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A Meta-Synthesis On Gamification In High School Chemistry Education

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Abstract– Gamification, the integration of game design elements into non-game settings, has emerged as an innovative approach to enhance student engagement and learning in education. The influence of gamification on high school chemistry education was meta-synthesized from the 12 selected studies published between 2023 and 2025. Using the PRISMA 2020 flow diagram, the selected studies were screened from Google Scholar and Scopus databases. The Critical Appraisal Skills Programme (CASP) checklist was utilized to finally screen the 12 studies. The transformative impact of gamification on students' learning and engagement was identified as the meta-theme that emerged from the thematic analysis. Consequently, three themes emerged, namely, opportunities in utilizing gamification in teaching chemistry, challenges in implementing gamification in teaching chemistry, and strategies for effective implementation of gamification in teaching chemistry. Nine sub-themes were extracted from the overarching themes, as follows: elevated student motivation and enjoyment, enhanced learning and knowledge retention, development of the 21st century skills, teacher-related constraints, student-related difficulties, infrastructure and resource limitations, content-driven and aligned with the curriculum, storytelling and feedbacking, and integrating technology with the aid of emerging tools. These findings underscore the potential of gamification as a powerful pedagogical tool in high school chemistry education. It is recommended that targeted teacher training and the development of advanced digital infrastructure be provided to support the long-term sustainability of game-based environments.

Keywords: gamification, high school chemistry, meta-synthesis

I. Introduction

In the evolving landscape of science education, there is an increasing call for innovative pedagogies that promote student engagement, conceptual understanding, and long-term retention, particularly in challenging disciplines such as chemistry. As part of the broader sciences, chemistry is central to fostering scientific literacy, an essential outcome in the 21st century (Joynes et al., 2019). However, modern educational paradigms face a challenge in sustaining student engagement and motivation, especially in complex subjects like chemistry (Üce & Ceyhan, 2019; Timilsena et al., 2022). Such circumstances may diminish students' classroom involvement, adversely influencing their learning outcomes (Zajda, 2023).

Based on the recent results of the Programme for International Student Assessment (PISA) 2022, the average science performance of 15-year-old students across Organization for Economic Co-operation and Development (OECD) countries declined compared to previous cycles, with fewer students reaching the highest proficiency levels in interpreting scientific data and applying scientific knowledge to real-life contexts (OECD, 2023). In the Philippines, science scores remain significantly below the OECD average, reflecting long-standing challenges in content delivery and student engagement in subjects like chemistry (Chi, 2023).

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Hence, adopting innovative pedagogical strategies has become increasingly prevalent across various educational disciplines to address these issues (Christopoulos & Mystakidis, 2023; Zainuddin et al., 2020).

In line with Sustainable Development Goal (SDG) 4, which advocates for inclusive and equitable quality education and promotes lifelong learning opportunities for all (Saini et al., 2022), there is a pressing need to transform traditional teaching methods in the sciences. The Harmonized National Research and Development Agenda (HNRDA) 2022-2028 also stipulates that education systems need to evolve and equip individuals with the skills to navigate various digital environments brought by Industry 4.0 (Department of Science and Technology, 2022). Education can facilitate this transition by making learning more engaging, interactive, and effective, helping learners develop the digital competencies needed for smart factories, cities, and societies.

Gamification, integrating game mechanics into non-game contexts, has emerged as a potentially transformative pedagogical strategy (Chans & Castro, 2021). It holds significant promise for transforming traditional learning environments into more interactive and motivating experiences (Byusa et al., 2022; Da Silva et al., 2025; Haruna et al., 2021; Kadeshanavar, 2023; Kalogiannakis et al., 2021).

Despite the growing interest in gamification, a significant gap remains in the literature regarding both the effectiveness of gamification and the practical challenges involved in its implementation within high school chemistry classrooms (Hu et al., 2022). While numerous studies employ quantitative or mixed-method designs to evaluate the effects of gamification, there is a notable lack of synthesis focused exclusively on qualitative findings. These findings offer rich insights into learner experiences, motivational dynamics, and pedagogical challenges, yet remain under examination in existing reviews (Byusa et al., 2022). This meta-synthesis addresses this methodological gap by isolating and integrating the qualitative components of both qualitative and mixed-method studies.

Research Objectives

This study seeks to consolidate and critically analyze existing research on gamification in high school chemistry education. It aims to provide educators and researchers with evidence-based insights into its potential benefits, challenges, and best practices. Accordingly, this research is anchored on the following objectives:

- to identify and synthesize qualitative findings from existing qualitative or mixed-method studies on gamification in high school chemistry education;
- to explore the perceived benefits and challenges of gamification in high school chemistry education from the perspectives of students, teachers, and other educational stakeholders; and
- to analyze strategies that influence the effectiveness and implementation of gamified approaches in high school chemistry instruction.

II. Literature Review

Gamification—incorporating game design elements and principles into non-game contexts has attracted growing interest as a potentially transformative educational strategy (Smiderle et al., 2020). Its implementation spans various educational settings, from primary and secondary schools to higher education institutions, underscoring its versatility and perceived effectiveness in enhancing student engagement (Ruíz et al., 2024). At its core, gamification is grounded in the belief that the motivational appeal of game mechanics can be harnessed to enrich educational experiences, thereby fostering greater student motivation and facilitating learning (Kalogiannakis et al., 2021). Importantly, gamification is not simply about introducing games into the classroom; it involves integrating game-based elements into the learning environment to influence student behavior and support academic achievement (Li et al., 2023). This approach recognizes the capacity of game mechanics to activate intrinsic motivation, making learning more engaging, enjoyable, and effective (Smiderle et al., 2020). Ultimately, gamification aims to reshape educational experience by leveraging the inherent appeal of games to cultivate a more stimulating and rewarding learning environment (Chen & Liang, 2022).

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The educational benefits of gamification are multifaceted and have been examined across disciplines and academic levels. It has emerged as a promising strategy for enhancing students' motivation to learn and improving academic performance compared to traditional instructional methods (Hellín et al., 2023). Among its most frequently cited advantages is its capacity to boost student motivation (Li et al., 2023). This motivational effect is often linked to game elements such as points, badges, leaderboards, and challenges, which provide learners with a sense of achievement and progress (Baig & Yadegaridehkordi, 2023). These components function as extrinsic motivators, encouraging active participation and sustained effort in academic tasks.

