Journal of Research Administration
Society of Research Administrators International

SYSTEMATIC LITERATURE REVIEW ON THE USE OF GAMIFICATION APPROACHES IN MASTERING THE PERIODIC TABLE OF ELEMENTS (CHEMISTRY)

Suzinursolahah Binti Saleh[1], Wan Ismail, W.O.A.S.[1*], Asma Nur Fatihah Mohd Noor[2]
[1*]Faculty of Islamic Contemporary Studies, University Sultan Zainal Abidin, Malaysia
[2]Faculty of Islamic Contemporary Studies, University Sultan Zainal Abidin, Malaysia
***Corresponding Author:** Wan Ismail, W.O.A.S.
*Faculty of Islamic Contemporary Studies, University Sultan Zainal Abidin, Malaysia

Abstract
Gamification applications as tools, students can independently construct knowledge about the lesson content, surpassing the achievements obtained through conventional methods. Therefore, it is essential for studying gamification, especially on periodic tables of elements, as it is the backbone and crucial topic for chemistry. This article aims to explore the application of gamification in learning the Periodic Table of Elements in the timeframe spanning from 2019 to 2023. A systematic literature review was conducted, utilising online databases such as Scopus and Web of Science and relevant information on the subject. Specific keywords, including "Periodic Table," "Teaching Approach," and "Gamification," were used to search for studies related to the topic through online search engines. The study yielded relevant literature from 13 countries: Pakistan, Indonesia, Japan, Spain, the United States, Macedonia, Israel, Morocco, Brazil, Portugal, Croatia, Mexico, and Malaysia. The review's primary focus was to identify commonly used gamification methods and assess the impact of gamification in terms of motivation, academic achievement, and usability. The findings revealed that researchers frequently studied board games, digital cards, puzzles and Virtual Labs as the main gamification approaches. A comprehensive analysis of 27 literature review articles determined that motivation emerged as the primary impact examined in mastering the periodic table using a gamification approach. This study has significant implications for Chemistry teachers in the classroom, STEM researchers and the Teacher Education Division in Malaysia Education Ministry. By understanding learners' preferences, educators can tailor their instructional approaches to meet the specific needs of their students.
Keywords: Gamification; Periodic table; Teaching Approach

1. Introduction

Presently, there is a notable decline in the number of students opting for Science, Technology, Engineering, and Mathematics (STEM) subjects in both schools and higher education institutions (HEIs), as reported by the Ministry of Energy, Science, Technology, Environment and Climate Change [1]. This decline poses a potential shortage of skilled individuals for STEM-related industries. Given Malaysia's aspirations to become a developed country by 2020 and the significance of STEM outlined in the TN50 plan, the importance of these subjects cannot be overstated [2][3]. The STEM field encompasses various subjects, including Science, Physics, Mathematics, Chemistry, Biology, Computer Science, Design, and Technology.

© 2024 The Authors

According to the TIMS International Benchmarking Science Achievement Report 4, a significant proportion of fourth and eighth-grade students, 92% and 85% respectively, perform at a low benchmark (400), indicating limited comprehension of scientific concepts and restricted access to fundamental scientific knowledge [4]. Many countries provide students with a minimum level of science education, and Malaysia ranks among the lowest with an average grade of 460 for eighth graders. The PISA 2018 report reveals that 78% of students attain at least level 2 in science, enabling them to identify and explain scientific phenomena and draw conclusions.

Science Education concentrates on process-oriented learning, emphasizing scientific skills that encompass critical thinking and science process skills. Science process skills are essential for students to learn and master through the application of strategic activities that facilitate meaningful learning and practical application in everyday life. These skills also prove vital during the research process, enabling the creation of scientific products encompassing concepts, principles, laws, and theories [5]. However, there has been significant improvement in science literacy based on the PISA 2018 report, with an average score of 438 compared to 420 in PISA 2012. The report indicates that students primarily employ basic scientific knowledge to identify scientific information, formulate research questions, design experiments, interpret data, and draw conclusions based on the data obtained. Consequently, various modifications have been introduced in the national education system to enhance students' mastery of chemistry, particularly the Periodic Table, and one such approach is gamification.

Chemistry is a scientific discipline that utilizes models or graphics to understand the phenomena observed in everyday life [6]. However, it is often considered a challenging subject for some students, as highlighted in Osman's study [7]. The study of Othman and Talib [8] attribute this difficulty to the tendency of students to rely on rote methods without grasping the abstract concepts. Moreover, the lack of mastery in teaching chemistry among teachers creates a monotonous and inflexible learning environment [9a]. Consequently, it is crucial for educators to adopt an engaging and student-centered approach that is carefully planned.

The implementation of gamification in the PAK21 approach has shown positive effects on the learning process [9]. Additionally, Nurfarhana Rosly *et al.* [10] note that technology has become deeply ingrained in students' lives and aligning gamification elements with technology fulfills their inherent desires for fun, competition, and achieving success as in a game. The goal of gamification aligns with the objectives of teachers, who aim to create a better learning environment where students actively participate, comprehend the content, and retain the knowledge, thereby enhancing performance [11].

The periodic table holds significant importance in science education across all levels as it provides information about the fundamental physical and chemical properties of different elements that constitute matter. The periodic table (PT) is the most commonly used tool for information about chemical characteristics, including their names, symbols, states of aggregation, metallicity, atomic numbers, oxidation states, electronegativity, and electronic configurations [12]. Traditionally, the periodic table is introduced historically, highlighting the properties of elements and the gradual development of the table over time. This tool serves as a fundamental cornerstone in chemistry

© 2024 The Authors

and all branches of science, making it essential in teaching and learning science at all educational levels.

Research and studies indicate that teaching chemistry often follows a traditional approach, focusing primarily on memorizing names and formulas. This approach alienates students from real-world applications, making the subject difficult and uninteresting. Among the challenging topics in chemistry, the periodic table stands out as many students struggle to comprehend its properties and the arrangement of elements [13]. Games have emerged as an alternative to address this difficulty, providing teachers with didactic and pedagogical tools to engage students interestingly and dynamically. In this context, this study aimed to examine the acceptance and impact of the Periodic Domino game on understanding the periodic table in a classroom setting. Field research was conducted with 19 ninth-grade students at Centro Educational Espaço Criativo School in Quiterianópolis-CE [14]. Data was collected through an evaluation questionnaire, and a graphical presentation of the results revealed that the game piqued the students' interest, with 64% of them assigning the highest score, significantly contributing to their better understanding of the content according to 95% of the students.

However, the process of learning the periodic table is often perceived as dull, mechanical, and lacking engagement for students [15]. Familiarizing oneself with the facts related to the periodic table, such

as element names, symbols, metallic properties, electronegativity, and so on, can appear tedious and monotonous depending on the teaching approach employed. One method to invigorate students is through gamification, where learning occurs almost unconsciously due to playing games [16]. Specific educational applications have shown promise in enhancing teaching effectiveness and shaping student characteristics [17]. Mobile applications can be utilized to captivate science students by providing a flexible platform for learning topics of interest. They are an alternative means to supplement traditional teaching methods and can dedicate more time to the subject matter.

