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APPLICATION OF DIGITAL ESCAPE ROOMS IN GENERAL CHEMISTRY EDUCATION: STUDENTS' PERSPECTIVES

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The concept of using Escape Rooms (ERs) in chemistry education enables students to apply their knowledge in a practical context, develop collaborative skills, and learn in an enjoyable and engaging way. This study aims to design a digital escape classroom for chemistry teaching and gather feedback from students on its implementation. This paper presents an example of a digital ER designed for first-year high school students (ages 14–15), focusing on the topic of Atomic Structure. The ER was implemented during the 2023–2024 school year. Student feedback was collected using the The Students' Opinion on the Application of ER for Learning Chemistry (SOAER), which comprises five subscales: Previous Experience in Participating in ERs (PE), Impact of ERs on Motivation for Learning Chemistry (IML), Teamwork and Collaboration in ERs (TWC), Opinion on Tasks Included in ERs (OT), and Technical Challenges in Using Digital ERs (TC). The study sample consisted of 70 first-year high school students in Serbia. The results revealed that students generally held a positive perception of the use of ERs in general chemistry classes, particularly valuing the teamwork and active engagement the activity promoted. Additionally, the ER fostered the development of communication, tolerance, and collaboration skills.

Key words: chemistry education; escape room; atomic structure; teamwork; students' perception

ПРИМЕНА НА ДИГИТАЛНИТЕ СОБИ ЗА БЕГСТВО ВО НАСТАВАТА ПО ОПШТА ХЕМИЈА: ПЕРСПЕКТИВИ НА СТУДЕНТИТЕ

Концептот на користење соби за бегство (ЕР) во наставата по хемија им овозможува на студентите да ги применат своите теоретски знаења во практичен контекст, да развијат соработнички вештини и да учат на забавен и интерактивен начин. Оваа студија има за цел да дизајнира дигитална соба за бегство за наставата по хемија и да собере повратни информации од студентите за нејзината примена. Овој труд претставува пример на ЕР дизајнирана за ученици од прва година средно образование (возраст 14–15 години), со фокус на темата Атомска структура. ЕР беше имплементирана во текот на учебната 2023–2024 година. Повратните информации од учениците беа собрани со користење на анкетата „Мислење на учениците за примена на соба за бегство во изучувањето на хемијата“ (SOAER), која содржи пет потскали: Претходно искуство во учество во соба за бегство (PE), Влијание на собата за бегство врз мотивацијата за учење хемија (IML), Тимска работа и соработка во собата за бегство (TWC), Мислење за задачите вклучени во собата за бегство (OT) и Технички предизвици при користење дигитална соба за бегство (TC). Студијата опфати 70 ученици од прва година во средните училишта во Србија. Резултатите покажаа дека учениците општо земено имаа позитивно мислење за користење на собата за бегство во наставата по општа хемија, особено ја ценеа тимската работа и активното ангажирање што ја поттикнува оваа активност. Дополнително, собата за бегство придонесе за развој на комуникација, толеранција и соработка.

Клучни зборови: образование по хемија; соба за бегство; атомска структура; тимска работа; перцепција на учениците

1. INTRODUCTION

In the last few years, a type of an interactive recreational game, where small groups of players solve a series of tasks within a certain period of time to win or escape from a room, has gained popularity.[1,2] This game is referred to by several different names in the literature. In this paper, the term 'escape room' (ER), which is widely recognized globally, is used to describe it.

The concept of ERs for the purpose of entertainment began in Japan in 2007. Since then, their application has grown rapidly across the countries of Europe, Asia, and the United States, not only as a form of entertainment but also for educational purposes.[3] ERs can be implemented in both real and virtual environments (physical and digital ERs).[3] Digital ERs have been developed due to their cost-effectiveness, affordability, and ease of use.[4] These digital versions utilize free web-based applications to create a series of locks and tasks that players must solve.[5]

By utilizing ERs, students are transformed from being passive recipients of knowledge to active participants in the learning process. While solving tasks, students engage in exploring new data, accepting challenges, and solving problems and mysteries.[6] In addition to successfully solving the assigned activities, the aims of the game include acquiring knowledge, developing skills, forming general and specific competencies, and achieving the planned educational outcomes.[7]

