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IV INTERNATIONAL CONFERENCE ON ADVANCES IN SCIENCE AND TECHNOLOGY

PROCEEDINGS COAST 2025

FACULTY OF MANAGEMENT HERCEG NOVI

HERCEG NOVI, MONTENEGRO 04 JUNE - 07 JUNE 2025

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IV INTERNATIONAL CONFERENCE ON ADVANCES IN SCIENCE AND TECHNOLOGY

BOOK OF PROCEEDINGS

HERCEG NOVI, 04 JUNE - 07 JUNE 2025

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ASSESSING THE CHEMISTRY EDUCATIONAL OUTCOMES USING DIGITAL ESCAPE ROOM. ANALYSIS OF GRAMMAR SCHOOL STUDENTS' ACHIEVEMENTS

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ABSTRACT:
Evaluating students' achievements is one of the key aspects of education, providing insights into learning effectiveness. In this context, digital tools have emerged as innovative assessment methods, enhancing both students' engagement and the accuracy of knowledge evaluation. The aim of this research was to examine the level of grammar school students' chemistry educational outcomes, through an innovative and interactive teaching tool. In order to ascertain the level of accomplished learning outcomes, a digital escape room was designed as an assessment instrument, structured around four key educational outcomes. Instrument covered four topics: types of substances, atomic structure, dispersed systems and chemical reactions. The study included 139 first-year grammar school students enrolled in the department for natural sciences and mathematics. The findings indicate that students demonstrated a satisfactory level of knowledge only in the topic of atomic structure. In contrast, for the remaining three topics, barely over a half of the students provided correct answers. These results suggest the need for both improvement in students' knowledge and the refinement of instructional strategies in chemistry education. Given the specific sample and the custom-designed questionnaire, further research with a broader and more diverse sample is recommended, incorporating additional educational outcomes and qualitative methods to achieve a more comprehensive understanding of students' chemistry achievements. Nonetheless, the newly developed digital escape room presents a promising and innovative approach to assessing students' learning within an interactive and engaging educational environment.

Keywords: *chemistry education, educational outcomes, escape room, digital tools, grammar school*

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1. INTRODUCTION

Evaluating students' achievements is one of the important aspects of the educational process. It may seem like a straightforward task, but evaluating requires careful planning and implementation. Although the terms evaluation and assessment are often used interchangeably, they have distinct meanings [1]. Assessment refers to the process of measuring students' performance against predefined educational outcomes. It is an ongoing activity that helps teachers track progress, identify learning needs, and support students' development. On the other hand, evaluation is a broader concept encompassing assessment as one of its components [2]. It also involves systematically analyzing the effectiveness of teaching methods, curricula, and educational outcomes.

Assessment serves as an integral element of teaching and learning, conducted in accordance with legal and regulatory frameworks, and ensures continuous tracking of student progress and adherence to learning outcomes [3]. It is a pedagogical practice that fosters a positive attitude toward learning, enhances motivation, and supports the development of academic engagement. Furthermore, it enables students to objectively evaluate their own achievements and those of their peers while facilitating the establishment of personal learning goals. The evaluation of students' development, progress, and achievement throughout the school year(s) is carried out through: 1) formative and 2) summative assessment. While formative assessment is primarily descriptive, summative assessment is generally numerical. By integrating both formative and summative assessment methods, teachers can effectively monitor student progress, support individualized learning, and ensure alignment with educational outcomes and standards [2].

The widespread integration of Information and Communication Technology (ICT) has become an essential aspect of modern life, extending into various domains, including education. Chemistry educational tools have encountered significant transformations in the last decades owing to the use of computers (animations, virtual laboratories, and simulations), and other electronic devices [4-7]. ICT provides many tools and patterns that can be utilized through constructive learning strategies in teaching chemistry. The incorporation of digital tools in teaching facilitates the development of digital literacy, enhances collaboration, promotes motivation for learning and offers numerous pedagogical benefits [8-10].