If students lack motivation to learn the periodic table, their understanding of chemistry can be adversely affected. To enhance student motivation, interest, and attention, teachers should provide interactive and engaging learning materials that incorporate elements such as sound, background voices, animations, videos, and other captivating features [18]. When students possess motivation and interest in the subject they are studying, they are more likely to achieve positive outcomes as they concentrate and exert effort in their learning [19]. Therefore, an intriguing and captivating approach to learning is necessary to boost students' motivation and understanding of chemistry. Consequently, the researcher recognized the need for a study to evaluate the effectiveness of the gamification approach in enhancing student motivation and knowledge of the periodic table, developing a modified model based on the conceptual framework of Digital Game-Based Learning in science education adapted from Wong & Osman [20] as the foundation for this study. Furthermore, it is worth noting that previous studies have predominantly focused on assessing students' levels of motivation and understanding in chemistry without thoroughly examining the integration and effectiveness of gamification [21]. Thus, this study will also determine how much

© 2024 The Authors

the gamification approach effectively enhances student motivation and understanding in mastering the periodic table.

2. Methodology

This chapter outlines the procedures followed in conducting the study. A literature review involves collecting, identifying, analysing, formulating, and critically evaluating the relevant issues to be examined [22]. This study used the keywords "gamification" and "periodic table of elements" to obtain research data

2.1 Search Strategy

Researchers employ detailed and comprehensive search techniques to locate articles and journals related to gamification in the periodic table of elements. Data sources are obtained through electronically searchable databases. Three electronic databases, namely Scopus, Google scholar and World of Science (WoS), are selected for the search. The selection of Scopus databases begins on June 4, 2023, as they provide access to all Social Science Citation Indexed (SSCI) and Science Citation Indexed (SCI) journals. The search string: (("Learn* model" OR "guidelines") AND ("mobile" OR game* OR gamification*) AND ("periodic table" OR "periodic table of elements")

2.2 Acceptance Criteria

The criteria for accepting articles include empirical studies relevant to gamification in the periodic table of elements. The publication year for the selected papers falls between 2019 and 2023. Accepted articles include those published in journals or conference materials. The accepted language for the articles is English or Malay.

2.3 Rejection Criteria

Studies lacking empirical evidence or unrelated to the investigation topic are rejected. Articles published before 2019 are not considered for selection. Book chapter reviews and reports without full-text availability are also excluded. Non-English and Malay articles are not considered for inclusion.

2.4 Data Extraction

Selected articles must meet the criteria mentioned above to ensure accuracy. Each relevant and applicable theme is coded using parameters such as study design, findings, and measurement methods.

2.4 Article Selection Process

This systematic review follows the methodology that Khan, Kunz, Kleijnen & Antes [19]. proposed. The article selection process consists of five stages:

Step 1: Formulate survey questions:

© 2024 The Authors

Clear and organised questions are formulated before the study. The two questions in this review are to identify the commonly used gamification methods in mastering the periodic table (chemistry) and to determine the impact of gamification on motivation, academic achievement, and student attitude.

Step 2: Identify relevant articles:
A comprehensive search is conducted, encompassing various sources (both computerised and printed) without language restrictions. The selection criteria align with the research questions, with exceptions mentioned above.

Step 3: Assess study quality:
The quality assessment of the systematic review includes three inclusive criteria: research questions, research methodology, and research findings. This evaluation aims to ensure that the systematic review can address the research questions by analysing the articles and their results to facilitate further discussions.

Step 4: Summarise the evidence:
Data synthesis involves tabulating study characteristics, quality, and effects. Statistical methods are employed to explore differences between studies and combine their results, potentially through meta-analysis. Plans are made to explore heterogeneity and its sources (as mentioned in Step 3). A subgroup meta-analysis may be considered if an overall meta-analysis is not feasible.

Step 5: Interpret the findings:
The issues highlighted in each of the previous four steps are addressed. An exploration of publication bias and related biases should be conducted. The examination of heterogeneity should help determine the reliability of overall summaries. If not possible, effects observed in high-quality studies can be used to conclude. Any recommendations made should be evaluated based on the strengths and weaknesses of the evidence obtained.

© 2024 The Authors

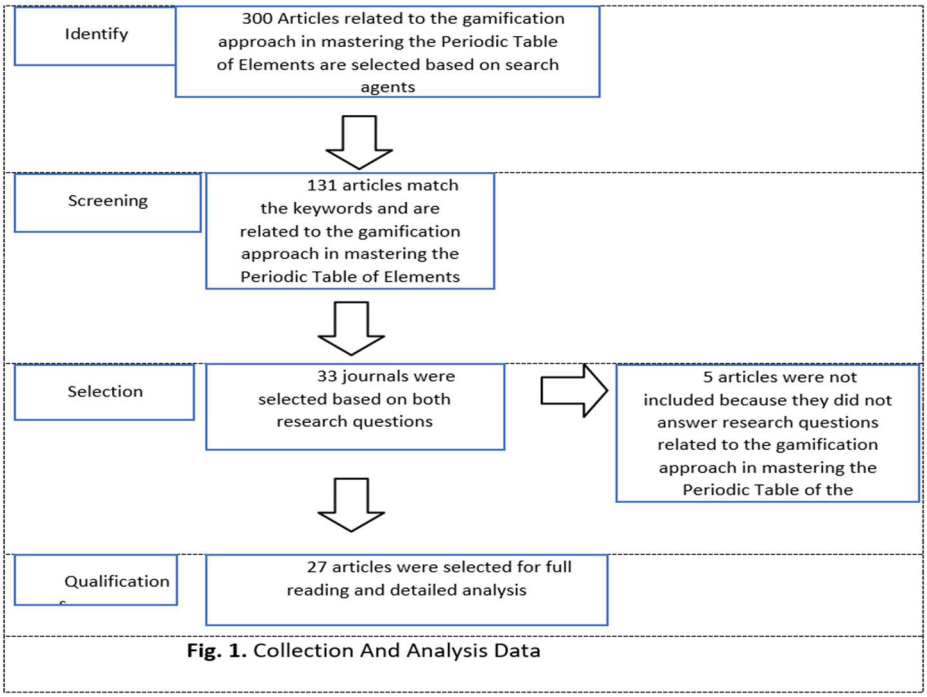

Fig. 1. Collection And Analysis Data

Table 1. List of articles published in 2019, 2020, 2021, 2022 and 2023

No.	Authors	Title	Location	Aim	Methodology	Finding
1	(Carabelli et al., 2023)	Historical and philosophical foundations of a game-based learning strategy for teaching periodic law	Brazil	to propose a method that gives precedence to chemical theories and models over physical ones, while still recognizing the contributions of this field, which can aid in defining and comprehend	An analysis was conducted, considering the epistemological and ontological aspects, enabling the establishment of definitions for the periodic properties employed in the game	The selection of periodic tables as game boards was based on how visually appealing the different representations were. Regarding the development of the new game mechanics, changes were made to ensure learning takes place during the game, not just afterwards.

