Asian Journal of Research in Education and Social Sciences
e-ISSN: 2682-8502 | Vol. 7, No. 2, 433-443, 2025
https://asianscholarsnetwork.com/asnet-journals
SPECIAL ISSUE: International Conference on Future and Sustainable Education (ICFSE) 2024

The Influence of Chemistr.io On Chemical Bonding Education: A Quantitative Analysis

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Received: 15 July 2024 | Accepted: 1 December 2024 | Published: 1 March 2025

DOI: https://doi.org/10.55057/ajress.2025.7.2.41

Abstract: *Gamification approach has become a popular method of engaging students in the learning process across all levels of education and disciplines, including chemistry. Chemistry is often considered a challenging subject because it involves complex concepts and understanding how they relate to one another. This study addresses the challenges faced by learners, especially pre-university students, in grasping abstract chemical bonding theories through traditional pedagogical methods. Thus, a mobile game-based called Chemistr.io was developed and incorporated with assessment that tailored with one of the topics in Physical Chemistry, namely Chemical Bonding. The gamification approach was evaluated based on overall feedback towards the gamification element of Chemistr.io quantitatively, using a 5-point numerical rating scale. The data collected from the chemistry students were then analysed descriptively using mean value, combined with PLS-SEM. The results revealed that students engaged in these gamification activities demonstrated positive and a deeper grasp of the subject matter with the* $t > 1.96$ *and* $p \leq 0.05$*. Incorporating gamification into Chemistry could leverage motivation and critical thinking in the subject matter. The Chemistr.io mobile game can be commercialized further and serve as an interactive learning module for Physical Chemistry subjects.*

Keywords: Chemistry, Chemical Bonding, Gamification, Mobile Games, PLS-SEM

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1. Introduction

The integration of technology in education has revolutionized traditional teaching methodologies, making learning more engaging and effective. One of the most promising advancements is the adoption of gamification, which incorporates game design elements into educational environments to boost student motivation and engagement (Dichev & Dicheva, 2017). Research indicates that integrating technology-assisted activities into classroom environments can significantly enhance student engagement, capturing their interest for extended periods and making the learning experience more enjoyable while effectively conveying knowledge (Tokac et al., 2019). The shift in the educational landscape brought about by the pandemic has further highlighted the need for more engaging and interactive learning techniques, particularly in the absence of direct, physical interaction between educators and students. This situation highlights the critical importance of adopting innovative approaches, such as gamification, to bridge this gap and maintain meaningful and effective learning experiences in virtual settings (Toledo Palomino et al., 2023).

Gamification has become a popular approach in modern education, infusing fun game design elements that help students stay motivated and improve learning outcomes. Platforms like Kahoot and Quizizz have turned conventional educational activities into more engaging and dynamic games (Lestari, 2019). These tools utilize features like leaderboards, points and timed quizzes to motivate and increase participation of the students. This also causes students to study harder before playing the games to compete with their friends. Thus, gamification helps to enhance memory and understanding of complex subjects by making learning fun and competitive (Asmolov & Ledentsov, 2023). Among other well-established games are Minecraft Education and Mario is Missing! This innovative approach has shown significant potential in enhancing problem-solving skills, higher-order thinking, and teamwork, ultimately leading to improved comprehension and retention of complex subjects (Christopoulos & Mystakidis, 2023).

Apart from that, the imposed gamification elements in Chemistr.io can truly show that it will work better in this new revolving era, especially on Alpha Generation. This generation represents the latest cohort of digital natives and is like two peas in a pod with technology, especially smartphones where mobile gaming has become their preferred platform (Fernando & Premadasa, 2024). These tech-savvy kids spend a significant amount of time with digital games and have familiarity with technology due to their adept at touchscreen interactions from an early age. Therefore, we believe that mobile gaming plays a significant role in this trend to be a success. Furthermore, gamification can provide a sense of achievement and progress through mechanisms such as points, badges, and leaderboards. These elements can help to maintain students' focus and drive, particularly in a virtual setting where traditional classroom dynamics are absent (Zhang et al., 2023). The use of storylines, quests, and challenges can also make the learning process more compelling, fostering a deeper connection to the material and enhancing retention. Traditional teaching methods are no longer sufficient for this generation even schools are shifting toward more holistic understanding and engaging approaches (Pandey et al., 2023). Other than that, gamified education allows educators to be creative in their field and have adaptive strategies to cater to Gen Alpha’s unique traits. In summary, gamified education has gained prominence in education, leveraging its affinity for technology and interactive experiences.