Researchers analyzing educational trends, along with international organizations (OECD; European Commission) have developed and adjusted digital tools for diverse teaching methods and approaches [11-14]. Over time, the escape room methodology has also been adapted as an innovative digital instructional strategy in science education. Numerous good practice examples demonstrate its effectiveness, especially in chemistry teaching, where digital escape rooms have been successfully integrated to enhance student engagement, problem-solving skills, and conceptual understanding [15-17]. In general, an escape room is an interactive, game-based learning activity where students solve a series of subject-related tasks and challenges to *escape* within a set time frame. This method fosters engagement, critical thinking, and collaboration. Further information on escape

rooms, their design, and implementation in educational settings can be found in various studies and pedagogical resources [18,19].
ICT supports the assessment process by offering various digital tools designed for administering tests and quizzes [20-22]. Commonly used digital assessment tools in educational settings include platforms such as *Kahoot!*, *Socrative*, and *Mentimeter* [23]. Additionally, *Google tools* offer a broad array of functionalities that enhance both teaching and learning. Among these, *Google Forms* stands out as one of the most widely used tools for creating surveys, quizzes, and collecting data from students [24]. This platform enables educators to easily design custom forms with various question types, including multiple-choice, text fields, image selection. Furthermore, it facilitates the automatic collection and analysis of responses, which significantly streamlines the assessment process, making it more efficient for teachers. These platforms provide essential features at no cost, with additional premium features available through subscription models. While teachers are required to create accounts to access these tools, students can typically use them without the need for registration. Depending on the educational context, teachers can use them for formative and summative assessments, adjusting their approach to support ongoing students' development.

2. RESEARCH METHODOLOGY

This study, conducted in May 2024, employed a quantitative research design to examine grammar school students' chemistry achievements in Kragujevac, Serbia. Participants, enrolled in the natural sciences and mathematics department, voluntarily took part in the research, adhering to ethical principles in educational studies. Before data collection, a detailed form was provided, outlining the study's objectives, procedures, and requirements. The research focused on the role of digital assessment tools in evaluating students' knowledge, aiming to identify their level of achievement and potential gaps in understanding.

2.1. Research aim and research questions

The evaluation of the teaching process is essential, as it provides insights into the effectiveness of teaching methodologies and the overall learning environment. Assessing the level of achieved learning outcomes is important for identifying areas of improvement and refining teaching practices. The aim of this research was to examine the level of grammar school students' chemistry educational outcomes, through an innovative and interactive teaching tool. In alignment with the aim of the research, the following research questions have been formulated:

1. To what extent have first-year grammar school students accomplished the educational outcomes in chemistry?
2. Which chemistry topics outlined in the first-year grammar school curriculum did students find most challenging?

2.2. Sample

A convenience sampling method was employed, as it is recognized for its practical applicability in educational research [25]. The study sample consisted of 139 first-year grammar school students enrolled in the natural sciences and mathematics department. The sample size was determined by the availability of students at the time of data collection. The selected grammar school operates within the national educational framework established by the Ministry of Education of the Republic of Serbia [3]. Following this framework, all students were provided with the necessary knowledge and skills for solving the knowledge test.

2.3 Instrument

In order to explore to what extent the students achieved educational outcomes, an instrument was created based on outcomes defined in teachers’ lesson plans. Learning outcomes for all teaching topics for the subject chemistry could be found in educational documents proposed by the corresponding institution [26]. The curriculum for first-grade of the grammar schools (natural sciences and mathematics department) includes the 8 teaching topics: 1) Chemistry as a natural science; 2) Types of substances; 3) Atomic structure; 4) Chemical bonding; 5) Dispersed systems; 6) Chemical reactions; 7) Acids, bases and salts and 8) Oxidation-reduction reactions. In Serbia, within this framework learning outcomes are broadly defined, and teachers must specify them for personal lessons.
The designed instrument covered 4 teaching topics (Types of substances, Atomic structure, Dispersed systems and Chemical reactions). The selection of these topics has arisen from discussions with the subject teachers, the timing of the research, and a review of relevant scientific literature. The 7th and 8th topics were excluded from the assessment instrument, as students had not yet been introduced to these concepts. The 1st topic was eliminated because it serves as an introduction to the subject matter, and it was not anticipated that students would encounter difficulties with it. Additionally, the 5th topic was excluded due to the extensive body of research addressing common misconceptions related to [27,28]. The committee of experts (grammar school chemistry teachers and university chemistry teachers) who were not involved in its design confirmed the instrument's validity. Based on the evaluations, the revised items were held in the instrument.