© 2024 The Authors

				ing concepts.		
2	(Canbek et al., 2023)	PToPI: A Comprehensive Review, Analysis, and Knowledge Representation of Binary Classification Performance Measures/ Metrics	Singapore	To distinguish features, likenesses, and variances among instruments categorized as 'performance measures' and 'performance metrics' within the context of classification, marking the initial occurrence of this classification. The notions representing the inherent attributes of devices, such as canonical form, geometry, duality, complementation, dependency, and	The research initially brings attention to challenges in assessing performance through a survey of 78 studies on mobile malware classification, also examining terminology.	A novel exploratory table named PToPI (Periodic Table of Performance Instruments) was introduced, applying knowledge representation to 29 measures and 28 metrics (69 instruments, encompassing variant and parametric types). PToPI offers a comprehensive visual representation of conceptual relationships, incorporating graphical, probabilistic, and entropic instruments, facilitating the examination of their properties and dependencies in a unified manner. The utility of PToPI was demonstrated through six

© 2024 The Authors

				levelling, intend to uncover similarities and differences among various tools, including three redundancy and the contrast between ground-truth and prediction focuses.		examples across diverse domains, illustrating its effectiveness in the overall analysis of instruments and the selection of appropriate performance metrics tailored to specific classification problem requirements.
3	(Sundaram & Ramesh, 2022)	Effectiveness of joyful game-based blended learning method in learning chemistry during COVID-19	India	to help secondary school students learn science concepts using educational card games and digital media. Specifically, it focuses on teaching tenth-grade students' chemistry and the periodic table	A quasi-experimental sample comprises 240 students studying the tenth standard in 4 different private CBSE schools in Palakkad district, Kerala, India. The pre-test, post-test, gain scores, and	The study's findings revealed significant differences in the mean scores of students' learning in chemistry (precisely elements) when comparing the experimental and control groups' pre-test, post-test, and retention tests. The use of educational cards in learning chemistry was associated with positive attitudes among students. Implementing a game-based joyful blended learning method fostered reflective thinking and encouraged self-

© 2024 The Authors

				elements (1 to 30). The research will assess the effectiveness of a game-based blended learning approach	retention scores were compared.	regulated learning among students.
4	(Haimovich et al., 2022)	"The Masked Scientist": Designing a Virtual Chemical Escape Room	United States	To design (VChEsRm) that operates entirely in the digital realm and principles of the VChEsRm and explores the perspectives of both students and teachers on how it differs from the traditional Chemical Engineering Simulation Room (ChEsRm).	256 students completed a questionnaire after participating in the VChEsRm; it referred to their experience in the VChEsRm, what parts were more important to them	(VChEsRms) offer numerous advantages such as cost-effectiveness, accessibility, and ease of use. These virtual rooms have been successfully integrated into Jewish and Arab schools in Israel, even after students and teachers returned to physical classrooms following the pandemic. The VChEsRm's content seamlessly connects to subjects like history, human rights, sustainability, and everyday chemical facts. While originally created to meet the demands of remote teaching amid the pandemic, educators persist in utilizing the VChEsRm even in traditional classroom settings, where groups

© 2024 The Authors

						of 3−4 students commonly share a single computer. The VChEsRm has evolved into a lasting and beneficial fixture within the educational environment.
5	(Ali et al., 2022)	Interactive Cube for Effective Demonstration of Virtual Periodic Table	Pakistan	To Increase student motivation by presenting a Cube-based Interface in Virtual Periodic Table (CIVPT) to demonstrate detailed information on chemical elements: chemical elements, chemical properties, physical properties, electronic configuration, usage of a component in daily life and chemical	Ninety-four (94) students participated and were divided into two groups for the assessment.	It is revealed that CIVPT enhances students' learning and motivation to gain knowledge about chemical elements.

© 2024 The Authors

				bonding, respectively.		
6	(Da Silveira et al., 2021)	E-Guess: Usability Evaluation for Educational Games	Brazil	To assess educational games using Game User Experience Satisfaction (GUESS) and Nielsen's evaluation tools for user experience.	Conducted applied research employing both quantitative and qualitative methods, involving three expert users and four potential users in a case study on an educational game. The selection of GUESS as the initial framework was informed by a thorough review of usability literature. Users were then invited to interact with the educational game and share their	The study indicates that CIVPT enhances students' learning and motivation in understanding chemical elements. A new assessment tool, E-GUESS, was developed to address pedagogical issues and educational content, aiming to bridge the gap between "fun" and "educational" aspects in educational games. The research also contributed to the usability analysis of an educational game focused on the Periodic Table of Chemistry, offering valuable insights for gameplay adjustments during its validation phase.

© 2024 The Authors

					feedback in accordance with the model.	
7	(Ewais et al., 2021)	Mobile Learning Application for Helping Pupils in Learning Chemistry	Palestine	To explore the potential application of mobile educational apps for instructing chemistry courses in primary schools.	The article also describes the utilization of a qualitative research approach, involving seven students through interviews.	The research indicates that mobile learning technology can effectively support the comprehension of chemistry courses, aiding students in understanding the periodic table, properties of chemical elements, and their interactions. Additionally, the study demonstrates the feasibility of integrating the proposed mobile application into elementary school chemistry courses.
8	(Balasundram & Karpudewan, 2021)	Exploring The Use of a Writing-To-Learn Activity Embedded with Multiple Modes Using ': Popplet ' On Pre-University Students' Alternative Conceptions on	Malaysia	To assess the impact of integrating different modes of representation into a writing-to-learn exercise facilitated by 'Popplet' on diminishing alternative conceptions	A diagnostic test was given to 81 pre-university students as a pre-test before the writing-to-learn activity, and a post-test was administered after the exercise	After the post-test, fewer students exhibited alternative conceptions compared to the pre-test. The paired sample t-test revealed a significant difference in means between the pre and post-tests. Qualitative interviews shed light on how integrating modes within the writing activity using 'Popplet' contributed to the reduction of alternative conceptions. The study

© 2024 The Authors

		Transition Metals		related to transition metals. .		suggests a student-centered approach for teaching lessons on transition metals as an alternative for educators.
9	(Horikoshi, 2021)	Teaching Chemistry With LEGO® Bricks	Japan	To explain, LEGO-based teaching aid in chemistry is a simple-to-build tool that has the potential to benefit educators by inspiring the creation of additional innovative teaching aids.	LEGO bricks' diverse shapes and colours allow for creation of numerous teaching aids in chemistry, such as periodic tables, molecular models, polymer structures, and handmade measuring instrument frameworks. Unlike traditional ball-and-stick molecular models, LEGO bricks make building polymeric	LEGO bricks are ideal for crafting handmade measuring instruments due to their versatility, computer interface compatibility, and the absence of a need for specialised tools.