The application of ERs fosters investigative learning,[8] stimulates intellectual development,[6] and builds essential 21st century soft skills such as teamwork, leadership skills, and communication.[3,6] Effective teamwork requires the ability to think creatively, notice details, embrace diversity, and demonstrate tolerance toward different ways of thinking and cultures. The tasks within ERs require rational thinking and problem-solving skills, utilizing a broad range of knowledge – all under time pressure.[9]

The role of the teacher is crucial in gamification as a pedagogical model, since games must be effectively applied to achieve the learning objectives. In addition to acting as game designer, teachers also play specific roles during and after the execution of ERs. Implementing ERs requires teachers to assume multidimensional roles, including the following activities: (a) monitoring, (b) moderating, (c) guiding, (d) facilitating, (e) providing hints, (f) encouraging, and (g) debriefing.[10]

As innovative game-based educational tools, ERs should be designed with great care. Teachers, as ER designers, are tasked with creating active learning environments that will motivate students, increase their engagement, improve learning outcomes, and develop teamwork and communication skills.[5,11] When designing ERs for educational purposes, six critical aspects must be considered: participants, learning objectives, teaching content, tasks, equipment, and evaluation methods.[12]

Tasks in educational ERs are created for a specific target group, addressing specific well-defined goals, and learning outcomes. These games can be designed for individual students, groups, or entire classes, potentially engaging hundreds of students with different abilities and interests. The game must be adapted to align with students' developmental stages and the allotted time frame. If the game is conducted within one class, the game's complexity must suit the students' level, while for mixed-age groups, the content and task difficulty should be adjusted accordingly to ensure all students are equally involved.

Typically, classic (physical) ER games involve teams of 2 to 6 players. However, as classroom sizes are often much larger, the class should be divided into several teams with different tasks and challenges, or alternatively, several ERs can be designed with identical or different topics. When several rooms are used, organizing the space within the school becomes challenging, and it may be impossible for a teacher to monitor all groups. This problem can be addressed by organizing a project day, allowing for cross-curricular connections and the participation of multiple teachers in the same activity.[1]

Digital ERs offer several advantages over physical ERs, including convenience, as they eliminate the need for space transformation (e.g., moving furniture in the classrooms) during short breaks between classes, and providing necessary equipment and different materials on a limited budget. On the other hand, digital ERs demand that teachers possess digital skills and proficiency in specific software to design interactive problems, feedback mechanisms, and the ER itself.

Another consideration for teachers is the difficulty of the problems and tasks embedded in the game. A well-designed ER should tell a story, make each player feel valued, and ensure they remain engaged in the game. Challenging tasks can provide meaningful engagement, but overly simple tasks risk boring for students, while excessively difficult tasks may lead to frustration. Both extremes can result in students abandoning the tasks and leaving the game.[1]

1.1. *An overview of previous research*

Since 2006, an increasing number of studies have focused on the use of ERs in education, with a focus on formal education settings across various disciplines. The collected data shows that the majority of these studies target university students, followed by secondary school students. However, only a few papers relate to the application of ERs in primary education or lower.[10,13]

Research has shown that implementing ERs into educational contexts increases students' knowledge,[3,5,6,14] encourages teamwork,[13,15] and promotes active engagement in learning.[16,3,10] In recent years, research in the field of education has focused on the use of these games in educational settings due to the broad opportunities they offer to support the learning process,[5] and they can be integrated into many academic disciplines, including health care,[8,17] computing,[3] chemistry,[4,18,19] pharmacy,[5,20] mathematics,[21] and biology,[22] among others.

Additionally, studies reveal that students generally hold positive opinions on the application of ERs in education,[3,15,23] citing increased motivation, enjoyment, and the development of critical thinking skills. However, a review of the literature reveals a lack of studies related to students' perceptions of the use of ERs in high school chemistry education. This specific application of an ER presents unique challenges for both instructors and many students, as chemistry often involves numerous abstract concepts[16] that present learning difficulties.[24]

2. METHOD

2.1. *Aim of the research*

The aim of this quantitative study was to examine students' perceptions of a digital ER in chemistry education. A digital ER was chosen for teaching chemistry at the secondary school level. For its design, the topic Atomic Structure was selected, as it is introduced at the very beginning of the secondary-level chemistry curriculum. The teaching content covered in this topic includes: the structure of the atom, the structure of the electron shell, quantum numbers, electronic configurations of chemical elements, and the relationship between electronic configurations and the elements' positions in the Periodic Table of Elements.