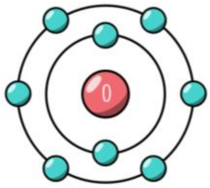
Table 1. Formulations of the selected learning outcomes in the teacher's lesson plan for the subject chemistry

Outcome No.	Teaching topic	Formulation of the selected outcome
1	Types of substances	-considers which procedures and in what order are applied when separating the components of a given mixture
2	Atomic structure	-interprets and predicts the properties of a chemical element based on the electronic configuration of the atom
3	Dispersed systems	-calculates the quantitative concentration, mass concentration and molality of a solution
4	Chemical reactions	-writes and interprets equations of chemical reactions

For the specified outcomes (listed in Table 1), four questions were initially constructed, followed by the creation of a digital escape room featuring problem-solving tasks. Available digital tools, such as *Google Forms*, *TikTok* and a *QR code generator* application, were utilized to develop the instrument [29]. The design of the digital instrument involved careful planning, with each task being meticulously formulated to align with the research aim and research questions. In addition to creating the tasks, a video required to solve the fourth task was recorded and edited to ensure its accessibility and usefulness to students. The use of *Google Forms* for task creation provided a notable advantage, as it allowed for interactive feedback. If a student answered a question incorrectly, they were immediately presented with the correct answer and a detailed explanation. This feature enabled students to learn from their mistakes in real-time, enhancing their understanding of the material and promoting further learning.

Students from each class were divided into five groups, with all groups receiving similar questions and tasks, differing only in the examples provided. In Table 2, a representative problem task from the digital assessment tool is presented, alongside the corresponding answer and feedback, to demonstrate the interactive assessment process.

Table 2. The second problem task from the digital assessment tool with the respective answer and feedback

Task format	Answer (Key for next task)	Feedback
	2P6G	The oxygen atom has an atomic number of 8. The atomic number indicates that the oxygen atom contains 8 protons and 8 electrons. The element's valence electron configuration reveals that its outermost energy level contains six valence electrons. This places oxygen in group 16 of the periodic table. Furthermore, the electron configuration of oxygen indicates that the valence electrons occupy the second energy level, positioning oxygen in the second period of the periodic table.

Students have had 45 minutes to solve the test, i.e. to *escape* room. Each of the four tasks was accessible by scanning the QR codes, which were distributed throughout the classroom. QR codes were followed by the results of the previous task, which was a clue to the other task. To prevent cheating and ensure fair progress, an additional rule was implemented: a 5-minute pause after an incorrect answer (random shot). This rule allowed students i.e. student groups to advance at their own pace, based on their knowledge, while maintaining the integrity of the assessment process.

3. RESULTS AND DISCUSSION

The data collected with the instrument are shown in Figure 1 along with a percentage of correct answers for each task, highlighting the varying levels of success across the different topics assessed.