© 2024 The Authors

					structure models easy and accessible.	
10	(Álvarez-Herrero & Valls-Bautista, 2021)	The Game as A Strategy of Learning Chemistry Among High School Students	Spain	to examine the relationship between periodic table learning and the types of strategies students choose to achieve learning outcomes related to it.	During a five-year investigation, 260 students actively engaged in constructing instructional materials to facilitate their learning of the periodic table. Notably, 195 of these students opted to create a game as a tool for this purpose.	No gender-based differences were found; students prefer engaging and motivating learning experiences, leading to a more profound understanding. Gamification and learning-based games are increasingly important in education, with more teachers adopting these approaches.
11	(Traver et al., 2021)	Educational Video Game to Learn the Periodic Table: Design Rationale and Lessons Learned	United States	To compare the effects of progressing through difficulty levels versus starting with all elements,	E-CHEMMEND is a digital game designed as an alternative to the traditional physical	E-CHEMMEND is more enjoyable when showing group and period numbers, but it enhances learning when these details are hidden with levels displayed. The game is adaptable for diverse educational purposes, offering valuable insights for

© 2024 The Authors

				and examine the impact of displaying groups and periodic numbers with symbols versus showing only element symbols.	card game, helping memorize the group and period numbers of chemical elements.	instructors and researchers. Access the desktop version at http://www.chemmend.uji.es/game.
12	(Watson et al., 2021)	Introducing Students to The Periodic Table Using a Descriptive Approach of Superheroes, Meats, And Fruits and Nuts	United States	To introduce students to the chemistry periodic table with diverse pseudo "periodic tables" using iPad Apps like Periodic Table, Fruits, Nuts, Meat, and Superheroes	introduced a unique approach to first-year chemistry students with the formal periodic table.	This introduction highlights crucial elements of table construction, including grouping items with columns, rows, blocks, and color; numbering items; utilizing abbreviations; combining individual elements; and transitioning both across and down the table, such as size variations in these directions.
13	(Siquiere, 2021)	A Proposal for The Periodic Table Teaching in	Brazil	to explore the construction and organisatio	It consists of two group dynamics that allow	-

© 2024 The Authors

		Science Teacher Training Courses and the High School Based on The Theme of Metals		n of the Periodic Table from the metal theme in a playful way, thereby allowing the content to be relevant for these students and understood by them.	to contextualise the presence of metallic chemical elements in objects/products, being the majority present in the students' daily lives, and to explore the construction and organisation of the Periodic Table playfully, thus allowing the contents to become relevant for these students and be understood by them.	
14	(Montejo Bernardo & Fernán	Chemical Battleship: Discovering and Learning	Mexico	To introduce Chemical Battleship as a	Chemical Battleship was evaluated with	The game's implementation was well-received by both groups of students, generating interest and

© 2024 The Authors

	dez González, 2021)	the Periodic Table Playing a Didactic and Strategic Board Game		chemical adaptation of the traditional board game Battleship. Its purpose is to facilitate learning about critical topics in the periodic table and the identification of standard laboratory glassware.	primary school and third-year students in the Primary Education Teacher Degree program.	curiosity among primary school students and enhancing knowledge among third-year students in the Primary Education Teacher Degree program. Notably, the game positively impacted students' subjective perception of their expertise and demonstrated tangible improvements in their understanding of the periodic table, as evidenced by higher scores.
15	(Stojanovska, 2021)	Celebrating The International Year of Periodic Table with Chemistry Educational Games and Puzzles	Spain	To emphasise the need for teachers to be creative in finding ways to implement game-based learning and design custom puzzles that suit their specific needs and classroom settings.	By embracing this approach, teachers can create a dynamic and immersive learning environment, fostering student engagement, critical thinking, and a deeper	The games provided are adaptable for creating an escape room-style classroom experience and for independent use. We strongly believe that incorporating educational games into learning will significantly benefit students.

© 2024 The Authors

					understanding of the subject matter.	
16	(Zhou et al., 2020)	Periodic Domino Game: A Possibility for Teaching and Learning One of The Periodic Table	Brazil	to verify acceptance and influence in applying the Periodic Domino game in the classroom on the periodic table.	It was carried out with 19 students of the 9th grade of Elementary School II of the Centro Educacional Espaço Criativo School in Quiterianópolis-CE. The data were collected through an evaluative questionnaire.	The results graphically presented showed that the game aroused the students' interest since 64% of them attributed a maximum score and had an excellent influence since 95% of the students stated that the match contributes significantly to a better understanding of the content addressed.
17	(Rychkova et al., 2020)	Orbital Battleship: A Multiplayer Guessing Game in Immersive Virtual Reality	Rusia	to reinforce the knowledge of the atomic structure.	A futuristic version called VR Orbital Battleship has been developed to offer a fully immersive and collaborative experience.	The headset used in the game provides a fully immersive experience, reducing distractions compared to the traditional version. The user-friendly and intuitive design enhances the overall immersive experience for players. The game is recommended as an interactive supplement for school and

© 2024 The Authors

					Unlike the pen-and-paper version, this game ensures students cannot input incorrect electron configurations due to its unique control elements. This feature motivates students to accurately apply Madelung's and Hund's rules to participate in the game.	university classes focusing on atomic structure. VR Orbital Battleship is free worldwide and can be accessed on portable mobile platforms like Oculus Go and PCs by downloading the game.
18	(Estudante & Dietrich, n.d.))	Using Augmented Reality to Stimulate Students and Diffuse Escape Game Activities to Larger Audiences	Portuguese	To introduce the original paper-based version explicitly designed for a high school/college audience,	Participants engage in a mysterious journey where they unravel the secrets of Solvay in Brussels by solving enigmas.	AR escape games offer a convenient way to engage large classroom audiences without needing a teacher's physical presence or extensive preparation. The advantages and limitations of these tools are examined, considering their potential benefits and

© 2024 The Authors

centred around the Solvay process. The scenario involves students following the journey of a young Belgian physicist, Ernest Solvay. Through this interactive experience, students are encouraged to explore and learn about the Solvay process and its significance in chemistry.	The puzzles revolve around various aspects of chemistry, such as the periodic table of elements, the CPK colour code, chemical reaction balancing, molar mass, the Solvay process, and the philanthropic conferences Solvay and other scientists organised. These elements serve to illustrate the fascinating chemical processes discovered throughout the game.	drawbacks. Feedback from students who participated in a test exercise using the device supports the notion that such activities can enhance student motivation.

© 2024 The Authors

19	(Setiawan et al., 2019)	Augmented reality application for chemical bonding based on android	Indonesia	Utilizing Augmented Reality to visualize 3D models of each chemical element and observe animated combinations between elements.	Generate 3D representations of chemical elements using marker/tracker cards. Multiple cards can be combined to create various chemical element combinations, detected by the camera. Testing includes elements like H, Ca, Na, K, C, Cl, Br, O, S, SO2, CO2, and OH, combining them to form compounds like HCl, NaCl, H2O, CO2, MgS, SO2, O2, CaCl2,	Testing the study results on students to assess their learning benefits.