The Atomic Structure topic is characterized by a high degree of abstract concepts. Previous research has identified numerous misconceptions and learning difficulties associated with this content.[16] The following research questions guided this study: What are high school students' perceptions of the digital ER? What are the differences in the students' perceptions of the digital ER based on their gender?

2.2. *Procedure*

The designed ER was implemented during the 2023/2024 school year as part of regular classes, specifically during lessons focused on reviewing previously studied material (for knowledge reinforcement). The ER was designed for teams of 3–4 students, ensuring the active engagement of all participants and collaborative problem-solving. Teams were either formed randomly or assigned by teachers.

The activity lasted 45 minutes and was structured as a competitive game, with students informed of this aspect at the start. An appropriate reward, such as additional points or grades, was provided to the winning team that successfully escaped the ER first. Following the ER implementation, students completed a questionnaire to assess their perceptions of the use of ER in chemistry education.

2.3. *Participants*

The ER was conducted with a sample of 70 first-year high school students in Serbia. However, only 55 students completed the questionnaire, as 15 either chose not to participate or did not complete the survey. Students were informed that the research was anonymous and that their participation was voluntary, allowing them to withdraw from the research at any time without facing any consequences.

2.4. *Instrument*

The Students' Opinion on the Application of ER (SOAER) for Learning Chemistry questionnaire was specifically designed for this study, drawing on relevant literature and expert input to ensure content validity. The questionnaire consisted of 44 items, divided into five subscales including: Previous Experience in Participating in ERs (PE), Impact of ERs on Motivation for Learning Chemistry (IML), Teamwork and Collaboration in ERs (TWC), Opinion on Tasks Included in ERs (OT), and Technical Challenges in Using Digital ERs (TC).

Participants provided responses using a 5-point Likert scale, ranging from 1 (completely disagree) to 5 (completely agree). In this study, the questionnaire demonstrated high internal consistency, with a Cronbach's alpha of 0.85.

2.5. *Data analysis*

In evaluating students' opinions on the use of the ER, a descriptive statistical analysis was applied. Differences in opinions between male and female students were examined using an independent-samples *t*-test. All analyses were performed using SPSS 20.0 software.

2.6. *Software used*

The ER was developed using the *ThingLink* software platform, which enables the display of three-dimensional spaces in the form of spherical photos (in 360° technology). These spaces can contain embedded interactive multimedia elements such as interactive tasks, games, video clips, sound recordings, photos, and texts files in formats like .doc and .pdf. The software also allows the creation of virtual tours, enabling users to move between rooms freely or by unlocking a digital code. Once completed, the resource can be distributed to potential learners via a link or a QR code.

A variety of task types were integrated into the ER using the *LearningApps* software, including multiple-choice questions, fill-in-the-blank questions, crossword puzzles, grouping of concepts, matching pairs, and arranging concepts in a specific order. The *LearningApps* tool was selected for its valuable feedback feature, which provide students with responses after solving each task. This feedback can take the form of traditional messages like, "Well done, you've done the exercise successfully". However, for the purpose of this ER, this option was adapted to offer additional information or guidance to help students discover the digital code.

3. RESULTS AND DISCUSSION

3.1. *Description of the ER*

This section contains an overview of the ER, including its floor plan, the various rooms, and the tasks embedded within them. The ER consists of five spaces: the corridor, two chemical laboratories, a classroom, and a library, as shown in Figure 1.

Players enter the game through the Entrance (a green space on the floor plan). From the corridor, they can reach Lab1 and Lab2. The entrance to the library is hidden and can only be unlocked by solving the digital code. The classroom can be reached only through Lab 2. In order to finish the game, all spaces must be reached and the tasks within them must be solved. A spherical photograph of Lab1, included in the ER, is shown in Figure 2.