Additionally, gamification can promote a sense of autonomy and competence by offering students opportunities to make choices, solve problems, and develop new skills (Li et al., 2024). As a result, learners are more likely to engage deeply with the content, participate actively in class, and persist through academic challenges. Including rewards, levels, and competitive elements fosters a sense of accomplishment and satisfaction, further motivating students to advance in their studies (Jaramillo-Mediavilla et al., 2024). Moreover, gamification has significantly enhanced student engagement across various educational contexts (Chan & Lo, 2024).

On the other hand, gamification leverages several key educational and psychological theories to promote learning, engagement, and motivation. Central to this is the self-determination theory, which suggests that intrinsic motivation arises when individuals feel a sense of autonomy, competence, and relatedness (Vang, 2023). Gamified learning environments often fulfill these psychological needs by offering meaningful choices, appropriately challenging tasks, and opportunities for social connection (Hellín et al., 2023). For instance, Luarn et al. (2023) found that incorporating game elements such as achievement, immersion, and social interaction can significantly boost learners' motivation by satisfying their core psychological needs.

Additionally, flow theory—proposed initially by Mihaly Csikszentmihalyi—also serves as another foundational framework in the study of gamification. Although developed in the 1990s, its relevance persists in contemporary research. Flow theory describes the mental state of being completely immersed in an activity, characterized by focus, enjoyment, and a sense of accomplishment (Beese & Martin, 2019). Gamification seeks to induce flow by providing learners with appropriately challenging tasks and clear goals that match their skill level (Aldalur & Pérez, 2023). It suggests balancing skill level and challenge to avoid anxiety and continue the game's flow (Nadeem et al., 2023). The optimal experience that brings each student to a state of flow is one in which they enjoy the activity and are immersed in it (Manzano-León et al., 2022).

Moreover, cognitive load theory provides another key perspective by emphasizing how instructional design can affect working memory. According to recent findings, gamification can reduce extraneous cognitive load—an unnecessary mental effort that distracts from learning—using a structured progression, visual aids, and guided tasks (Baah et al., 2024). Sancar-Tokmak and Dağlı (2025) argue that interactive game mechanics, such as scaffolding, real-time feedback, and modular challenges, help streamline learners' cognitive processing and facilitate deeper comprehension. It creates an engaging but not overwhelming learning environment (Nitiasih et al., 2020).

Correspondingly, behaviorism highlights the role of external reinforcement and repeated practice in shaping learning (Brau et al., 2022). Educational games often incorporate this approach to strengthen core skills and enhance the memorization of essential concepts (Gupta, 2025). By strategically rewarding desired behaviors and offering frequent opportunities for practice, these games reinforce learning in a manner consistent with behaviorist principles (Molina-Carmona & Largo, 2020).

Equally important, constructivist theory underpins gamification by emphasizing learner-centered, experiential educational approaches. Constructivism posits that learners build knowledge through active participation and reflection (Ahmadvand & Khoshchehreh, 2023). Yan and Zhao (2023) found that students participating in gamified, scenario-driven tasks demonstrated enhanced conceptual understanding and increased motivation. Moreover, gamification frequently incorporates collaborative features that resonate with Vygotsky's concept of the Zone of Proximal Development (ZPD), wherein learners advance through peer interaction and scaffolded support. Consequently, gamification grounded in constructivist principles fosters meaningful participation and supports the retention of learning over time (Li et al., 2023; Park & Kim, 2021).

In chemistry education, gamification fosters student engagement by incorporating elements such as friendly competition, challenges, and rewards. Thereby, making the learning process more dynamic and enjoyable (Zainuddin et al., 2019). It reimagines conventional lectures and textbook-based tasks as interactive experiences that mirror real-world contexts, effectively stimulating student interest and motivation (Martínez-Jiménez et al., 2021). When learning activities are thoughtfully aligned with course objectives, students are more inclined to participate actively and enjoy the process, leading to enhanced knowledge retention through experiential and intellectually engaging learning strategies (Baig & Yadegaridehkordi, 2023).

Indeed, gamification in educational settings has gained considerable attention, especially as teachers want to increase the motivation and performance of students in traditionally defined complex subjects, like chemistry (Martí-Parreño et al., 2023). With its abstract concepts and complex problem-solving character, chemistry in secondary schools is likely to pose cognitive and motivational challenges to students. Against such challenges, gamification—using game design elements in non-game situations—has been proposed as a pedagogical approach to transform passive learning into active and interactive processes (Fernández-Río & Suárez, 2024). The significance of exploring gamification in this regard is underscored by its compatibility with the educational goals of the 21st century, including the facilitation of autonomous learning, critical thinking, and digital literacy. These trends suggest that gamification, if appropriately incorporated into curriculum standards and the requirements of learners, can be an efficacious tool for augmenting science education.

Despite the encouraging potential, the application of gamification in teaching secondary school chemistry is plagued with several challenges. Significant research challenges include variability in the design and application of gamification in studies, the lack of longitudinal data measuring quantitatively the long-term impact of learning, and limited agreement on which specific game mechanics (e.g., points, levels, badges) are most conducive to rich conceptual understanding (Nguyen et al., 2023). Moreover, teachers are often forced to weigh learning content against game features, which can lead to an overemphasis on competition or fun rather than profound learning (Martí-Parreño et al., 2023). There is also a tendency to report gains in motivation rather than gains in cognition, so there is little worthwhile evidence on improving higher-order reasoning or problem-solving skills (Ramos & del Rosario, 2024). Some of the criticisms also pinpoint the superficial level of the use of gamification features without adequate pedagogical foundations, which can lead to higher levels of engagement but not necessarily enhanced learning outcomes (Othman & Ching, 2024).