© 2024 The Authors

					HCN, N2, and more.		
20	(De Oliveira et al., 2019)	QUIMIVOX MOBILE 2.0: Application for Helping Visually Impaired People in Learning Periodic Table and Electron Configuration	Brazil	The Quimivox Mobile 2.0 application is being introduced as a new version designed for Android devices. It aims to provide accessible information about the periodic table and electronic configuration of chemical elements for visually impaired individuals, including those who are blind or have limited vision and those facing challenges related to colour vision.	The interaction in the application is based on vocal commands and simple gestures, providing information through both graphical and voice synthesis means. Comparative assessments were conducted between two versions of the application. The second version included typical information access tools for non-disabled individuals and	The application was found to be an effective and enjoyable tool that promotes inclusive education.	

© 2024 The Authors

					automated tests to assess its compatibility with colour blindness.	
21	(Daaif et al., 2019)	Progress Of Digital Learning Resources: Development and Pedagogical Integration of a Virtual Environment Laboratory for The Practical Experiments in Chemistry	Morocco	To implement a simulation laboratory for practical chemistry tasks and assessing the educational impact of virtual learning environments in university teaching.	Examining how the periodic table and chemical kinetics are used in practical work. Qualitative study on students in the Physical Chemistry of Materials Lab to identify factors influencing progress with our computer solution.	
22	(Domjanić Drozdek et al., 2019)	The Role of the iPad Tablet in Higher Education Science Teaching	Croatia	Offers four applications under the unit titled "Preparing Solutions," including "Periodic	Practical classes in Biology and Chemistry are included in the	In Biology class, tablet apps (e.g., "Cytogenetics," "Diseases and disorders," "Gene Screen") enhance learning on Genetics and Cell Structure,

© 2024 The Authors

				Table," "Molarity," "Chemist," and "Beaker."	undergraduate programs for Environmental Health Engineering and Laboratory Medical Diagnostics.	providing additional support alongside traditional teaching methods.
23	(Guerra et al., 2019)	Constructing A Periodic Table: A Proposed Practice Activity for High School Chemistry Classes	Brazil	Highlighting a fun classroom activity where public high school students collaboratively build a periodic table	A qualitative case study employed a practical activity, constructing a periodic table with accessible materials, to enhance students' understanding and connect it to their daily lives.	Contextualizing the activity enhanced subject understanding and realism. Schools should prioritize playful activities for student development, allowing teachers to diversify methods and create dynamic and differentiated classes.
24	(Bruno, 2019)	The international year of the periodic table and the teaching of chemistry: From	Portuguese	To study how the periodic table is used in chemistry education, focusing on production and	Reviewed Chemical Education papers (2009-2018) from six journals, identifying four	Analyzing 28 articles revealed four categories: education level, approach, strategy, and didactic resource. Among the publications, 40% used didactic approaches, with clarity (43%) and games (card, board,

© 2024 The Authors

		letters to digital		exploring didactic strategies.	categories: education level, approach, strategy, and didactic resource.	digital) being common resources.
25	(Lopper, 2019)	A Digital Periodic Table That Instructors Can Use in The Classroom to Highlight Elements and Illustrate Periodic Trends	United State	To study a digital periodic table designed as a visual aid for high school or college chemistry classrooms.	To capture students' focus on specific elements, using style schemes for colouring groups and illustrating periodic trends.	The periodic table, written in HTML, CSS, and JavaScript, allows users to customize its appearance and size for classroom screens. Users can also add atomic data for expanded capabilities.
26	(Yayon et al., 2019)	Do-It-Yourself: Creating and Implementing a Periodic Table of The Elements Chemical Escape Room	Israel	To explore ChEsRm (PTOE Chemical Escape Room) provides an engaging learning experience, blending chemistry puzzles with information on elements and properties,	Participants will be provided with a detailed narrative surrounding the mysterious demise of an individual. Rather than conducting experiments in a laboratory setting,	While many escape rooms typically rely on locks and keys, this escape room utilises a different and adaptable mechanism to unveil the solution. Below, we offer a comprehensive description of all the puzzles involved and provide instructions on how to operate the escape room within a school laboratory setting.

© 2024 The Authors

				along with non-laboratory tasks to reinforce chemical concepts.	they will rely on their analytical abilities to piece together evidence, examine witness statements, and explore various leads.	
27	(Joaquina De Oliveira Barboza, n.d.)	Periodic Race: Demystifying the Scientific Language of The Chemical Elements	Portuguese	Examining how the educational game "Periodic Race" aids in understanding Periodic Table symbolism.	Qualitative research in two 10th-grade classes at a Salgadinho-PE Secondary School, using a game proposed by researchers and implemented by the class teacher. Data collected through a field diary and student interviews.	Highlighting teacher-student interactions during the game and gathering student perspectives through interviews. Observations revealed students' familiarity with common elements but difficulty understanding periodic properties. The game facilitated direct contact with the Periodic Table, aiding comprehension and emphasizing its knowledge-based significance in studying chemistry concepts.

© 2024 The Authors

3. Results

A systematic Literature Review (SLR) has the main objective to identify journals that discuss related to this central issue to be taken as a reference. So, this section answers the research questions by reporting and examining the use of a gamification approach in mastering the periodic table (chemistry). Furthermore, this section also analyses the various impacts of using the gamification approach, which includes three main aspects, namely in terms of understanding, motivation and usability. This study also develops a conceptual framework based on gamification, which past researchers most often use. Research results from previous research articles found 27 articles that meet all criteria. It has thus summarised the purpose of the selected articles' study and will provide an overview of the research carried out on each paper. Therefore, the purpose of the study for the selected documents, which will give an overview of the survey carried out on each article, has been summarised in Table 1. The table summarises various research studies related to the teaching and learning of the periodic table, specifically focusing on innovative methods and strategies. Each entry includes the authors, their location, and their studies' purposes, methodology and findings. The studies aim to enhance student motivation, reduce alternative concepts, explore different teaching aids, examine learning strategies, investigate the role of gaming elements, introduce alternative periodic tables, and utilise augmented reality and mobile learning tools. These studies highlight the importance of incorporating interactive and playful approaches to make the periodic table more engaging and accessible for students.

3.1 Study Location

The collected studies have been published in several countries. The majority of published articles are from Brazil (26%), followed by the United States (15%), Portuguese (11%) and Spain 4%. Next, 11 countries (Croatia, Singapore, Malaysia, Japan, India, Palestine, Indonesia, Israel, Rusia, Pakistan & Africa) have the same number of publications with only one article (4%). Among the articles published from Brazil [25], [26], [27], [28], [15], [30] and [31], United State [27], [28], [29],[30] and Portuguese [31] [32] [33].

Spain [34] [35], Singapore [36], India [37], Pakistan [38], Palestine [39], Malaysia [40], and Japan [41]. Next is Mexico, [42-13A], Rusia, [43], Indonesia [44] Morocco [45], Croatia [46] and Israel [24]. United State [32], [33], [34],[35] and Portuguese [36] [37] [38]. Spain [39] [40], Singapore [41], India [42], Pakistan [43], Palestine [44], Malaysia [45], and Japan [46]. Next is Mexico, [16], Rusia, [47], Indonesia [48] Morocco [49], Croatia [50] and Israel [29].