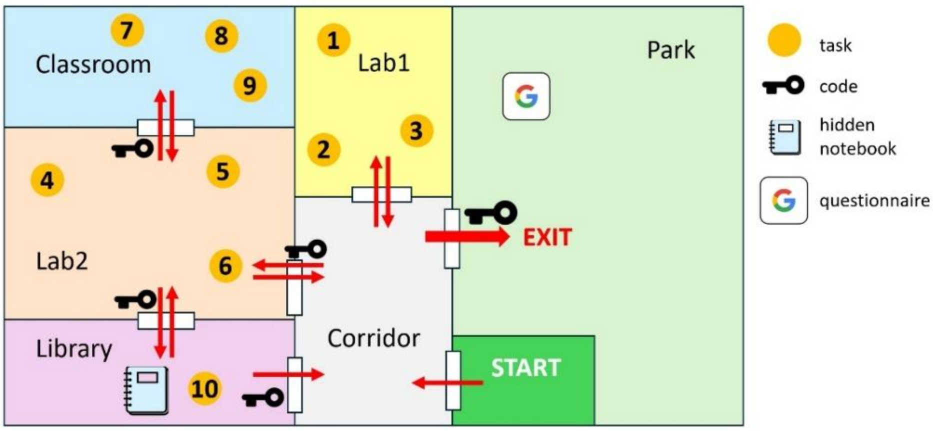

Fig. 1. Floor plan

Fig. 2. Spherical (panoramic) photo of Lab1

The introductory scene includes a short scenario of the game:

You have a chemistry test tomorrow, but you left your notebook in the library at school. You have to find it quickly! Solve tasks and collect codes that will help you find the notebook and go home to study as soon as possible. Good luck!

Players must solve ten tasks to complete the game. The tasks are organized according to Nicholson's pyramidal structure,[2] which represents a complex hybrid form. The tasks within a room can be solved independently from each other, but the order of rooms is pre-arranged and has to be followed. Successfully completing all tasks is required to break the final code and leave the ER.

The tasks are designed to engage a range of cognitive skills across four different levels: knowledge, understanding, application, and analysis. After solving a problem, players are given feedback in the form of an additional task, information, or a number. These numbers contribute to unlocking either a certain room or to the final code. As an illustration of the ER, tasks 1, 2, and 3, included in the virtual space Lab1, are shown.

Task No. 1: *Arrange the given terms in the appropriate table cells according to the type of substance they represent.*

This task requires students to apply their knowledge and analyze the properties of substances to classify them correctly. Upon completion, the feedback provided a part of the code needed to unlock the library (Fig. 3).

Task No. 2: *Click on the name of the category (phase of the substance) in the upper part of the image, and then on the names of all substances that belong to that category. After arranging all the substances correctly, carefully read what you need to do next.*

To solve this task, students need to know the phases of the given substances under normal laboratory conditions and classify them based on that property. In the second part (the feedback), students are required to interpret a graphic display and calculate the relative atomic mass of the chemical element based on the graphic data. This task involves various cognitive levels, including knowledge, understanding, and application. The value obtained from the second part of the task (multiplied by 10) formed a part of the code needed to access Lab2 (Fig. 4).