In science courses, particularly at the pre-university level, the volume of content delivered can often be overwhelming and complex, making it challenging for students to easily manage. Students are required not only to acquire knowledge across various fields but also to develop new laboratory skills and master analytical techniques. In addition, chemistry subject is well known with its intricate concepts, and interrelationships, poses a considerable hurdle for students (Archer et al., 2023). Traditional pedagogical methods sometimes fall short in effectively conveying these complex ideas, leading to a need for more interactive and engaging learning tools. The use of educational games follows the flipped classroom model, that gives the opportunity for students to explore new content at home, as well as applying the knowledge during class. By engaging with chemistry games outside the class through educational games, students can grasp the fundamental concepts according to their own pace preferences. This allows them to dive deeper into practicality and problem-solving skills to embrace the real challenges. Furthermore, this approach also aligns with the Malaysia's Sustainable Development Goals (SDG), that ensure inclusive and equitable quality of education besides promoting a sustainable overall learning for everyone by 2030. By incorporating educational games into various learning models, students are not only influenced to be more motivated, but their interests towards numerous learning methods can be nurtured as well.

Chemistr.io, a mobile game-based learning platform, was developed in this present work to bridge this gap. By focusing on one of the fundamental topics in Physical Chemistry, namely Chemical Bonding, aims to enhance students' grasp of the subject through a gamified learning experience. The game features five levels, each dedicated to a specific subtopic within Chemical Bonding, providing a structured and progressive learning experience. This study evaluates the effectiveness of Chemistr.io's gamification approach in enhancing student performance and comprehension. Hence, gamified education like Chemistr.io, aligns well with their learning preferences. This is because Chemistr.io can be accessed easily through smartphones where it has the potential to increase the engagement of Gen Alpha with their education and practically a better solution to reduce their tendency to be immersed in their screens with non-educational related activities.

Figure 1: Games simulation (Chemistr.io) with the students taking Chemistry subject

This present work has been focusing on the evaluation of gamification approach namely Chemistr.io towards the overall learning experience that involved both quantitative and qualitative analyses, focusing on students' feedback and performance. The primary aim of this research is to quantitatively assess the impact of Chemistr.io on students' overall learning and understanding of chemical bonding concepts. By employing various quantitative methods, this study seeks to measure how effectively Chemistr.io enhances students' grasp of these essential chemistry topics. To achieve this aim, the study has outlined two key objectives. Firstly, it aims to evaluate the respondents' feedback regarding their experience with Chemistr.io. Gathering and analyzing this feedback will provide valuable insights into the user experience and perceived effectiveness of the platform. Secondly, the study aims to understand the relationships between different variables affecting overall learning. By examining these relationships, the research will identify factors that significantly influence the learning process and how Chemistr.io contributes to the improvement of students' understanding of chemical bonding concepts.

2. Methodology

This section discusses the methodology employed in this study. To achieve the study's objectives, a quantitative approach was adopted, which provided a comprehensive evaluation of the game's impact. This approach allowed for a detailed analysis of statistical data, ensuring a thorough assessment of the outcomes.

Population and sampling

The population for this study consisted of **200** students enrolled in chemistry courses within semester 2, 2023/2024. These students represented a diverse demographic in terms of gender, and educational program. A convenience sampling technique was employed due to respondents' convenient accessibility and willingness to participate in the study, The sample size was determined based on a statistical power analysis, resulting in the selection of 65 students. This size was deemed sufficient to detect meaningful differences and relationships within the data. Inclusion criteria for the study required students to be currently enrolled in a chemistry course and to have access to the Chemistr.io game.

Data collection method

To gather data for this study, a questionnaire survey was employed to provide quantifiable information regarding the students' experiences of the Chemistr.io game. The questionnaire was designed to measure various aspects such as gamification design and elements, perception of gamification, learning outcomes, and overall learning satisfaction.

Data analysis techniques

The collected data were then statistically analyzed using mean value calculations combined with Partial Least Squares Structural Equation Modeling (PLS-SEM). The mean values provided a summary of the central tendency of the responses, while PLS-SEM allowed for the examination of relationships between the variables. This combination of techniques provided a robust analysis of the data, enabling a comprehensive evaluation of the impact of the Chemistr.io game on students in relation to learning chemical bonding subject.