3.2 Types of research instruments

Previous studies have been divided into three methodological categories, namely quantitative, qualitative and mixed methods. The complete list of past studies based on the three methodological categories shows in Table 2.

© 2024 The Authors

Table 2. Methodology and The Impact of Study Participants Through Gamification in The Periodic Table of Elements of past research articles

Study	Research Design	Understanding	Motivation	Usability	No Impact
1	MM		/		
2	QN			/	
3	QN	/	/		
4	QN		/	/	
5	QN	/	/		
6	MM	/	/	/	
7	QL	/	/	/	
8	MM	/			
9	QN				/
10	QN		/		
11	QN		/		
12	QN	/		/	
13	QN				/
14	QN	/	/	/	
15	QN		/		
16	QN	/	/		
17	MM	/		/	
18	QN		/		
19	QL				/
20	QN	/			
21	QL	/			
22	QN				/
23	QL		/		
24	QL				/
25	QN				/
26	QN				/
27	QL	/	/		
		12	14	7	7

. QN- Quantitative QL-Qualitative MM-Mixed Method

Based on Table 2, most past studies use quantitative research methods. A total of 63%, 17 out of 27 articles used a set of questionnaires. However, the quantitative approach is less able to provide a general interpretation regarding the issue to be discussed in more depth. It is likely due to the constraints of the Covid-19 pandemic, which limits the dissemination of this questionnaire and is only carried out online. In addition, the researcher can also know an issue in more depth and contextually by using this mixed method. Using a set of questionnaires and semi-structured

© 2024 The Authors

interviews to obtain research data is among the methods used in four out of 27, i.e15% of the article studies use mixed methods. Meanwhile, the qualitative method is as much as 22%, six out of 27 articles.

The table also assesses the impact of different gamification approaches on various aspects, such as understanding, motivation, and usability, based on the frequency of their mention in the journals. The table also includes a category for approaches that have no impact. The data in Table 2 shows the effect of using gamification, which has been divided into three characteristics: understanding, motivation and attitude. The findings recorded that most of the impact of gamification in mastering the periodic table was motivation in 14 articles (52%). Next, the survey focusing on understanding is 44% followed by 26%, which is the usability from 2019 to 2023. The article that does not involve any impact is about 26%. The article that studies all three effects is about 11%. Aspect understanding and motivation showed about 15% studied them, followed by experience and usability, about 7%. Lastly, motivation and usability in only one journal contribute only 4%.

Table 3. Types of gamification approaches in mastering the periodic table of Elements (chemistry)

Journal	Gamification Approaches
5,17	Cubes in Virtual Periodic Table (CIVPT), Virtual Immersive Reality
8	Writing activity using 'Popplet.'
9	LEGO
2,6,7,10	Project and WebQuest, mobile-malware classification, E-Guess, mobile learning
11	Digital cards as an aid in memorising group and element number
12	Pseudo, iPad application, fruit and beans, meat and superheroes.
13	Period table from metal theme
1,3,14,24,	Chemical Battleship version, digital and game card
15,26	Game and riddle/ Riddle escape Room,
16	Domino game
18,19	AR 3d Chemical Compound / AR electron arrangement, AR diffuse escape game
20	Inclusive. Electronic Configurations
4,21,22	Virtual Laboratory
23,27	Playful activity, didactic (dice)
25	Click and show

4. Conclusions

© 2024 The Authors

A systematic survey was conducted to identify the gamification approaches used to enhance mastery of the Periodic Table in Chemistry. This review explains the relationship between impact variables when using gamification for the Periodic Table. Understanding and motivation are two main aspects of the impact variable in mastering the Periodic Table through gamification. The researcher utilised an electronic database, Scopus, to obtain relevant articles. A total of 27 articles meeting the criteria were analysed. The findings highlight that researchers commonly studied Project and WebQuest, mobile-malware classification, E-Guess, mobile learning and Chemical Battleship version, digital and game card approaches.

Regarding impact, the second part of the study reveals that 14 articles demonstrate a motivational effect. In comparison, 12 articles report an improvement in student understanding compared to only seven pieces indicating changes in usability. Therefore, implementing gamification to master the periodic table can enhance student motivation and academic performance. Nazatul Aini and Nur Faizah [51] suggest combining virtual and real data in gamification can increase enjoyment and engagement and improve academic performance.

Acknowledgement

This research was not funded by any grant.

References,

1. Hashini Kavishtri Kannan. “Lack of interest in STEM subjects worrying.” *New Straits Times,* https://www.nst.com.my/news/nation/2019/11/535682/lack-interest-stem-subjects-worrying, accessed 4 November 2019.
2. Sapora Sipon. “STEM penuhi impian jadi negara pencipta.” *Berita Harian,* https://www.bharian.com.my/taxonomy/term/10/2017/07/304215/stem-penuhi-impian-jadi-negara-pencipta, accessed 21 July 2017.
3. Fatin Aliah Phang. “STEM boleh jayakan agenda TN50.” *Berita Harian*, https://www.bharian.com.my/kolumnis/2017/06/293471/stem-boleh-jayakan-agenda-tn50 accessed 16 June 2017.
4. Ina V.S. Mullis et al., “TIMSS 2019 International Results in Mathematics and Science.” *TIMSS 2019 International Results in Mathematics and Science.* https://www.iea.nl/sites/default/files/2020-12/TIMSS-2019-International-Results-in-Mathematics-and-Science.pdf accessed 2020.
5. Prayitno, Baskoro & Corebima Aloysius, Duran & Susilo, Herawati & Zubaidah, Siti & Ramli, Murni. “Closing the science process skills gap between students with high and low level academic achievement.” *Journal of Baltic Science Education.* 16 (2017): 266-277. https://doi.org/10.33225/jbse/17.16.266, accessed April 2017.
6. Srisawasdi, Niwat, and Patcharin Panjaburee. “Implementation of Game-Transformed Inquiry-Based Learning to Promote the Understanding of and Motivation to Learn Chemistry.” *Journal of Science Education and Technology* 28, no. 2 (2019): 152–64. https://www.jstor.org/stable/48699951.

