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THE ROLE OF GAMIFICATION IN ENHANCING CRITICAL THINKING SKILLS IN ONLINE SCIENCE EDUCATION

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ABSTRACT
This study examines the role of gamification in enhancing critical thinking skills in online science education, centring on the impact of specific game-based elements and learner cognitive behaviour. The research question examines which gamification features best enhance critical thinking and how motivation and prior knowledge influence possible outcomes. Using a quantitative research design with a survey method, a sample of 600 students was selected from three universities with 200 participants from each institution by a multi-stage sampling technique, initially identifying the science education departments and then selecting participants through simple random sampling of the 400-level students. A researcher-design instrument was used to collect data. Data were analysed using descriptive and inferential statistics, including regression analysis, to assess the relationship between gamification elements and critical thinking skills. Results revealed that gamification, particularly reflection tasks and progress-tracking, significantly aids critical thinking by promoting self-assessment and engagement. However, competitive elements like leaderboards proved less effective, indicating a need for balance in gamified educational learning designs. The study recommends structured reflection tasks and progress tracking for online learning. This suggests gamification's potential to enhance critical thinking when directed to varied learner profiles.

INTRODUCTION

The continuous growth of online education, particularly in science, has called for innovative approaches to ensure the development of higher-order critical thinking skills. Critical thinking, defined as the ability to examine, synthesise and evaluate information effectively (Ennis, 2018), is a must for success in science education. In the digital learning environment, traditional teaching and learning methods are often insufficient to enhance these skills, leading to a search for another pedagogical approach. One promising move is gamification, the application of game design elements in non-game contexts (Sailer et al., 2017). Integrating gamification into online science education has shown potential for acceleratory engagement, motivation, and improving critical thinking skills. This study researches the role of gamification in fostering critical thinking within online science education. It seeks to understand how game elements can improve students' critical thinking skills in complex scientific situations. The demand for critical thinking in science education is well-documented. As a discipline, science requires students to question assumptions, analyse data, draw reasoned conclusions and apply learned concepts to real-world problems (Raj et al., 2022). However, the challenge lies in effectively teaching these skills, especially in online learning, where students are often physically detached and may lack the hands-on experiences typical of traditional

classroom contexts. The online environment, though flexible and accessible, can decrease student engagement and limit opportunities for developing critical thinking (McCarroll & Hartwick, 2022). Based on this fact, educators have turned to gamification as a systematic approach to counteract these limitations.

As an instructional approach, gamification incorporates elements of gaming—such as points, badges, leaderboards, and quests—into educational contexts to stimulate motivation and engagement (Alsawaier, 2018). By engaging students in a competitive yet collaborative environment, gamification can create a more interactive and immersive learning experience. This interactive nature of gamification is especially beneficial for developing critical thinking skills, as it often requires learners to navigate complex scenarios, make decisions, and reflect on the consequences of their actions (Christopoulos & Mystakidis, 2023). For example, in a gamified online science class, students may be tasked with solving a series of scientific challenges, where each step requires them to apply critical thinking to progress through the game. This aligns well with constructivist theories of learning, which emphasise active participation and problem-solving as key to knowledge acquisition (Ah-Nam & Osman, 2017; Zajda & Zajda, 2021). Several studies have explored the relationship between gamification and critical thinking in various educational contexts. For instance, Liu et al. (2013) found that students who participated in gamified learning environments demonstrated significantly higher levels of critical thinking than those in traditional online courses. Similarly, Asigigan and Samur (2021) revealed that using gamified assessments in science education improved students' critical thinking abilities and increased their motivation to engage with complex material. These findings suggest that gamification could be a powerful tool in overcoming challenges associated with teaching critical thinking skills online.

Moreover, the specific elements of gamification have been shown to influence the development of critical thinking differently. For example, quests and challenges, common in gamified learning, encourage problem-solving and decision-making, key components of critical thinking (Cavus et al., 2023). Similarly, leaderboards and badges can create a sense of competition and accomplishment, driving students to reflect on their performance and improve their strategies critically (Tumbaco-Loor & Llerena Izquierdo, 2023). However, the effectiveness of these elements may vary depending on factors such as student demographics, prior knowledge, and the subject matter being taught (Dichev & Dicheva, 2017). Thus, while gamification holds promise for enhancing critical thinking, its success depends on the thoughtful design and implementation of game elements that align with the course's learning objectives. In online science education, where students often engage with abstract and complex concepts, gamification can provide the structure and motivation to develop critical thinking skills. Science education, particularly at higher levels, often requires students to approach problems systematically, assess evidence, and formulate well-reasoned arguments (Jolaoluwa et al., 2024). Gamification can facilitate this process by offering scaffolded learning experiences that challenge students to apply scientific concepts in novel and interactive ways. For instance, in a gamified biology course, students may be presented with a virtual ecosystem and tasked with maintaining its balance by making decisions based on real-world data. Each decision would require critical thinking, as students would need to weigh multiple factors, predict outcomes, and justify their choices. This type of engagement reinforces scientific knowledge and fosters the development of critical thinking skills essential for success in the field.

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Despite the growing interest in gamification, there remains a gap in the literature concerning its specific impact on critical thinking in online science education. While studies have explored the general effects of gamification on student engagement and motivation (Hakulinen et al., 2015; Hanus & Fox, 2015), few have focused explicitly on its role in enhancing critical thinking skills, particularly in science education. Furthermore, existing research often lacks a clear delineation of how different gamification elements contribute to developing critical thinking and whether certain elements are more effective than others. This study aims to fill this gap by investigating how gamification can enhance critical thinking skills in online science education, focusing on identifying which game elements are most effective in fostering these skills.