The growing but dispersed literature invites a meta-synthesis to analyze and synthesize evidence on gamification in secondary school chemistry. The current research gap is the lack of synthesized evidence comparing different gamification models, best practices, and long-term educational performance. A meta-synthesis is poised to offer a nuanced understanding of what works, for whom, and under what conditions—thereby providing valuable information to teachers, curriculum planners, and policymakers who aim to maximize gamified approaches to chemistry education.

III. Methodology

This study used meta-synthesis, a type of systematic review that evaluates findings from interrelated qualitative studies to develop a more comprehensive understanding of a phenomenon (Polat & Ay, 2016). It goes beyond simply summarizing individual studies; it aims to generate a new interpretation or theory and advance a field of knowledge by integrating and transforming existing research findings. This approach is used to identify commonalities, differences, and new insights across studies, ultimately contributing to a richer understanding of a particular topic (Dawson, 2019; Finfgeld-Connett, 2018).

3.1 Search Strategy

Using the Publish or Perish software (Harzing, 2007), qualitative or mixed-method studies from Google Scholar and Scopus databases were used to gather data on gamification in high school chemistry. Keywords used were “gamification” and “high school chemistry.” All studies on gamification in high school chemistry published between 2023 and 2025 have been downloaded and analyzed. The entire process of reviewing the search results was systematically documented, guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 Flow Diagram (Page et al., 2021), to ensure a transparent and structured overview of how studies were identified, screened, and selected (or excluded) during the review process.

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3.2 Selection/Inclusion Criteria

The studies included in the meta-synthesis were chosen using specific inclusion criteria. The study focused on gamification in high school chemistry education. Only studies with qualitative or mixed-method research designs, with clearly displayed or described qualitative data, will be considered for inclusion. Articles will be excluded if they are only about student outcomes, use only quantitative designs, or are not explicitly related to gamification. The search was limited to studies published between 2023 and 2025, written in English, and available in full text.

To ensure methodological rigor, the researchers used the Critical Appraisal Skills Programme (CASP) (2024) checklist for qualitative research to assess the quality of all the eligible articles. Each researcher independently evaluated the eligible studies using the designated checklist, after which the average rating per article was computed. Only studies with a mean score of at least seven (7) were included in the meta-synthesis to ensure high-quality evidence. This process helped maintain rigor and consistency in the selection of studies.

3.3 Search Result

Figure 1 presents a comprehensive search result to identify studies included in the meta-synthesis, as illustrated in the PRISMA 2020 flow diagram. The process followed three main phases: identification, screening, and inclusion. In the identification phase, one thousand five (1,005) studies were retrieved using the Publish or Perish software—nine hundred eighty-four (984) from Google Scholar and twenty-one (21) from the Scopus databases. Before screening, six (6) duplicate records and one (1) non-English record were removed. Figure 1 shows the screening process using the PRISMA 2020 flow diagram.

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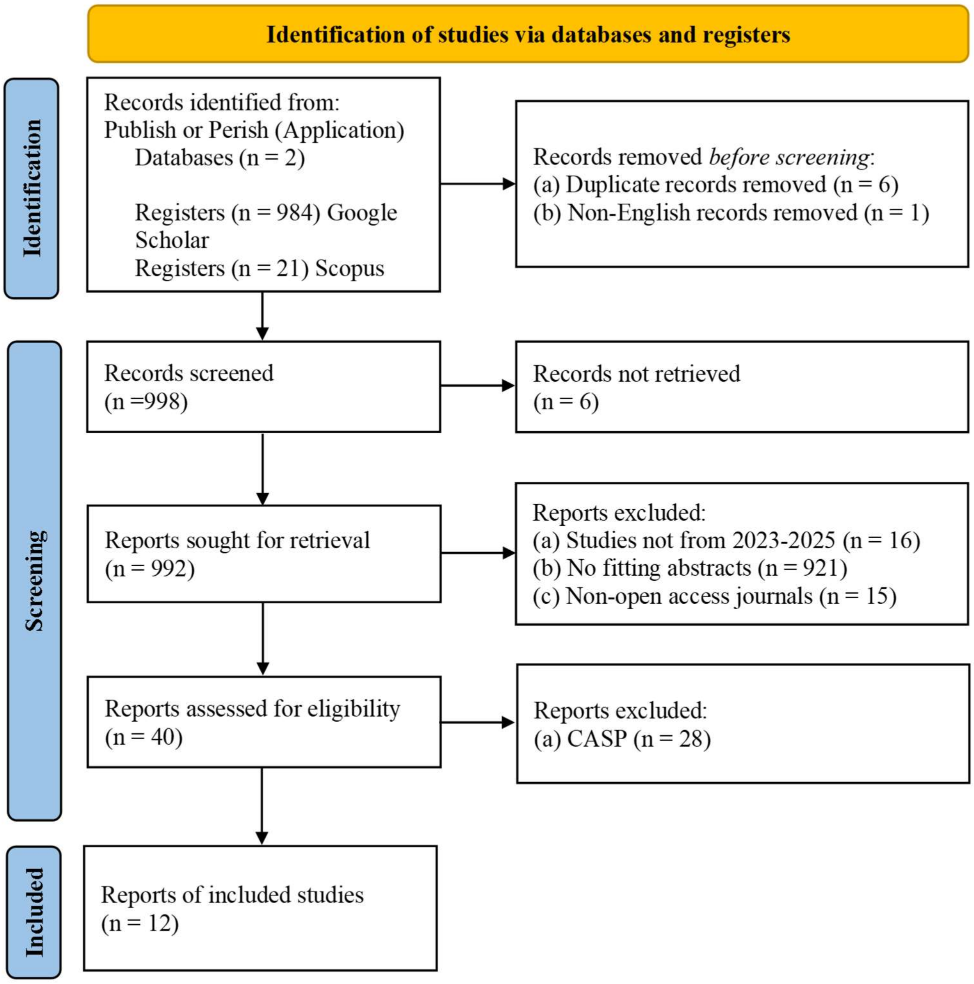

Figure 1. The Flow Diagram of the Study Utilizing PRISMA 2020

During the screening phase, nine hundred ninety-eight (998) sources were reviewed; however, six (6) were inaccessible, sixteen (16) were not published from 2023 to 2025, nine hundred twenty-one (921) had non-fitting abstracts, and fifteen (15) were non-open-access journals. Because of these exclusion criteria, forty (40) reports remained for eligibility assessment. Of the remaining studies assessed for eligibility, twenty-eight (28) did not meet the CASP checklist criteria. Ultimately, twelve (12) research articles were included in this study, meeting the minimum requirement of 10 to 12 studies for a meta-synthesis (Willig & Wirth, 2018) as displayed in Table 1.