© 2024 The Authors

7. Kamisah Osman. “Students as digital game designer: addressing the 21stcentury chemistry education needs in Malaysia.” *Proceeding ofThe 1stInternational Seminar On Chemical Education:* Bangi, Selangor: The National University of Malaysia. 2015. https://chemistryeducation.uii.ac.id/wp-content/uploads/2015/10/6-20-Kamisah-Osman.pdf
8. Othman, Azraai, Dani Asmadi Ibrahim, and Othman Talib. 2019. “TEACHING AND LEARNING BASED ON ORGANIC CHEMISTRY TAXONOMY BLOOM (12 - 21)”. *Jurnal Pendidikan Bitara UPSI*. 8(1):12-21. https://ejournal.upsi.edu.my/index.php/JPB/article/view/2446.
9. Qian, Meihua and Karen R. Clark. “Game-based Learning and 21st century skills: A review of recent research.” *Computer in Human Behaviour*. 63 (2016): 50-58. https://doi.org/10.1016/j.chb.2016.05.023
10. Li, Qinghua. 2018. “Improvement of Chemistry Teaching Practice to Deep Learning,” January. https://doi.org/10.2991/essaeme-18.2018.40.
11. Rosly, Nurfarhana Shahira, Normaliza Abd Rahim, and Hazlina Abdul Halim. "Utterance Interaction in Children through Digital Elements in Storytelling." *Gema Online Journal Of Language Studies*. 16, no. 1 (2016): 89-108.
12. Ismail, M., & Mohamad Nasri, N. “Keberkesanan Pendekatan Gamifikasi Dalam Pembelajaran Bahasa Inggeris Dari Segi Penglibatan Murid dan Pengekalan Pembelajaran.” *Jurnal Penyelidikan Sains Sosial (JOSSR),* 4(10) (2021), 49 - 61. http://www.jossr.com/PDF/JOSSR-2021-10-03-06.pdf
13. Adam Hoffman and Mark Hennessy. “The People Periodic Table: A Framework for Engaging Introductory Chemistry Students.” *Journal of Chemical Education*. 95 (2)(2018): 281-285. https://doi.org/10.1021/acs.jchemed.7b00226
14. Chowdhury, Pinaki. “Learners' Misconceptions in Periodic Table: An Analysis of Cognitive Skills Development.” Universal Journal of Educational Research (2022): n. pag.
15. Souza, Fernanda Oliveira de, Jakson Fernandes Lima, Railo Cavalcante Nunes, Daniel Alves da Silva, Glória Fernandes Lima, Rubya Macêdo Lima, Sandra Maria Barbosa de Araújo, Rosilene Rosa Rodrigues, Maria Izabel Florindo Guedes, and Luiz Francisco Wemmenson Gonçalves Moura. 2020. “Periodic Domino Game: A Possibility for Teaching and Learning One of the Periodic Table”. *Research, Society and Development* 9 (10): e4189108617. https://doi.org/10.33448/rsd-v9i10.8617
16. Montejo Bernardo, Jose M., and Alfonso Fernández González. “Chemical Battleship: Discovering and Learning the Periodic Table Playing a Didactic and Strategic Board Game.” *Journal of Chemical Education* 98, no. 3 (2021). https://doi.org/10.1021/acs.jchemed.0c00553.
17. Smiderle, R., Rigo, S.J., Marques, L.B. et al. The impact of gamification on students’ learning, engagement and behavior based on their personality traits. Smart Learn. Environ. 7, 3 (2020). https://doi.org/10.1186/s40561-019-0098-x
18. Zulaikha Mohd Basar, Azlin Norhaini Mansor, Khairul Azhar Jamaludin and Bity Salwana Alias. “The Effectiveness and Challenges of Online Learning for Secondary School Students

© 2024 The Authors

– A Case Study". *Asian Journal of University Education.* v. 17, n. 3, p. 119-129, aug. 2021. https://doi.org/10.24191/ajue.v17i3.14514.

19. Sukamto. "The Use of Interactive Multimedia to Increase Students' Motivation and Achievement in Learning Islamic Education." *Journal of Islamic Education Research* | Vol. 3 No. 02 (2022). https://doi.org/10.35719/jier.v3i2.341.
20. Zourmpakis, Alkinoos-Ioannis, Michail Kalogiannakis, and Stamatios Papadakis. 2023. "Adaptive Gamification in Science Education: An Analysis of the Impact of Implementation and Adapted Game Elements on Students' Motivation" C*omputers* 12, no. 7: 143. https://doi.org/10.3390/computers12070143
21. Wong Weng Siong and Kamisah Osman. "Pembelajaran Berasaskan Permainan dalam pendidikan STEM dan penguasaan kemahiran abad ke-21." *Journal of Social Sciences and Humanities,* 3 (2018):128–2875. https://app.mypolycc.edu.my/journal/index.php/PMJSSH/article/view/153/100
22. Chans, Guillermo M., and May Portuguez Castro. 2021. "Gamification as a Strategy to Increase Motivation and Engagement in Higher Education Chemistry Students" *Computers 10*, no. 10: 132. https://doi.org/10.3390/computers10100132
23. Zahra Hazari, Geoff Potvin, Jennifer D Cribbs, Allison Godwin, Tyler D Scott and Leidy Klotz."Interest in STEM is contagious for students in biology, chemistry, and physics classes." *Science advances* vol. 3,8 e1700046. 9 Aug. 2017, https://doi.org/10.1126/sciadv.1700046
24. Khalid S Khan, Regina Kunz, Jos Kleijnen and Gerd Antes. "Five steps to conducting a systematic review." *Journal of the Royal Society of Medicine* vol. 96,3 (2003): 118-21 https://doi.org/10.1177/014107680309600304
25. Carabelli, Patricia, Andrea S. Farré, and Andrés Raviolo. "Historical and Philosophical Foundations of a Game-Based Learning Strategy for Teaching Periodic Law." Revista Eureka 20, no. 2 (2023). https://doi.org/10.25267/REV_EUREKA_ENSEN_DIVULG_CIENC.2023.V20.I2.2803.
26. Silveira, Aleph Campos da, Ronei Ximenes Martins, and Estela Aparecida Oliveira Vieira. "E-Guess: Usability Evaluation for Educational Games." *RIED-Revista Iberoamericana de Educacion a Distancia* 24, no. 1 (2021): 245–63. https://doi.org/10.5944/ried.24.1.27690.
27. Siquiere, Dayane Cristielle. "A Proposal for the Periodic Table Teaching in Science Teacher Training Courses and in the High School Based on the Theme of Metals" 13, no. 3 (2021): 822–35.
28. Aleph C., Ronei X., & Estela Aparecida O. "E-Guess: Usability Evaluation for Educational Games." RIED-Revista Iberoamericana de Educación a Distancia 24, no. 1 (2021):245-263. Redalyc, https://www.redalyc.org/articulo.oa?id=331464460012
29. Yayon, Malka, Shelley Rap, Vered Adler, Inbar Haimovich, Hagit Levy, and Ron Blonder. "Do-It-Yourself: Creating and Implementing a Periodic Table of the Elements Chemical Escape Room." *Journal of Chemical Education*, 2019. https://doi.org/10.1021/acs.jchemed.9b00660.