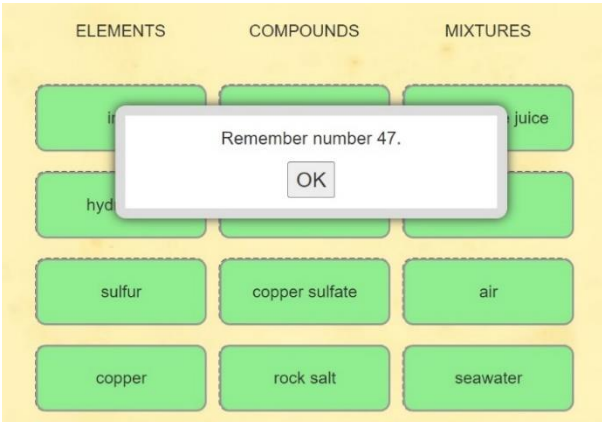

Fig. 3. Task No. 1 and the feedback obtained after the correct answer

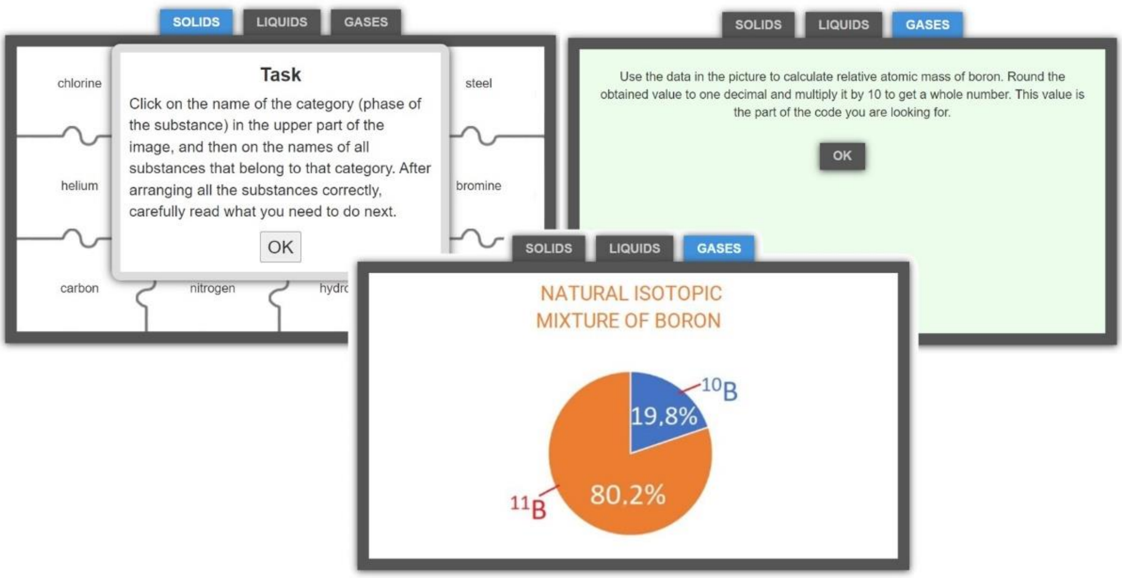

Fig. 4. Task No. 2 and the obtained feedback after the correct answer

Task No. 3: *Arrange the chemical elements on a scale according to the number of neutrons in the nucleus of their atoms.*

Students are given atomic data (atomic mass A and atomic number Z) for four chemical elements and tasked with calculating the number of neutrons in the atom of each chemical element. After applying their knowledge to determine the number of neutrons, students are required to practice graphical representation of the obtained values by finding the correct position on the number line. After successfully solving the task, the feedback includes a number that forms part of the code for entering Lab2 (Fig. 5).

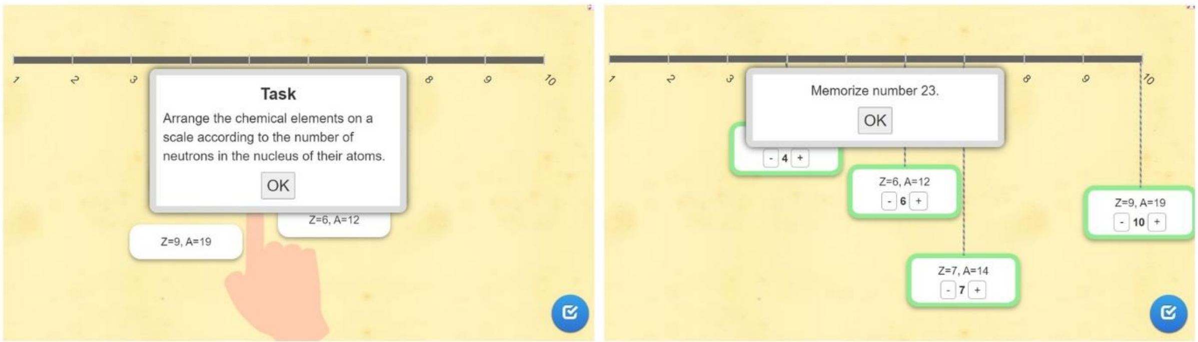

Fig. 5. Task No. 3 and the obtained feedback after the correct answer

3.2. *Students' opinions on the application of ER for earning chemistry*

Table 1 presents the results of the study conducted following the implementation of the ER. The descriptive indicators suggest that students have a positive opinion on the application of ERs in chemistry teaching. The mean score on the questionnaire assessing opinions was 158.76 (the maximum possible score was 196), with a SD of 19.23. This very positive attitude toward the use of ERs has also been confirmed in other studies.[3,5]