Table 1. Studies Focusing on Gamification in High School Chemistry Education

No.	Author/s & Year	Setting	Publi-cation type	Design	Game/ Game-Based Element Used	Salient Findings
S1	Filippas, A., & Xinogalos, S. (2023)	Greece	Article	Mixed	Elementium	• High acceptance and perceived relevance • Enhanced engagement • Improved knowledge retention • Strong didactic utility • Effective feedback and guidance system • Supported self-directed learning • Limitations for classroom use • Game mechanics reinforce chemistry concepts • Balance between learning and fun • Appealing aesthetics and audio
S2	Girón-Gambero, J. R., & Franco-Mariscal, A. J. (2023)	Spain	Article	Mixed	Atomizados	• Favor classroom dynamics • Deeper reasoning and conceptual understanding • Improvement in students' self-perception and attitude towards the content • Promoted students' ability to work as a team • Fostered individual engagement
S3	Lathwesen, C., & Eilks, I. (2024)	Germany	Article	Mixed	Digital Educational Escape Room (EER)	• Entertaining, engaging, and fun classroom • Fosters student interdisciplinary skills • Technical problems • Unmoderated teacher intervention may interrupt student immersion • Difficulty in achieving instructional equilibrium
S4	Manipon, M. N. O. (2023)	Philippines	Article	Mixed	Chemi-cooking	• Increased student motivation and engagement • Supported interdisciplinary learning • Positive teacher perceptions • Enhanced practical and inquiry-based learning • Strengthened conceptual understanding through visual and interactive tools • Improved communication and collaboration • Challenges with digital navigation and complex tasks • Replayability and story integration as a limitation

S5	Maršálek, R., Trčková, K., & Václavíková, Z. (2024)	Czech Republic	Article	Mixed	Escape Game Room	• Increased student motivation and engagement • Supported the development of interdisciplinary skills • Enhanced practical and inquiry-based learning • Strengthened conceptual understanding through visual and interactive tools • Improved communication and collaboration • Challenges with digital navigation and complex tasks • Replayability and story integration as a limitation
S6	Naaim, M. N. M., & Karpudewan, M. (2024)	Malaysia	Article	Mixed	STEM-PT Traveler (An Analog Periodic Table Board Game)	• Developed competencies for facilitating group dynamics in gamified settings • Enhanced student motivation • Increased self-efficacy • Encouraged classroom participation • Fostered positive perceptions toward chemistry • Significant time needed for designing and preparing activities • Demand for meticulous development of puzzles and gathering materials • Critical role of effective debriefing sessions
S7	Naumoska, A., Dimeski, H., & Stojanovska, M. (2023)	Macedonia	Article	Mixed	Online Escape Room	• Increased student engagement and motivation • Improved the communication skills of students • Encouraged creative, critical, and logical thinking skills • Promoted students' ability to solve problems • Cultivated students' positive attitude towards chemistry • A more interesting and effective way of mastering the content • Encouraged discussion and cooperation • High student satisfaction • Time-consuming to prepare puzzles • Needed to be mindful of instructional time limits • Technical issues • Adapting may take time
S8	Olim, S. C., Nisi, V., & Romão, T. (2024)	Portugal	Article	Mixed	Augmented Reality (AR)	• Engaged students with learning content • Opportunity to visualize concepts • Helped in understanding complex content • Increased concentration levels and stimulated learning

						• Positive attitude, enjoyment, and success in chemistry • Increasingly gathered student interest • Multi-sensory and fun approach • Fostered curiosity and user engagement • Transformed abstract theories into tangible experiences • Competitive-collaborative elements • Needed collaboration among game experts and researchers • Limited AR implementation due to teachers' lack of technical skills, training, and support • High cost of developing 3D experiences • Time constraints
S9	Tarigan, S. F., & Wiji, W. (2023)	Indonesia	Article	Quali-tative	Quizizz, Wordwall, periodic table games, Unreal Chemist	• Increased student motivation and learning • Facilitated various learning styles of students • Provided a more pleasant learning atmosphere • Trained students' 21st-century abilities • Helped visualize abstract chemical materials • Made learning more interesting • Multiple features of the games • Amount of training needed • Limited support available for technical issues
S10	Valdiviezo, H. C., & Zaldívar, M. A. B. (2023)	Ecuador	Article	Mixed	Didactic Games (Periodic Table Quiz, Chemistry App, Quimitris, Puzzle, Periodic Table Bingo, The Atomic Deck)	• High student motivation and engagement • Promoted student collaboration and teamwork • Developed students' positive attitude and interest in chemistry • Improved students' content learning and retention • Promotion of interdisciplinary skills • Needed adequate teacher training • Value of immediate feedback • Repetition and reinforcement features led to better student retention • Addressed different learning styles
S11	Yacoub, M. S. W., & Holton, A. J. (2023).	USA	Article	Mixed	Online Narrative Detective Game (via Qualtrics)	• Significant increase in student confidence • An effective student engagement tool • Positive student feedback • Reduced intimidating classroom atmosphere • Needed training for game-based design • Technical/navigation issues

						• Needed varied types of problems, images, and clues • Appreciation for prompt feedback • Story-driven learning sparks interest • Desire for retry and review opportunities
S12	Yulina, I. K., Putri, A. M., & Gusman, T. A.	Indonesia	Article	Mixed	Web Gamification Media	• Increased critical thinking • Reinforced learning through peer teaching • Positive student engagement and motivation • Improved understanding of acid-base concepts • Facilitated immediate feedback • Developed communication skills • Enhanced autonomy and responsibility • Promoted interactive learning through technology integration • Challenges in digital access and familiarity

3.4 Data Analysis

The collected data were analyzed using constant comparison and thematic analysis to identify key or recurring themes (Nicolas, 2021). To systematically analyze and synthesize the qualitative data from the selected studies, this research utilized Braun and Clarke's six-phase framework for thematic analysis, chosen for its methodological rigor and flexibility in capturing patterns of meaning across diverse qualitative sources—an approach particularly well-suited for meta-synthesis (Maguire & Delahunt, 2017).