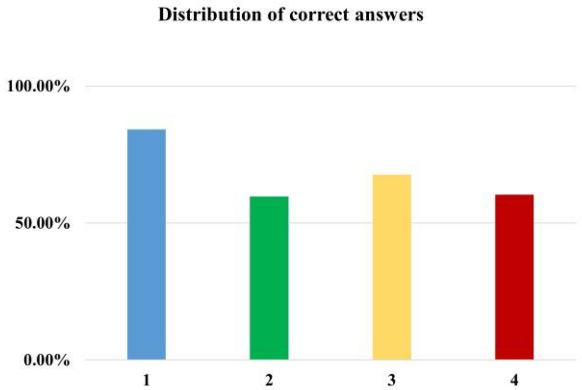


Fig. 1. Distribution of correct answers (%) per tasks

Students answered all four questions correctly with a success rate exceeding 50%, highlighting a solid knowledge of fundamental concepts. The first task was the most successfully completed, with 84.2% of students providing correct answers. This percentage reflects a satisfactory understanding of the concept of electron configuration in atoms. Students demonstrated proficiency in determining the arrangement of electrons in shells, an important concept in understanding the chemical properties of elements. This outcome also serves as a good foundation for further study in chemistry, particularly in more advanced topics related to atomic structure (chemical bonding). For task 2, which assessed students' understanding of the procedures involved in separating the components of a mixture, the correct answer rate was 59.7%. This result suggests that this topic was more challenging for students than others, which is reflected in a lower level of accomplishment. This may be attributed to a lack of practical experience, as many schools lack adequately equipped laboratories, which hinders students' ability to observe and engage with the necessary apparatus for such experiments. Without hands-on practice and visual exposure to the process, theoretical understanding becomes significantly more difficult. In task 3, which involved the calculation of quantitative concentration, students demonstrated a somewhat higher understanding, with a correct answer rate of 67.6%. This finding indicates that while students are generally familiar with the basic concept of quantitative concentration, further emphasis on accurate application of formulas and systematic problem-solving strategies is recommended to enhance their proficiency. Task 4, focused on the ability to write and interpret chemical equations, yielded a correct answer rate of 60.4%. This reveals that students struggled with composing and balancing equations and thus interpreting chemical reactions. Given the importance of stoichiometry and the law of conservation of mass in chemistry, further practice and guidance are needed to improve students' ability to balance equations and predict the products of chemical reactions.

The difficulties with mixture separation procedures were also noticed in a study that developed a positive intervention to help students distinguish essential differences between mixtures and chemical compounds, highlighting the importance of laboratory activities in teaching such chemistry concepts [30]. The observed students' errors in the present study involved confusion between subscripts and coefficients in chemical equations, a challenge that has also been documented in a similar study [31]. The difficulties observed in this research regarding calculating molar concentration, align with challenges noted in two similar studies [32,33]. Both studies report that students often struggle with applying mathematical concepts to chemistry, such as calculating concentrations and interpreting formulas, which is important for understanding this concept.

The research findings align with national assessments, such as the Programme for International Student Assessment (PISA), which indicate that students in our country demonstrate lower achievement levels in the natural sciences, including chemistry, compared to their peers in other countries [34]. The findings of this study indicate a relatively more favorable situation compared to similar studies and national assessments on different chemistry topics, which have consistently reported low levels of student achievements across various conceptual domains and an unsatisfactory level of chemistry knowledge related to chemical literacy [35-38]. In the context of written assessments, previous research has shown that students do not experience significant anxiety regarding written knowledge tests, suggesting that the presented form of assessment could be an effective approach for evaluating students' knowledge while also fostering their confidence in using digital tools [39]. Also, there are findings that students prefer competitive and fun tools that provide immediate feedback, which was also a characteristic of the designed assessment tool in this study [40].

Although the collected data does not reflect a concerningly low level of knowledge and accomplishments of the outcomes, there is still potential for improvement in all areas, including the first one. Improving comprehension in these areas is essential because chemistry topics are interconnected, and a solid understanding of foundational concepts is crucial for grasping more advanced topics. Furthermore, strengthening these areas will enhance students' overall comprehension and problem-solving abilities, which are essential for academic success in chemistry and other scientific disciplines.

4. CONCLUSION

In conclusion, the study revealed that first-year grammar school students demonstrated satisfactory knowledge of atomic structure, but struggled with topics such as types of substances, dispersed systems, and chemical reactions. The digital escape room assessment highlighted gaps in their ability to apply key concepts and solve related problems. The implementation of the digital assessment tool demonstrated significant advantages by efficiently summarizing and archiving students' responses, thereby streamlining the grading process for educators. This functionality supports both individual and group work, rendering the tool adaptable to various educational contexts and enhancing the overall efficiency of the evaluation process. While digital tools showed promise in enhancing student engagement, the results underscore the need for improved teaching strategies and further development of both students' conceptual chemical and critical thinking skills. Limitations of the study include the small, homogenous sample and the exclusion of some topics from the assessment. Future research should involve a broader, more diverse sample and explore the use of additional educational tools and methods to address these gaps. Also, it should incorporate qualitative methods for a deeper understanding of students' engagement and experiences with digital assessment tools.

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