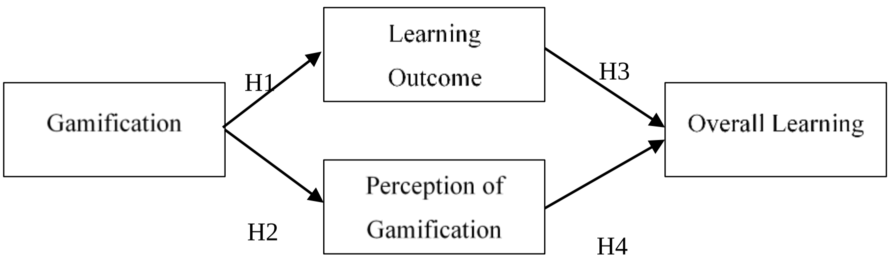


Figure 2: A proposed research framework

Figure 2 demonstrate the research framework adapted from previous researches (Yu et al., 2020; Huang et al., 2019) for the use of this present work. Among the focus highlighted in the study is about learning outcome and overall learning. Herein, we develop several hypotheses that align with the proposed research framework. This research tested the following hypotheses at 0.05 significant level.

Gamification integration

Gamification become emerging platform to apply innovation in teaching pedagogical. It is an interactive way to take advantage of student's interest in games that can be part of teaching process (Putra & Priyatmojo, 2021). Gamification has demonstrated the potential to improvise learning outcomes among student as reviewed by Dehghanzadeh et al., 2024. The role of engagement in game based learning revealed that there are several ways can be incorporated into teaching and learning practices (Su & Cheng, 2015). Integration of gamification g=can give meaningful connections and stimulate participation and hence achieving the learning outcome. Based on this, the following hypothesis can be expressed;

H1: *Gamification has a positive influence towards the learning outcome.*

Perception of gamification

Student's perception of the gamification is crucial to examine based on the efficacy of educational games and to get feedback from students for areas of improvement. Based on the student's perception, the stakeholder can identify challenges and enhancing the efficacy of the education games (Permana et al., 2023). In another study conducted by Dichev & Dicheva, 2017, it is important to explore on the perception of students towards gamified games that able to attract students to involve during teaching and learning (Kashive & Mohite, 2023). Thus, the hypothesis can be stated as follows:

H2: *Gamification positively influence the perception of gamification among learners.*

Learning outcomes

Educational researchers and practitioners have been actively involved in gamification design concept in order to achieve mixed results on student's learning outcomes (Wang et al., 2024). Interactive learning platforms could increase student engagement and improving learning outcomes in more holistic ways (Jacob & Centofanti, 2024). The researchers need to provide an insight on gamification that could facilitate learning outcomes and offer new educational opportunities. Herein, the hypotheses can be developed as follows:

H3: *Learning outcomes has a positive influence towards overall learning.*

Overall learning

The use of gamification affects learning related behavioral of students. Understanding the perception towards gamification incorporated in teaching process is crucial in order to improvise the quality of teaching and learning session and to integrated games as leaning tools (Qiong, 2017). A study conducted by Permana et al., 2023 has highlighted a strong positive response that students have very good perception towards gamification implemented in learning process. Therefore, the hypothesis is presented as follows:

H4: *The perception of gamification positively influences overall learning*

3. Results and Discussions

This section presents the study findings on how the Chemistr.io mobile game enhances respondents' understanding of physical chemistry (i.e. chemical bonding) concepts compared to traditional learning methods. It begins with a basic statistical analysis, employing SPSS for descriptive statistics to address the first objective. For the second objective, advanced statistical analysis using Partial Least Squares Structural Equation Modeling (PLS-SEM) is conducted to provide deeper insights.

3.1 Descriptive Analysis

For this study, univariate descriptive analysis was employed, as shown in the following tables and figures.

Gender: The gender of the respondents as presented in Table 1

Table 1: Gender frequency distribution of respondents

Gender	Frequency	Percentage (%)
Female	47	72
Male	18	28
Total	**65**	**100**

Out of all respondents, forty-seven were female (72%) and eighteen were male (28%). This data indicated that majority of the respondents are female.