The process begins with familiarizing the data by repeatedly reading the findings sections of each included study, with close attention to participant quotations, thematic interpretations, and author commentaries. This deep engagement allows for the initial recognition of patterns and emerging insights.

Then, a systematic generation of initial codes is undertaken using inductive (data-driven) and deductive (theory-driven) approaches. Relevant excerpts—such as teacher narratives, student reflections, and observational notes—are coded to capture key concepts related to gamification's use, benefits, challenges, and contextual factors.

Next, the researchers organized the codes into broader candidate themes that reflect recurring ideas or perspectives across the studies. Thematic maps were developed to explore how various experiences and meanings cluster together.

Afterwards, the candidate themes were reviewed to ensure internal coherence, distinctiveness, and empirical support. Themes may be merged, split, or discarded based on their relevance and consistency with the data, which is revisited to confirm that each theme accurately represents participants' lived experiences. To ensure the credibility and validity of the generated themes, the paper was presented to experts in qualitative research for evaluation and confirmation of the generated themes and sub-themes.

Subsequently, the themes were named and defined, clearly articulating the scope and significance within the broader context of gamified chemistry instruction. Subthemes were identified to reflect more nuanced patterns, and each theme is named concisely to capture its essence.

Finally, the thematic synthesis is presented in a rich narrative format, supported by illustrative excerpts from the included studies. The final analysis connects each theme to the research objectives and existing literature, offering practical implications for how gamification shapes teaching and learning in high school chemistry from a qualitative perspective.

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IV. Results and Discussion

The results and discussions presented below correspond to the objectives established for this study. The transformative impact of gamification on students' learning and engagement was identified as the meta-theme. Three emerging themes have also been found, namely, opportunities in utilizing gamification in teaching chemistry, challenges in implementing gamification in teaching chemistry, and strategies for effective implementation of gamification in teaching chemistry.

Moreover, nine sub-themes have also emerged: elevated student motivation and enjoyment, enhanced learning and knowledge retention, development of the 21st century skills, teacher-related constraints, student-related difficulties, infrastructure and resource limitations, content-driven and aligned with the curriculum, storytelling and feedbacking, and integrating technology with the aid of emerging tools. Table 1 below provides an overview of the final collection of 12 studies included in the meta-synthesis.

Meta-Theme: Transformative Impact of Gamification on Students' Learning and Engagement

The meta-synthesis reveals a transformative impact of gamification on students' learning and engagement in high school chemistry, marking a transition from traditional pedagogical approaches towards more interactive and student-centered learning environments (Gaurina et al., 2025). Integrating gamified elements into chemistry curricula has demonstrated a capacity to revolutionize how students perceive and interact with complex scientific concepts, fostering a deeper appreciation for the subject matter and cultivating a more proactive approach to learning (Zeng et al., 2024). However, like any pedagogical approach, gamification comes with opportunities and challenges, as well as the demand to develop effective strategies for implementation (González, 2022). This comprehensive impact underscores gamification's capacity to not only enhance academic performance but also to nurture a lifelong passion for scientific exploration and discovery, ultimately preparing students to excel in a rapidly evolving and technology-driven world.

Theme 1: Opportunities in Utilizing Gamification in Teaching Chemistry

Gamification in high school chemistry has consistently demonstrated the potential to reshape traditional learning experiences into more dynamic, interactive, and student-centered environments. Gamification holds a substantial promise in transforming the landscape of high school chemistry education by providing opportunities to increase student motivation and enjoyment, foster enhanced learning and knowledge retention, and cultivate the development of critical 21st-century skills (Vang, 2023). The heightened engagement positively affects cognitive functioning, enhancing students' readiness to tackle intricate chemical concepts and principles, leading to a deeper and more robust scientific understanding (Kalogiannakis et al., 2021).

Sub-theme 1.1: Elevated Student Motivation and Enjoyment

Across multiple studies, gamified learning environments significantly enhanced student motivation and interest. For instance, Elementium and Atomizados both demonstrated high acceptance and engagement through immersive role-playing and scenario-based activities (Filippas & Xinogalos, 2023; Girón-Gambero & Franco-Mariscal, 2023; Olim et al., 2024; Yacoub & Holton, 2023). Escape room formats, such as Digital Educational Escape Rooms (EERs), created a playful atmosphere, increasing students' enjoyment and leading to sustained classroom participation (Lathwesen & Eilks, 2024; Maršálek et al., 2024; Naumoska et al., 2023). Didactic games, e.g., puzzles and board games, can also provide chemistry education with excitement and engagement by turning what might be perceived as tedious tasks into captivating challenges (Manipon, 2023; Tarigan & Wiji, 2023; Valdiviezo & Zaldívar, 2023; Yulina et al., 2024).

It aligns with the findings of Hellín et al. (2023), who emphasized that game-based learning increases engagement by offering immediate rewards and emotional stimulation, which in turn fosters intrinsic motivation. Similarly, Smiderle et al. (2020) found that game elements such as badges and points can positively influence behavioral engagement, especially when personalized to student needs. The integration of personal and social elements creates immersive learning environments, and when gamification techniques are appropriately implemented, learning outcomes improve (Smiderle et al., 2020).

This plethora of empirical evidence emphasizes the need to embed strategically gamified elements into the curriculum and classroom activities. This means incorporating typical game mechanics (e.g., points, badges, leaderboards, and progress indicators) into lesson design to make learning objectives transparent and rewarding. Teachers can implement dynamic, collaborative, or competitive gamified tasks that acknowledge student effort and engagement rather than solely recognizing correct responses. Additionally, delivering prompt and affirming feedback through level-up notifications or congratulatory animations can strengthen conceptual understanding and motivate learners to persevere despite challenges. Allowing students to choose gamified tasks that match their interests further promotes autonomy, which in turn increases both engagement and enjoyment in the learning experience.