Table 1

Descriptive statistics of SOAER

Subscale	Min	Max	M	SD	Skewness	Kurtosis
PE	5	15	10.61	2.68	–0.29	–0.88
IML	22	53	38.94	7.98	–0.43	–0.69
TWC	32	64	49.61	7.73	–0.37	–1.0
OT	19	40	2.86	4.58	0.17	0.02
TC	21	41	30.96	4.13	–0.28	0.29

Note: PE – Previous experience in participating in ERs; IML – Impact of ERs on motivation for learning chemistry; TWC – Teamwork and collaboration in ERs; OT – Opinion on tasks included in ERs; TC – Technical challenges in using digital ERs; M – Mean, SD – Standard deviation.

3.2.1. *Previous experience in participating in ERs*

The first subscale focused on students' prior experiences with ERs. The majority of students (approximately 75 %) reported that they generally enjoyed playing games. However, around 43 % of students indicated that they had not previously participated in any form of ER, whether real or digital, and 67 % of students indicated that they had never had the opportunity to learn chemistry through an ER.

3.2.2. *Impact of ERs on motivation for learning chemistry*

Students expressed enjoyment in practicing chemistry through ER, citing their fondness for competition and finding games more engaging and interesting than traditional methods of reviewing studied material. Approximately 70 % of students found the application of ERs in chemistry teaching to be interesting, while only about 13 % described it as boring. These results align with the findings of other study,[15] which indicated that students enjoy

ERs and would recommend the game to others. The arithmetic means of the items related to students' opinions on the impact of ERs on their motivation to learn chemistry are presented in Table 2.

Table 2

Students' opinions on the impact of ERs on their motivation to learn chemistry

Items	M	SD
I found ER in chemistry boring.	2.18	1.15
Solving tasks in ER makes me more engaged and puts in more effort.	3.77	1.19
I enjoy learning through ER because I like the competition.	3.75	1.25
I enjoy learning through ER because I love winning.	3.59	1.25
I dislike learning through ER because the time limit pressures me to solve tasks faster.	3.21	1.14
I find learning through ER difficult because I cannot work at my own pace.	2.89	1.21
I get annoyed by the need to memorize or write down codes.	2.71	1.36
Learning through ER feels too chaotic because I have to switch between different digital rooms.	2.43	1.28
I enjoy practicing chemistry through ER because the game is more interesting than traditional review, and it does not feel like studying.	3.73	1.12
This way of learning makes chemistry more interesting.	3.87	1.05
I do not find ER engaging; I prefer learning in a traditional way.	2.33	1.16

Note: M – mean, SD – standard deviation

Additionally, we calculated the percentage of students' agreement with individual items. To do this, we combined responses in two categories: (1) disagreement – which includes both 'completely disagree' and 'disagree' responses, and (2) agreement – which includes both 'agree' and 'completely agree' responses. The majority of students' sample (64 %) believed they were more engaged when using ER compared to traditional teaching methods. Around half of the students (58 %) enjoyed the ER due to its competitive nature and the desire to win. However, approximately 40 % of students expressed dissatisfaction with the pressure caused by limited time for solving tasks, feeling unable to work at their own pace. A smaller proportion (approximately 30 %) expressed frustration with the need to memorize or record codes.

Previous studies[1,7,15] have shown that students often experience stress during ER activities, which is understandable given the time constraints for winning the game. This finding was also reflected in the present study, where 18% of students described the ER as chaotic due to its structure, involving multiple digital rooms.

More than half of the students (58 %) preferred reviewing material through an ER, while only 14 % favored traditional learning methods. Overall, students preferred ERs over traditional teaching approaches. These findings are consistent with previous studies, which also revealed that students prefer educational escape rooms over traditional classroom experiences.[5]

3.2.3. *Teamwork and collaboration in ERs*

Teamwork is an important feature of solving educational ER activities. Previous studies have emphasized the value of ERs as an innovative approach that promotes the development of critical thinking, teamwork, and communication skills.

The arithmetic means of the items concerning students' opinions on teamwork during task solving in the ER, as obtained in the present study, are given in Table 3.

