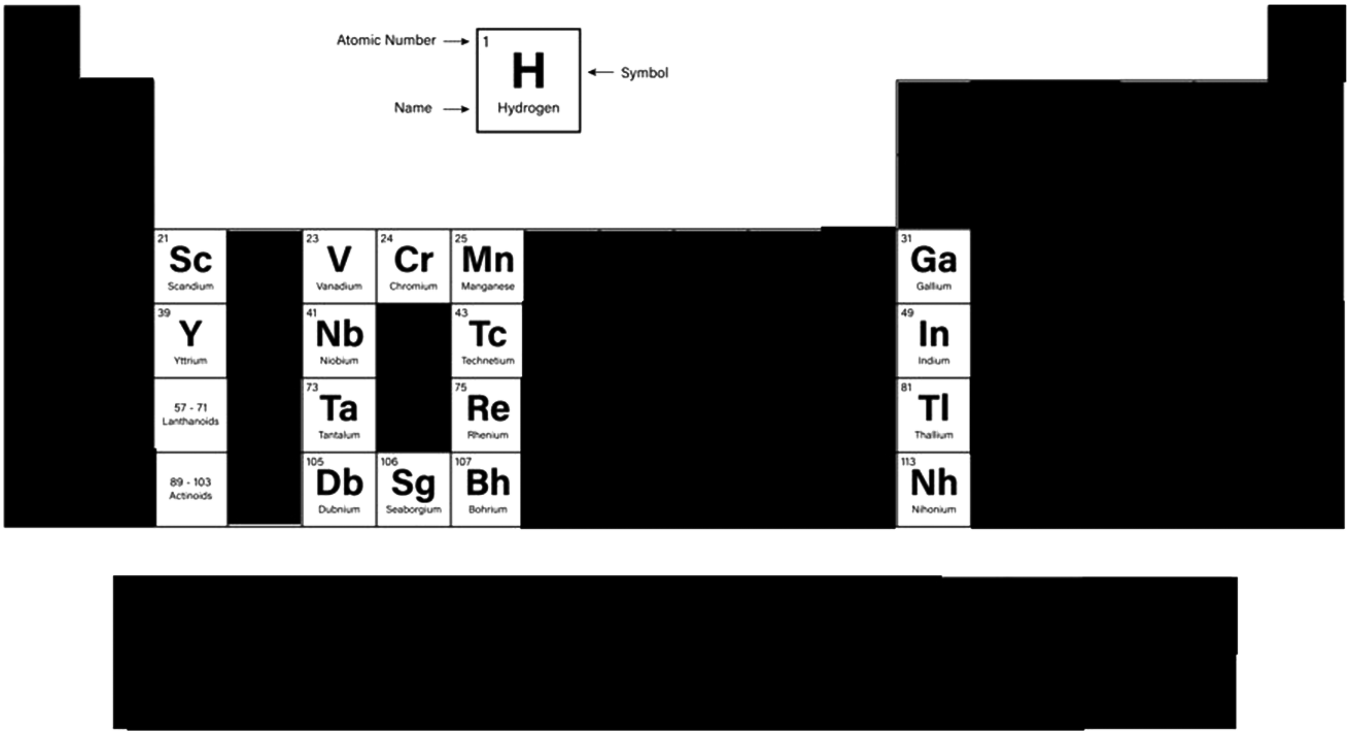

Figure 3. Joint solution of the ChEsRm that provides the code (101) to unlock a wallet with a UV flashlight.