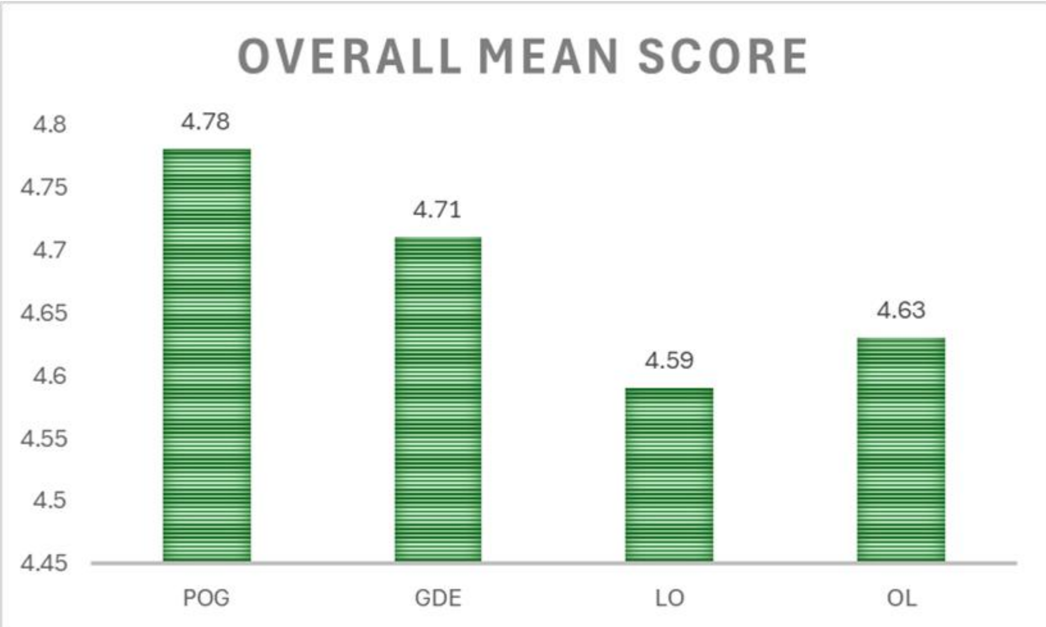
Program: The academic program of the respondents as presented in Table 2

Table 2: Respondents' academic program

Program	Frequency	Percentage (%)
Medical	13	20
Dentistry	11	17
Pharmacy	41	63
Total	**65**	**100**

Based on Table 3, most of the respondents are students enrolled in the pharmacy program, accounting for forty-one respondents (63%). This is followed by the medical program with thirteen respondents (20%), and the dentistry program with eleven respondents (17%).

Respondents' feedback on their experience with Chemistr.io: The respondents' feedback on how the game impacts their understanding of chemistry concepts is presented in Figure 3. The mean score was utilized to evaluate the feedback, providing an average measure of their experiences.



Note: POG is perception of gamification; GDE is gamification design elements; LO is learning outcome, OL is overall learning.

Figure 3: Overall mean score of respondents' feedback towards gamification in learning chemistry

The majority of respondents have positive feedback on their experience with Chemistr.io, the mobile gamification approach in chemical bonding subject. The mean values of 4.78 (POG), 4.71 (GDE), 4.59 (LO), and 4.63 (OL) are relatively high, typically above the midpoint of the 1 to 5 numerical scale, as depicted in Figure 1. This suggests that the responses are clustered toward the higher end of the scale, indicating a generally favourable view of the gamification approach.

3.2 Advance Statistical Analysis

To address the second objective of this study, Partial Least Squares Structural Equation Modeling (PLS-SEM) was employed. The advanced statistical analysis involved assessing both the measurement model and the structural model using PLS-SEM, conducted with SmartPLS software.

Full model of Chemistr.io in relation to learning chemical bonding.

The full model for this study was developed using SmartPLS by running the PLS algorithm with the path weighting scheme. As illustrated in Figure 4, the model includes both the measurement model and the structural model. The measurement model (outer model) shows the relationships between manifest variables (i.e., items/indicators), represented by rectangular shapes, and their latent variables (i.e., constructs), represented by oval shapes. The structural model (inner model) depicts the relationships among the latent variables.

The full model of this study consists of four latent variables: gamification design element, perception of gamification, learning outcome, and overall learning. All four latent variables, which are first-order constructs, were measured reflectively using a total of twelve manifest variables. This comprehensive approach allows for a detailed examination of the relationships among the constructs and provides a robust framework for analysis.