Sub-theme 1.2: Enhanced Learning and Knowledge Retention

The reviewed studies also highlight the cognitive benefits of gamification. Platforms like Chemi-cooking and AR-enhanced tools (e.g., 3D visualizations of molecules) helped students understand and retain abstract chemistry concepts more effectively (Manipon, 2023; Olim et al., 2024). Games such STEM-PT Traveler and didactic games reinforced knowledge retention through repetition and multisensory engagement while also supporting differentiated learning (Filipas et al., 2023; Girón-Gambero & Franco-Mariscal, 2023; Nauoska et al., 2023; Tanigan & Wiji, 2023; Naaim & Karpudewan, 2024; Valdiviezo & Zaldívar, 2023; Yulina et al., 2024).

These findings are supported by related studies, where gamification helps reduce extraneous cognitive load, thereby facilitating deeper processing of complex scientific material (Baah et al., 2024; Lutfi et al., 2023). Likewise, Hu et al. (2022) found a positive correlation between game-based interventions and enhanced content mastery in chemistry. By providing practical, real-world applications of theoretical concepts, gamified learning environments significantly aid in the mastery of chemistry concepts and skills (Li et al., 2023; Vang, 2023).

Therefore, to improve learning and promote long-term retention in chemistry, instructional practices should harness gamification to stimulate active engagement and support spaced repetition. This entails crafting gamified scenarios that compel students to apply chemical principles in problem-solving contexts, thereby transitioning from passive information reception to active cognitive engagement. Examples include interactive simulations for balancing chemical equations or predicting reaction outcomes. Integrating mini-games or periodic quizzes that revisit previously introduced content is crucial for aiding long-term retention. Moreover, structuring gamified tasks that gradually increase in difficulty enables learners to master fundamental concepts before tackling more advanced chemistry topics.

Sub-theme 1.3: Development of the 21st Century Skills

Many studies emphasized that gamification helps in the cultivation of critical thinking, communication, collaboration, and self-directed learning skills, which are crucial characteristics of a 21st-century learner (Filippas & Xinogalos, 2023; Lathwesen & Eilks, 2024; Manion, 2023; Maršálek et al., 2024; Naaim & Karpudewan, 2024; Tarigan & Wiji, 2023; Valdiviezo & Zaldívar, 2023). For example, web gamification and escape rooms promoted problem-solving, peer teaching, and logical reasoning (Naumoska et al., 2023; Yulina et al., 2024). The online detective game, in particular, highlighted how narrative-based challenges can enhance autonomy and confidence (Yacoub & Holton, 2023). In alignment with these observations, research indicates that games often necessitate strategic thinking and adaptability, thereby fostering cognitive flexibility (Çavuş et al., 2023).

These outcomes align with the self-determination theory framework, which posits that gamified environments can fulfill learners' psychological needs for autonomy, competence, and relatedness (Luarn et al., 2023; Vang, 2023). It promotes self-regulation and deeper engagement with the learning content, which is essential in modern educational paradigms. Constructivist learning principles further support this, emphasizing the role of experiential, collaborative learning (Ahmadvand & Khoshchehreh, 2023; Chen et al., 2020; Rudolf, 2022).

Evidently, instructional strategies should focus on designing activities that demand critical thinking, collaboration, and digital proficiency. This implies creating gamified scenarios that pose intricate chemical challenges, which need critical analysis, hypothesis formulation, and iterative problem-solving. Implementing team-based activities where students must collaborate, communicate effectively, and share tasks to reach a common goal is essential for strengthening interpersonal and cooperative skills. Lastly, encouraging students to create their own gamified chemistry challenges or solutions promotes creativity and innovation within a structured learning setting.

In summary, when considering the substantial potential offered by gamification in teaching high school chemistry, the main points for successful implementation center on elevating student motivation and enjoyment, enhancing learning and knowledge retention, and developing essential 21st-century skills. Effective implementation requires deliberate incorporation of game elements, such as points, badges, leaderboards, and progress indicators, making learning objectives more transparent and instantly rewarding. By introducing competitive and collaborative gamified tasks, educators can elevate student enthusiasm and move beyond traditional assessment methods to value effort and active participation. Moreover, gamified scenarios should actively compel students to apply chemical concepts to solve problems, promoting active learning and aiding long-term knowledge retention through spaced repetition and progressive challenges. These approaches inherently support the development of critical thinking, problem-solving, collaboration, and digital literacy by requiring students to work together, communicate effectively, and utilize educational technologies to navigate complex chemical puzzles and simulations.

Theme 2: Challenges in Implementing Gamification in Teaching Chemistry

Despite the promising opportunities, the implementation of gamification in teaching chemistry is not without its challenges, spanning teacher-related constraints, student-related difficulties, and infrastructure and resource limitations (Lathwesen & Belova, 2021). Knowing these limitations can provide awareness for any potential adopters of gamification in chemistry (Álvarez-Herrero & Valls-Bautista, 2021; Brassinne et al., 2020; Kabilan et al., 2023).

Sub-theme 2.1: Teacher-Related Constraints

Many educators reported a lack of training and limited familiarity with game mechanics, especially in the design and facilitation of gamified instruction (Yacoub & Holton, 2023; Naaim & Karpudewan, 2024). Teachers also emphasized the time-intensive nature of creating puzzles, managing storylines, and balancing instructional time with gameplay (Manipon, 2023; Tarigan & Wiji, 2023). Furthermore, some studies noted that insufficient moderation could disrupt the immersive experience, affecting student learning (Lathwesen & Eilks, 2024).

These issues echo earlier findings by Christopoulos & Mystakidis (2023), who argue that teacher preparedness is crucial in bridging the gap between pedagogical intent and student experience. Therefore, comprehensive training is essential to empower teachers to effectively use game mechanics and adapt gamified strategies to align with their curriculum while facilitating meaningful learning.