Students appreciated teamwork in ER for several reasons. Their self-confidence increased when they successfully solved tasks and received validation from their peers. Teamwork ensured active engagement from all members, and discussions fostered the development of communication, tolerance, teamwork abilities, and other social skills. A significant majority of students (76 %) stated that they enjoyed teamwork, noting that discussions and conversations helped them reach accurate conclusions. Additionally, approximately 65 % of students believed that all team members were actively involved in solving tasks, worked collaboratively, received confirmation from others about the correctness of their solutions, and enhanced their communication skills, tolerance, and teamwork competencies through these activities. These findings align with previous studies.[15,23]

Additionally, about 65 % of students were not annoyed by differences in the speed of solving tasks among team members, did not feel pressured when others imposed their solutions, and were willing to accept that others might notice their mistakes. Overall, students preferred teamwork over individual task-solving in the ER. Only three students (approximately 5 %) indicated that they disliked teamwork, citing shyness as the primary reason.

T a b l e 3

Students' opinions on teamwork during task solving in ERs

Items	M	SD
I prefer solving tasks in ER independently rather than in a group.	2.35	1.26
All members of my team were active in solving the tasks.	3.79	1.27
When working in a team, I get annoyed when others work faster than me.	2.20	1.09
When working in a team, I get annoyed when others work slower than me.	2.23	1.31
When working in a team, I get annoyed when others impose their solutions on me.	2.30	1.07
I like teamwork because I get confirmation from my peers that I am right.	3.84	1.17
I like teamwork because through conversation and discussion, I can reach the correct conclusion.	4.02	1.10
In the team, we solved all the tasks in ER together.	3.96	1.18
I like teamwork because I can show my peers how much I know.	3.34	0.95
I dislike teamwork because others can see where and how much I make mistakes.	2.21	1.17
I do not like working in a team because I am shy.	1.71	0.95
I dislike teamwork because I do not have time to produce a solution on my own, someone always says it before me.	2.20	1.17
In this way of working, we develop social skills (communication, tolerance, teamwork abilities).	3.89	0.91

Note: M – mean, SD – standard deviation

3.2.4. *Opinion on tasks included in ERs*

The majority of students (approximately 75 %) expressed satisfaction with their success in solving the tasks. The major reason for their enjoyment was the immediate feedback they received on the accuracy of their solutions, which two-thirds of the students (67 %) found satisfactory. About 60% of the students found the tasks interesting because they had an additional purpose – escaping from a room. Furthermore, students believed that learning through trial and error, as well as discussing their mistakes, helped them learn concepts they had not previously mastered.

The arithmetic means of the items related to students' opinions on the tasks included in the ER are presented in Table 4.

T a b l e 4

Students' opinions on the tasks included in ERs

Items	M	SD
Tasks in ER are interesting to me because they have a purpose; they are not just for practice but help me exit ER and win.	3.66	1.21
I like tasks in ER because I immediately know whether I solved them correctly.	3.84	1.20
I don't like tasks in ER because they can be solved by guessing, without actual knowledge.	2.57	1.32
I like tasks in ER because, by making mistakes and correcting them, I can learn what I don't know yet.	3.70	1.11
I don't like tasks in ER because they are too easy.	2.18	1.01
I don't like tasks in ER because they are too difficult.	2.48	1.08
I am satisfied with my performance in the tasks.	3.86	1.10
The tasks feel more like playing than learning.	2.96	1.26

Note: M – mean, SD – standard deviation

3.2.5. *Technical challenges in using digital ERs*

Technical issues play a significant role in the organizing and conducting a digital ER, impacting both teachers and students. The arithmetic means of the items related to students' opinions on technical aspects of the ER are presented in Table 5.

Table 5

Students' opinions on the technical aspects of the ERs

Items	M	SD
I had technical problems while using ER.	2.52	1.37
It is easier to play this kind of ER on a computer than on a phone.	3.20	1.37
Playing digital ER on a phone is difficult because everything is too small.	2.82	1.32
I like that the game can be resumed, and I do not have to start over.	3.93	1.09
I am not good at using computers, so I have difficulty navigating digital ER.	2.04	1.19
I do not like that playing digital ER requires using my phone or computer.	1.91	1.11
I do not like that playing digital ER uses my internet data.	2.43	1.41
I do not like that the game stops if the internet connection is lost.	2.84	1.38
I would prefer solving ER tasks in real life rather than on a phone or computer.	3.36	1.33

Note: M – mean, SD – standard deviation

Only six students (10 %) reported difficulties navigating the digital ER, citing distractions caused from using phones or computers while solving tasks. Approximately 24 % of the students reported having technical issues while solving tasks in ER. Previous studies[3,23] have highlighted similar challenges, emphasizing the need for escape room designers to provide clear initial guidelines that outline the objectives, rules of the game, and how students can ask for help when they encounter difficulties.