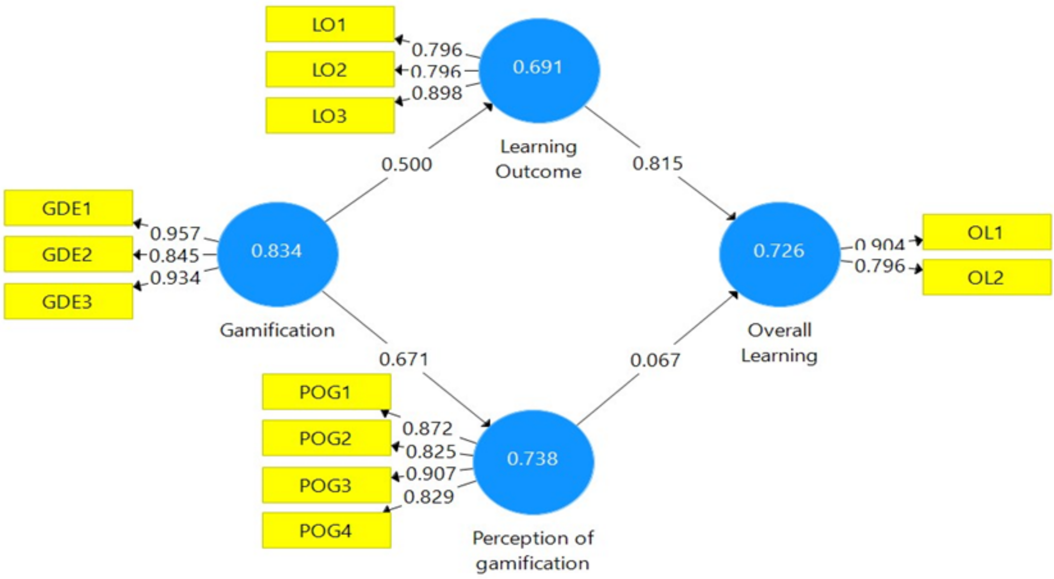


Figure 4: Full model (i.e., inner and outer model) – PLS Algorithm

Measurement Model Assessment

Measurement models can be categorized into two types: reflective and formative (Hair et al., 2019)(Garson, 2016), each requiring different evaluation criteria (Hair et al., 2019). This study employs a reflective measurement model. Evaluating a reflective measurement model involves assessing three main criteria: item loadings, internal consistency reliability, and validity (including both convergent and discriminant validity) (Hair et al., 2019).

The first step in assessment is to evaluate the significance of each item's loading, which reflects the reliability of individual items. Item loadings should ideally meet or exceed a threshold of 0.7, with a minimum sample size of 60 cases to ensure adequate significance (Hair Jr et al., 2017). The next criterion, internal consistency reliability, measures the extent to which items

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within a construct consistently represent that construct. Using Dijkstra-Henseler's rho (ρA) reliability coefficient, values should fall within the range of 0.7 to 0.9 (0.7 ≤ ρA ≤ 0.9) [4].

Finally, validity encompasses both convergent and discriminant validity. Convergent validity is assessed through the Average Variance Extracted (AVE), with a threshold of 0.5, indicating that the reflective constructs should explain at least 50% of the variance in their items (Hair et al., 2019). Discriminant validity is typically evaluated using the Heterotrait-Monotrait (HTMT) ratio, as proposed by (Henseler et al., 2015). To confirm discriminant validity, an HTMT value of 0.85 or below is recommended (Kline, 2023). Table 3 summarizes the results of the reflective measurement model assessment for this study, providing an overview of its validity and reliability.

Table 3: Summary of reflective assessment model

Reflective construct (Latent variable)	Reflective indicators (Manifest variables)	Outer loading (>0.70)	Dijkstra-Henseler's rho (pA) (0.7 ≤ pA≥ 0.9)	AVE (>0.50)	HTMT (<0.85)
Gamification Design and Element (GDE)	GDE1	0.957	0.838	0.834	Yes
	GDE2	0.845			
	GDE3	0.934			
Learning Outcome (LO)	LO1	0.796	0.800	0.691	Yes
	LO2	0.796			
	LO3	0.898			
Perception of Gamification (POG)	POG1	0.872	0.783	0.738	Yes
	POG2	0.825			
	POG3	0.907			
	POG4	0.829			
Overall Learning (OL)	OL1	0.904	0.898	0.726	Yes
	OL2	0.796			

As depicted in Table 3 and Figure 4 all reflective indicators have outer loadings above 0.70, demonstrating acceptable item reliability by explaining more than 50% of each indicator's variance. Additionally, Dijkstra-Henseler's rho (ρA) values of 0.838, 0.800, 0.783, and 0.898 indicate strong internal consistency reliability. The AVE values, all exceeding 0.50, denote that each construct explains more than 50% of the variance in its items. Furthermore, an HTMT value of less than 0.85 confirms both convergent and discriminant validity, ensuring the robustness of the measurement model.