Hence, addressing teacher-related constraints in the adoption of gamification requires a multi-faceted approach from both institutions and teachers. This involves offering targeted professional development workshops for chemistry teachers, focusing on foundational gamification concepts, practical tools, and pedagogical strategies. To mitigate time constraints, institutions should provide ready-to-use templates, curated gamified materials, and access to shared digital platforms, enabling gradual integration instead of requiring extensive curricular revisions. Establishing a sustained support system or community of practice can further empower educators to exchange insights, collaboratively address challenges, and build on shared expertise. Finally, overcoming skepticism about gamification can be achieved by showcasing successful case studies that highlight its positive effects on student engagement and learning outcomes.

Sub-theme 2.2: Student-Related Difficulties

Student obstacles were prevalent in the gamification of chemistry. Chemi-Cooking and the Escape Game Room appeared to pose difficulties for students due to less intuitive navigation and a lack of clarity in the instructions, which influenced their concentration and participation (Manipon, 2023; Maršálek et al., 2024). Group work issues and becoming accustomed to the novelty of formats were also apparent in STEM-PT Traveler and the Online Escape Room (Naaim & Karpudewan, 2024; Naumoska et al., 2023). Furthermore, the lack of content variety in the Online Narrative Detective Game decreased students' motivation to engage in task activities, and they sought more attractive and diversified activities (Yacoub & Holton, 2023). These results highlight the importance of well-designed, incrementally introduced, and diversified content in order to promote effective student engagement in gamified learning.

In support of this sub-theme, Lampropoulos and Kinshuk (2024) found that learners experienced frustration and a lack of engagement through complicated game mechanics and vague goal settings as presented in gamified science-based platforms. Likewise, Araújo and Carvalho (2022) found that students who were not familiar with digital games found digital game formats confusing and time-consuming to adapt to, and that the difficulty of navigating digital games led to limited collaboration and participation in group-based learning exercises.

In essence, addressing student-related challenges in gamified instruction requires the adoption of flexible and inclusive strategies. Teachers must utilize scaffolding and differentiation to accommodate diverse learning needs and prior knowledge across gamified activities with varying levels of difficulty, emphasizing personal growth and mastery over simply winning the game. To prevent student disengagement, teachers should introduce novel gamified approaches regularly to sustain their interest or offer opportunities for second attempts or alternative learning pathways to uphold motivation. Furthermore, ensuring equitable access to necessary technology is critical; this includes providing offline gamified alternatives for students with limited technological resources, coupled with foundational support in digital literacy where necessary.

Sub-theme 2.3: Infrastructure and Resource Limitations

Infrastructure and resource problems are serious barriers to deploying gamification in chemistry education. Technical issues, such as bugs, navigation problems, and low replay value, had an impact on students' engagement and learning (Lathwesen & Eilks, 2024; Maršálek et al., 2024; Naumoska et al., 2023; Yacoub & Holton, 2023). High development expenditure and expert assistance required to collaborate in AR-based games also restricted utilization in low-resource neonatal settings (Olim et al., 2024). Although some support existed, access to gadgets and digital literacy was still unequal (Tarigan & Wiji, 2023; Yulina et al., 2024). These constraints demonstrate the necessity of increased infrastructure and support for effective gamified learning that is inclusive to all.

Reinforcing this sub-theme, Okolie and Okoye (2023) stated that inconsistent access to reliable internet and compatible devices ultimately hindered students from fully engaging in gamified science activities. Likewise, poor teacher training, over-technicality of use, and lack of institutional support are the main obstacles to successful gamification in low-resource educational settings (Kaimara et al., 2021; Sambo et al., 2025).

Given the importance of infrastructure and resources for implementing gamification, strategic planning and resource allocation from institutions, alongside innovative pedagogical strategies from educators, are necessary. Practically, this entails advocating for dedicated funding to support educational technologies and gamification platforms, prioritizing stable internet connectivity and adequate device availability. Utilizing free or open-source gamification tools (e.g., free versions of Quizizz, Kahoot!, or Classcraft) can significantly minimize costs. Teachers can also develop creative offline gamified activities using physical cards, board games, or classroom challenges that require minimal technology. Finally, establishing partnerships with educational technology providers or local organizations can facilitate discounted access to resources and crucial implementation support.

Overall, overcoming the inherent challenges associated with gamification in chemistry education demands comprehensive and forward-looking strategies from both institutions and educators. Central to this effort is the provision of extensive professional development for teachers, equipping them with the pedagogical and technical competencies to design and integrate gamified lessons effectively, supplemented by pre-made resources and templates to mitigate time-related constraints. For students, implementation should emphasize differentiated and scaffolded gamified activities to accommodate diverse learning needs and address potential disengagement. In terms of infrastructure, resolving resource limitations calls for institutional commitment to funding educational technologies, prioritizing reliable internet access and sufficient device availability, and exploring cost-effective or open-source gamification tools. Creative low-tech solutions and potential partnerships can also assist in bridging resource gaps, thereby ensuring equitable access and support for all students and teachers. Addressing these challenges is essential for the successful adoption and long-term effectiveness of gamification.

Theme 3: Strategies for Effective Implementation of Gamification in Teaching Chemistry

Following the challenges identified in implementing gamification, this theme centers on strategies that promote its effective integration into chemistry instruction. It stresses the need to align gamified tasks with curriculum standards and subject content, incorporate storytelling and timely feedback to sustain student engagement, and leverage emerging technologies such as simulations, mobile applications, and game-based platforms to foster interactive learning experiences (Alomari et al., 2019).

Sub-theme 3.1: Content-Driven and Aligned with the Curriculum

When integrated within the curriculum application, gamification can be best applied. In Elementium, learners appreciated the high educational importance and supportiveness of the chemistry lesson, increasing engagement and knowledge retention (Filippas & Xinogalos, 2013). Similarly, in STEM-PT Traveler, debriefing sessions were critical in assisting students to make links between the gameplay and the key learning objectives (Naaim & Karpudewan, 2024). These studies point to the importance of more intentional game design that maps core content and reviews it through guided reflection.

Closely related to this sub-theme, studies noted that students are able to develop conceptual understanding and increased motivation to learn in science classes when game mechanics are directly linked to curriculum frameworks (Meng, 2023; Jiménez-Valverde et al., 2025). In the same vein, curriculum-congruent gamification, along with reflective tasks, facilitates transfer of learning through gameplay to the formal classroom (Dreimane, 2018; Lampropoulos et al., 2022).