About 40 % of students found it easier to solve tasks on a computer rather than on a phone, with 30 % noting that the phone screen was too small for comfortable work. A significant majority of students (76 %) appreciated the option to continue the game from where they left off if the game was interrupted, without needing to restart. However, about half of the students expressed a preference for solving ER tasks in a real-world setting over digital devices like a phone or computer.

3.2.6. *Differences in students' opinions based on gender*

This study explored the differences in the opinions of male and female students, as previous research[25] has shown the existence of such differences. For instance, female students escaped an ER statistically faster than male students, were more likely to recommend the game to others, and believed that the game encouraged them to view the material in a new way.

The findings of the present study also show gender differences in the perception of ERs between male and female students, based on the response of 44 students who indicated their gender (24 male and 20 female). The results showed that their opinions differed regarding teamwork, while a borderline statistically significant difference was found in their attitudes toward the tasks within the ER. The results of the *t*-test are presented in Table 6.

An analysis of responses to questions from the subscale *Teamwork and Collaboration in ERs* revealed that female students were unanimous in their attitude towards usefulness of the teamwork. All female students (100 %) stated that they enjoyed working together to find the correct solution through conversation and discussion. In contrast, only around 50 % of male students agreed with this statement.

Female students were less likely to worry about the impressions they made on other members of a team if they gave incorrect answers. About 80 % of females disagreed with the statement "*I dislike teamwork because others can see where and how much I make mistakes*", compared to 37% of male students who shared this view.

Differences between female and male students were also observed in the attitude toward teamwork and individual solving of problems. Female students showed a greater preference for teamwork, while male students preferred solving ER tasks independently. Specifically, around 80% of female students disagreed with the statement that they prefer independent work to working in a team, expressed by only 45 % of male students.

T a b l e 6

Differences in students' opinions on the application of ER in chemistry teaching based on gender

Subscale	Gender	M	SD	*t*	df	p
PE	Male	10.17	2.41	–0.62	43	0.55
	Female	10.67	2.97			
IML	Male	36.83	8.31	–1.20	42	0.24
	Female	39.75	7.62			
TWC	Male	46.21	6.60	–3.14	43	0.00
	Female	52.71	7.28			
OT	Male	21.17	4.17	–1.99	43	0.05
	Female	29.76	4.59			
TC	Male	30.42	3.76	–0.84	43	0.40
	Female	31.48	4.66			

Note: PE – Previous experience in participating in ERs; IML – Impact of ERs on motivation for learning chemistry; TWC – Teamwork and collaboration in ERs; OT – Opinion on tasks included in ERs; TC – Technical challenges in using digital ERs; M – mean, SD – standard deviation; *t* – t-test value, df –degrees of freedom, p – statistical significance.

4. CONCLUSIONS, LIMITATIONS, AND IMPLICATIONS FOR FURTHER RESEARCH

This paper presents an innovative, game-based educational tool – Chemistry ER – which covers the topic of Atomic Structure. First-year high school students generally have a positive attitude towards the use of digital ERs in learning, emphasizing their engaging nature, the ability to actively involve students, and the development of essential social and teamwork skills. Gender-based differences in students' perceptions indicate that female students value teamwork, joint discussions, and collaborative problem-solving more highly, which opens additional opportunities for further research.

However, this study has certain limitations. It was conducted on a small sample of students and covered only one topic from general chemistry. Future research should expand the scope to include more topics from various branches of chemistry and a larger and more diverse sample of students. Additionally, it is important to examine teachers' opinions on the use of ERs in education, as their perception significantly influences the implementation of new methods. Finally, it is necessary to investigate the impact of ERs on students' academic achievements and motivations toward learning chemistry in order to fully assess the effectiveness of this educational tool.

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