© 2024 The Authors

30. Oliveira, Alex Santos De, Bruno Merlin, João Elias Vidueira Ferreira, Heleno Fülber, and Allan Veras. "QUIMIVOX MOBILE 2.0: Application for Helping Visually Impaired People in Learning Periodic Table and Electron Configuration." In *IHC 2019 - Proceedings of the 18th Brazilian Symposium on Human Factors in Computing Systems*, 2019. https://doi.org/10.1145/3357155.3358436.
31. Guerra, Genaina Fernandes, Cinthia Maria Felicio, Julio Cesar Ferreira, and Matias Noll. "Constructing a Periodic Table: A Proposed Practice Activity for High School Chemistry Classes." *Creative Education* 10, no. 04 (2019). https://doi.org/10.4236/ce.2019.104050.
32. Haimovich, Inbar, Malka Yayon, Vered Adler, Hagit Levy, Ron Blonder, and Shelley Rap. "'The Masked Scientist': Designing a Virtual Chemical Escape Room." *Journal of Chemical Education* 99, no. 10 (2022). https://doi.org/10.1021/acs.jchemed.2c00597.
33. Traver, V. Javier, Luis A. Leiva, Vicente Martí-Centelles, and Jenifer Rubio-Magnieto. "Educational Videogame to Learn the Periodic Table: Design Rationale and Lessons Learned." *Journal of Chemical Education* 98, no. 7 (2021). https://doi.org/10.1021/acs.jchemed.1c00109.
34. Watson, Gregory S., David W. Green, and Jolanta A. Watson. "Introducing Students to the Periodic Table Using a Descriptive Approach of Superheroes, Meats, and Fruits and Nuts." *Journal of Chemical Education* 98, no. 2 (2021): 669–72. https://doi.org/10.1021/acs.jchemed.0c01143.
35. Lopper, Matthew E. "A Digital Periodic Table That Instructors Can Use in the Classroom to Highlight Elements and Illustrate Periodic Trends." *Journal of Chemical Education* 96, no. 2 (2019). https://doi.org/10.1021/acs.jchemed.8b00616.
36. Estudante, Anabela, and Nicolas Dietrich. "Using Augmented Reality to Stimulate Students and Diffuse Escape Game Activities to Larger Audiences USING AUGMENTED REALITY TO STIMULATE STUDENTS AND DIFFUSE ESCAPE GAME ACTIVITIES TO LARGER AUDIENCES 2 3." *Larger Audiences. Journal of Chemical Education* 2020, no. 5 (n.d.): 97. https://doi.org/10.1021/acs.jchemed.9b00933ï.
37. Bruno, S. Leite. "The International Year of the Periodic Table and the Teaching of Chemistry: From Letters to Digital." *Quimica Nova* 42, no. 6 (2019): 702–10. https://doi.org/10.21577/0100-4042.20170359.
38. Joaquina De Oliveira Barboza, Renata. "CORRIDA PERIÓDICA: DESMISTIFICANDO A LINGUAGEM CIENTÍFICA CORRIDA PERIÓDICA: DESMISTIFICANDO A LINGUAGEM CIENTÍFICA DOS ELEMENTOS QUÍMICOS PERIODIC RACE: DEMISTIFYING THE SCIENTIFIC LANGUAGE OF THE CHEMICAL ELEMENTS,".2019.
39. Álvarez-Herrero, Juan Francisco, and Cristina Valls-Bautista. "The Game as a Strategy of Learning Chemistry among High School Students." *European Journal of Science and Mathematics Education* 9, no. 3 (2021): 80–91. https://doi.org/10.30935/scimath/10947.
40. Stojanovska, Marina. "Celebrating the International Year of Periodic Table with Chemistry Educational Games and Puzzles." *Chemistry Teacher International* 3, no. 1 (2021): 1–9.

© 2024 The Authors

https://doi.org/10.1515/cti-2019-0012.

41. Canbek, Gürol, Tugba Taskaya, and Temizel Seref. "PToPI : A Comprehensive Review , Analysis , and Knowledge Representation of Binary Classification Performance Measures / Metrics." *SN Computer Science* 4, no. 1 (2023): 1–30. https://doi.org/10.1007/s42979-022-01409-1.
42. Sundaram, Sripriya, and Rajendran Ramesh. "Effectiveness of Joyful Game-Based Blended Learning Method in Learning Chemistry during COVID-19." *International Journal of Evaluation and Research in Education* 11, no. 4 (2022). https://doi.org/10.11591/ijere.v11i4.22427.
43. Ali, Numan, Sehat Ullah, and Muhammad Raees. "Interactive Cube for Effective Demonstration of Virtual Periodic Table." *Education and Information Technologies* 27, no. 2 (2022): 1635–54. https://doi.org/10.1007/s10639-021-10691-0.
44. Ewais, Ahmed, Rami Hodrob, Mohammed Maree, and Sireien Jaradat. "Mobile Learning Application for Helping Pupils in Learning Chemistry." *International Journal of Interactive Mobile Technologies* 15, no. 1 (2021). https://doi.org/10.3991/IJIM.V15I01.11897.
45. Balasundram, Nilavathi, and Mageswary Karpudewan. "Exploring the Use of a Writing-to-Learn Activity Embedded with Multiple Modes Using ': Popplet ' on Pre-University Students' Alternative Conceptions on Transition Metals." *Chemistry Education Research and Practice* 22, no. 2 (2021): 263–81. https://doi.org/10.1039/d0rp00119h.
46. Horikoshi, Ryo. "Teaching Chemistry with LEGO® Bricks." *Chemistry Teacher International* 3, no. 3 (2021): 239–55. https://doi.org/10.1515/cti-2020-0017.
47. Rychkova, Anastasia, Alexey Korotkikh, Andrey Mironov, Artem Smolin, Nadezhda Maksimenko, and Mikhail Kurushkin. "Orbital Battleship: A Multiplayer Guessing Game in Immersive Virtual Reality." *Journal of Chemical Education* 97, no. 11 (2020). https://doi.org/10.1021/acs.jchemed.0c00866.
48. Setiawan, Alexander, Silvia Rostianingsih, and Timotius Reinaldo Widodo. "Augmented Reality Application for Chemical Bonding Based on Android." *International Journal of Electrical and Computer Engineering (IJECE)* 9, no. 1 (2019). https://doi.org/10.11591/ijece.v9i1.pp445-451.
49. Daaif, Jabran, Siham Zain, Soufiane Zerraf, Malika Tridane, Abderrahim Khyati, Said Benmokhtar, and Said Belaaouad. "Progress of Digital Learning Resources: Development and Pedagogical Integration of a Virtual Environment Laboratory for the Practical Experiments in Chemistry." *International Journal of Innovative Technology and Exploring Engineering* 8, no. 11 (2019). https://doi.org/10.35940/ijitee.K2403.0981119.
50. Domjanić Drozdek, Sandra, Lana Feher Turković, Ana Mojsović Ćuić, and Ozren Digula. "The Role of the IPad Tablet in Higher Education Science Teaching." *Pedagogical Research* 5, no. 1 (2019): 1–7. https://doi.org/10.29333/pr/6339.
51. Nazatul Aini Abd Majid and Nurfaizah Abd Majid,"Augmented Reality to Promote Guided Discovery Learning for STEM Learning," *International Journal on Advanced Science, Engineering and Information Technology,* vol. 8, no. 4-2, pp. 1494-1500, 2018. [Online].

© 2024 The Authors

Available: http://dx.doi.org/10.18517/ijaseit.8.4-2.6801.

© 2024 The Authors