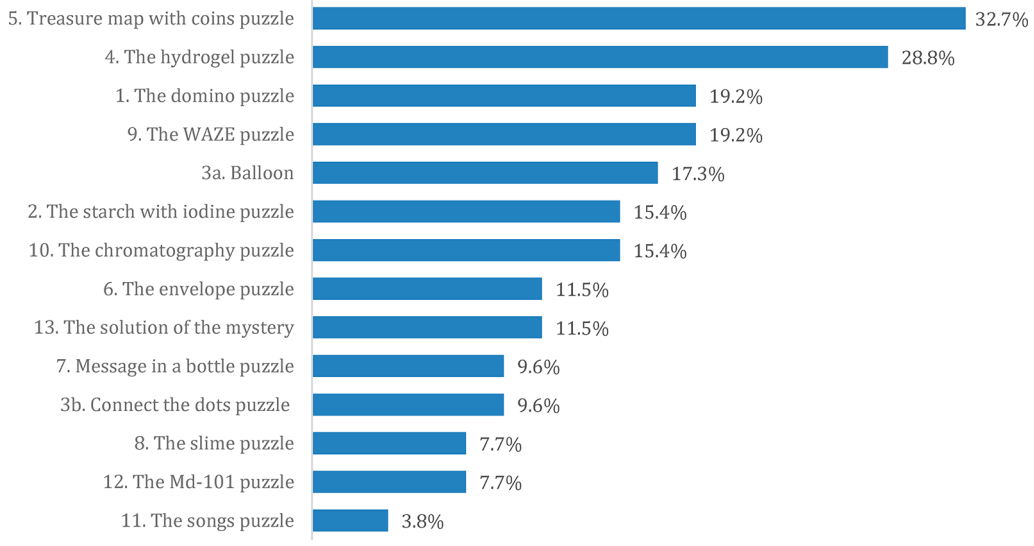

Figure 4. Percentage of teachers who chose their two favorite puzzles (N = 52).

program, the activity was improved and was published on the chemistry teachers' Web site, to allow them to build it by themselves and to implement it in their schools. In order to enable more teachers to build ChEsRm, the teacher−leaders conducted the activity in the professional learning communities (PLCs) of chemistry teachers they lead. In total, there were 7 exposures, and 105 teachers experienced the activity.

Teachers were asked to provide feedback on the puzzles, to choose their two favorite puzzles, and to indicate whether they intend to implement ChEsRm in their class. Figure 4 shows that the favorite puzzles were the treasure map with coins (5, Table 2), and the hydrogel puzzles (4, Table 2). The songs puzzle (11, Table 2) received the lowest rate.

Table 3 shows the mean rate of each puzzle on a Likert-type scale ranging from 1 as the lowest grade to 10 as the highest grade. Most of the puzzles were rated higher than 8, and only the balloon (3a, Table 2) and the song puzzle (11, Table 2) had a lower rate. It is interesting to note the correlation between Figure 4 and Table 3. The most favorite puzzles received the highest rate in both as well as the lowest. However, some were not correlated. The written feedback could explain why the songs puzzles were rated so low. Some of the songs that were chosen are in English, and the teachers were not familiar with them.

The written feedback was very positive and provided the teachers' viewpoints, as exemplified in the following quotes:

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Table 3. Comparison of Teachers' Mean Evaluation Ratings of the Puzzles

Name	Evaluation of the Puzzle[a]
1. The domino puzzle	8.08
2. The iodine puzzle	9.02
3a. The balloon	7.02
3b. The connect the dots puzzle	8.50
4. The hydrogel puzzle	9.29
5. The treasure map with coins puzzle	9.23
6. The envelope puzzle	8.17
7. The message in a bottle puzzle	8.63
8. The slime puzzle	8.79
9. The WAZE puzzle	9.08
10. The chromatography puzzle	8.50
11. The songs puzzle	5.46
12. The Md-101 puzzle	8.31
13. The solution of the mystery	8.94

[a]Scale has a range of 1−10, with 1 indicating the lowest grade, and 10 the highest grade. N = 52.

"I enjoyed the activity. The puzzles are not too complex, and this also provides a positive experience to people that are not familiar with the genre [EsRms]. But they also have chemistry and it was really fun to solve."

"This activity was fun and it also supported our group formation [the teachers in the PLC]. Each of us found her way of contributing to solve the puzzles. I felt that this really contributed to my self-efficacy beliefs to succeed in EsRms!"

"The EsRm was absolutely charming! I plan to implement it also in the lower grade of the middle school. I was very connected to this activity."

ChEsRm has had a great impact among teachers who have already implemented it in their class, since it is public and all teachers can download it. We do not know the number of teachers who actually implemented it, but 90.4% of the teachers who answered the questionnaire stated that they plan to implement ChEsRm in their class next year.

SUMMARY

This paper describes a unique ChEsRm that was designed to highlight the periodic table of the elements in honor of the 150 year anniversary of its creation. We presented a new approach for an educational ChEsRm that can be easily implemented in a regular classroom. According to this approach, all puzzles can be downloaded from the Web site and prepared in school. An additional innovation in designing this ChEsRm is that the puzzles are mostly independent of other puzzles. The only puzzle that is dependent on others is puzzle 12 (Table 2), in which all groups have to cooperate and join the periodic table to reveal the 101 number that opens one lock. These lead to the most important characteristic of ChEsRm, which is its flexibility. The teachers can choose which puzzles to use and can easily edit the puzzles according to their preferences in order to suit the students' knowledge. In this way, the periodic table ChEsRm can reach as many students as possible during the "year of the periodic table", and we hope also in the years to come.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.9b00660.

Detailed description of each one of the puzzles, how to build them, the related chemical content, hints, tips, and related graphics (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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