This growing repository of empirical insights shows the profound role of a content-driven approach in gamifying chemistry instruction, which must be closely aligned with curriculum standards. This means teachers are expected to clearly define learning outcomes for each lesson or unit, followed by the deliberate integration of gamified components that directly support these objectives to avoid superficial or disconnected applications. Gamified tasks that also function as formative assessments can provide valuable data on student understanding of chemistry concepts, making the learning process more efficient and effective. Schools also ought to offer training and resources to guide teachers in skillfully integrating standards-based gamification approaches into planning lessons and assessment, ensuring variations in sentence construction and complexity.

Sub-theme 3.2: Storytelling and Feedbacking

The addition of storytelling and immediate feedback enhances the efficacy of gamified chemistry instruction. Studies showed that engaging narratives foster curiosity and deeper involvement, as seen in students' praise for creative storylines and clues in digital games (Olim et al., 2024; Yacoub & Holton, 2023). Another area of top priority is the availability of immediate and constructive feedback. These studies concluded that direct responses while playing (referred to as in-situ feedback) were beneficial for supporting learning, dispelling misconceptions, and maintaining motivation (Filippas & Xinogalos, 2023; Valdiviezo & Zaldívar, 2023; Yulina et al., 2024). These results highlight the importance of appropriately designed narratives and real-time feedback systems in sustaining student engagement and helping them achieve conceptual understanding.

Park and Kim (2021) also reinforce these results, noting that in their study, gamified science lessons that incorporated immersive storytelling significantly enhanced emotional engagement and curiosity, which helped the students explore content in more profound ways. Additionally, immediate and tangible feedback through the educational game positively affected students' confidence in learning and corrected misconceptions in real-time during the gameplay process (Adipat et al., 2021; Anane, 2024).

These findings suggest that leveraging storytelling and feedback is crucial for effective gamification in teaching chemistry. In practice, this involves constructing engaging narratives or thematic "quests" that contextualize chemistry content and provide learners with a purposeful framework—for instance, framing a unit as a mission to reduce environmental pollution through chemical innovation. Delivering precise, timely, and constructive feedback within the gamified environment is essential. Instead of simply marking answers as wrong, the system should elucidate rationalizations behind errors and offer targeted guidance or resources for improvement. Additionally, embedding opportunities for students to evaluate their learning processes, strategies, and conceptual understanding can also deepen their engagement and retention.

Sub-theme 3.3: Integrating Technology with the Aid of Emerging Tools

The use of emerging tools provides an opportunity to integrate technology into gamified chemistry instruction, where more interactive and practical gamified experiences can help learning. Well-designed visuals, audio, and interactive components represent the content in an attractive and accessible manner, as adaptive video games like Elementium and Escape Game Room (Filippas &

Xinogalos, 2023; Maršálek et al., 2024). In addition to supporting mastery learning, self-paced exploration is supported with tools that allow for revisiting and re-attempting problems (Yacoub & Holton, 2023). Moreover, having digital platforms along with AR-based games strengthens visualization by translating abstract chemistry concepts into concrete, interactive experiences to promote greater conceptual understanding (Olim et al., 2024; Yulina et al., 2024). They exemplify how technology can significantly augment both engagement and understanding in a gamified learning context.

Supporting this sub-theme, Santos et al. (2023) reported that students can much better understand complex molecular structures and reactions in science classes because of gamification. Similarly, interactive, technology-enhanced platforms designed with multimedia and retry functionalities that support learners in continual learning fostered meaningful engagement and supported learners' agency in gamified STEM lessons (Brugliera, 2024; Chng et al., 2023; Makinde & Oyeniyi, 2024).

Based on the research findings, the strategic integration of technology, particularly emerging tools, is a key strategy for implementing gamification in chemistry. This calls for deliberate research and selection of gamification platforms or learning management systems (LMS) equipped with advanced functionalities conducive to chemistry instruction, such as virtual labs or interactive simulations. Exploring augmented reality (AR) based games and virtual reality (VR) applications enables students to visualize molecules in 3D, perform virtual experiments, or examine complex chemical processes in immersive environments. The use of AI-driven tools that adapt gamified learning trajectories based on individual performance, offer personalized feedback, or generate dynamic chemistry problems can significantly support differentiated instruction. In addition, making use of the data analytics features embedded within gamification systems allows educators to monitor learner progress, diagnose conceptual challenges, and refine instructional strategies accordingly.

To sum up, the effective implementation of gamification in teaching high school chemistry emphasizes a content-driven approach, compelling narrative, meaningful feedback, and the strategic integration of emerging technologies. To put these strategies into action, game-based elements must be carefully aligned with specific curriculum standards and learning goals to ensure instructional coherence. Furthermore, sustained professional development and institutional support are essential to provide educators with the skills and resources needed to design, implement, and adapt gamified learning experiences that are both pedagogically sound and engaging. Regular evaluation of these gamified interventions should also be undertaken to assess their impact on student learning and to inform evidence-based refinements.

Figure 2 illustrates the transformative impact of gamification in teaching high school chemistry. This framework lays out the opportunities, challenges, and strategies identified in existing studies, showing how gamification boosts motivation, learning, and 21st-century skills despite barriers such as teacher constraints, student difficulties, and limited resources. It also highlights the best practices for implementing gamification through curriculum-aligned content, the use of storytelling and feedback, and the integration of emerging technologies.

Figure 2: Thematic Framework on the Transformative Impact of Gamification in Teaching Chemistry

V. CONCLUSION

The power of gamification in high school chemistry education is transformative, significantly enhancing student motivation, engagement, comprehension, and learning of 21st-century skills. Its success, however, relies on such integration, teacher preparedness, and sufficient resources and technologies. For gamification to fulfill its potential, teachers and curriculum developers may integrate it purposefully, incorporating it by means of content, compelling narratives, and real-time feedback, while schools may invest in teacher training and digital infrastructure that makes meaningful, sustainable gamification possible.

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