Structural Model Assessment

The structural model (i.e., the inner model) illustrates the relationships among the latent variables. Figure 5 displays the results from the bootstrapping procedure, which was conducted using 5000 bootstrap samples, two-tailed testing, and a significance level of 0.05. Additionally, Table 4 summarizes the path coefficients, t-values, and p-values, providing a detailed overview of the strength and significance of the relationships between the latent variables.

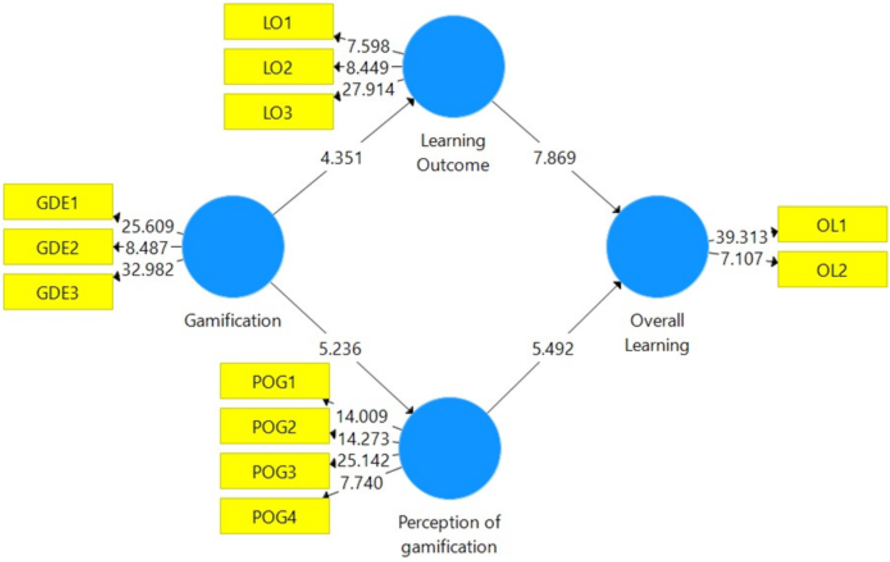

Figure 5: Bootstrapping t-value

Table 4: Summary of structural model path coefficient significance

	t-value (> 1.96)	p-value (<0.05)	Significance	Hypothesis supported?
Gamification □ Learning outcome	4.351	0.000	Yes	Yes
Gamification □ Perception of gamification	5.236	0.000	Yes	Yes
Learning outcome □ Overall learning	7.869	0.000	Yes	Yes
Perception of gamification □ Overall learning	5.492	0.006	Yes	Yes

The structural model (i.e., the inner model) illustrates the relationships among the latent variables. Figure 5 and Table 4 indicate that the path coefficients in the inner model were statistically significant, with t-values greater than 1.96 and p-values less than 0.05, as outlined by Hair Jr et al., 2017. As a result, all hypotheses, including those related to the first-order relationships, were confirmed. This aligns with the findings of (Malhotra, 2003), who asserts that hypotheses are deemed supported when the significance level is 5% or lower ($p \leq 0.05$). The comprehensive analysis reinforces the robustness and validity of the proposed model.

4. Conclusion

In this work, the incorporation of gamification into the Chemistr.io educational project has markedly enhanced student engagement and learning outcomes in chemistry, especially regarding chemical bonding. Chemistr.io's mobile game-based approach has been highly appreciated by students. Analysis reveals that students not only enjoyed the gamified learning experience but also demonstrated improved comprehension and retention of the material. The gamification elements substantially boosted student motivation and interest in the subject, making the learning experience both enjoyable and engaging. The factors presented in the proposed research framework, gamification has significantly influenced the learning outcome and perception of gamification. This study advocates for the use of educational gamification as a platform to promote students' pro-sustainability overall learning, integrating technology into teaching pedagogy. It suggests that gamification is an effective tool for enhancing student engagement and learning outcomes in chemistry. Incorporating gamified elements into the learning process improves students' understanding of chemistry concepts and increases their overall satisfaction with the learning experience. These findings offer valuable insights for educators and curriculum developers looking to integrate gamification into their teaching strategies to create a more interactive and effective learning environment.

Acknowledgements
The authors acknowledge Department of Chemistry and Department of Architecture and Environmental Design, Centre for Foundation Studies, International Islamic University Malaysia for the strategic collaborative in this research work. Deepest appreciation to all students taking Chemistry subject in Semester 2, 2023/2023 that involved in this research work. Special thanks to those who contributed to this project directly or indirectly.

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