Purpose of the Study. This study explores how gamification enhances the development of critical thinking skills within online science education. It seeks to determine which elements of gamification, such as points, badges, and challenges, contribute most significantly to fostering critical thinking and how factors like student background and motivation play a role in these outcomes.

Research Questions. The following stated research question guided this study: In what ways does gamification enhance critical thinking skills in online science education? Which gamification features most effectively promote critical thinking in online science education? How do student characteristics, including prior knowledge and motivation, influence the effects of gamification on critical thinking in online science education?

RESEARCH METHODOLOGY

This study employs a quantitative research design with a survey research method to examine the role of gamification in enhancing critical thinking skills among 400-level science education students from the University of Ilorin, Kwara State University, and Al-Hikmah University. The focus on 400-level students is justified by their advanced exposure to science education, which positions them to effectively engage with critical thinking tasks (Abuhamda et al., 2021). A sample of 600 students will be selected, with 200 participants from each university. The sampling technique follows a multi-stage approach, initially identifying the science education departments within these institutions, followed by simple random sampling to select participants. This technique ensures fair representation of different science education departments and minimises selection bias. The research instrument was a structured questionnaire to measure the students' critical thinking skills and experiences with gamified learning, ensuring alignment with the study's objectives. To ensure content validity, the questionnaire will be reviewed by experts in educational research and gamification. A pilot test involving 50 science education students from the National Open University, Ilorin Centre, was conducted to establish the instrument's reliability using Cronbach's alpha coefficient. A coefficient of 0.705 was obtained, which is considered good enough. Ethical considerations will be observed by obtaining informed consent from participants and ensuring confidentiality. Data collection will occur through the distribution of questionnaires, and the data analysis will involve descriptive and inferential statistics, including regression analysis, to explore the relationships between gamification and critical thinking development. This approach will help ensure robust and replicable findings that can be generalised within science education (Finkel et al., 2017).

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RESULT AND DISCUSSION

Research Question 1: In what ways does gamification enhance critical thinking skills in online science education?

Table 1. Percentage and Mean Score of gamification enhancement level of critical thinking skills in online science education

S/N	State of adoption of mobile technologies	N	Total Score	Percentage Score	Mean Score	Mean Ranking
1.	Gamification in online science courses has improved my ability to analyse complex problems.	600	1717	71.54	2.86	2
2.	Using gamified activities in science education has helped evaluate multiple perspectives in problem-solving.	600	1467	61.13	2.45	5
3.	Gamification settings make it easier for me to break down challenging concepts in science.	600	1657	69.04	2.76	3
4.	I feel that my decision-making skills in science education have gotten better due to gamified activities.	600	1526	63.58	2.54	4
5.	Gamification has improved my ability to reflect critically on my understanding of scientific topics.	600	1876	78.17	3.12	1

Table 1, which examines how gamification enhances critical thinking skills in online science education, shows that the highest mean score of 3.12 (78.17%) was observed for the statement, "Gamification has improved my ability to reflect critically on my understanding of scientific topics." This result ranked first indicates that participants felt that gamification notably fosters reflective critical thinking in science learning. The second-highest score, with a mean of 2.86 (71.54%), relates to enhancing analytical skills in complex problem-solving, suggesting that gamification aids students in engaging with analytical tasks. The ability to break down challenging concepts ranked third with a mean score of 2.76 (69.04%), indicating that gamified settings support conceptual simplification. Lower mean scores were observed for decision-making (2.54, 63.58%) and evaluating multiple perspectives (2.45, 61.13%), suggesting that while these areas benefit from gamification, they are less influenced than reflective skills.

Research Question 2: Which gamification features are most effective in promoting critical thinking in online science education?

Table 2. Percentage and Mean Score of gamification features that are most effective in promoting critical thinking in online science education

S/N	State of adoption of mobile technologies	N	Total Score	Percentage Score	Mean Score	Mean Ranking
1.	Points and rewards in gamified science activities encourage me to think critically when completing tasks.	600	1827	76.13	3.05	2
2.	Badges earned in gamified science education aid motivation to analyse complex topics.	600	1713	71.38	2.86	3
3.	Leaderboards in my science courses encourage competition that enhances my critical thinking skills.	600	1607	66.95	2.68	5
4.	Interactive challenges and quests encourage me to use my knowledge more thoughtfully in science activities.	600	1664	69.33	2.77	4
5.	Progress tracking in gamified activities has been efficient in helping me evaluate my progress in science learning.	600	1961	81.71	3.27	1

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Table 2 identifies which gamification features are most effective in promoting critical thinking. The feature "Progress tracking in gamified activities" scored the highest, with a mean of 3.27 (81.71%), suggesting that monitoring one's progress is a particularly impactful element in enhancing critical thinking. The next most compelling feature, "Points and rewards," scored 3.05 (76.13%), indicating that reward systems also benefit critical thinking. Badges and interactive challenges had moderate effectiveness, with means of 2.86 (71.38%) and 2.77 (69.33%), respectively, showing that these elements encourage motivation and thoughtful knowledge application. Leaderboards had the lowest impact on critical thinking skills, scoring a mean of 2.68 (66.95%). This may indicate that competitive features are less influential in fostering critical thinking than personalised progress tracking.

Research Question 3: How do student characteristics, including prior knowledge and motivation, influence the effects of gamification on critical thinking in online science education?

Table 3. Percentage and Mean Score of characteristics, including prior knowledge and motivation, influence the effects of gamification on critical thinking in online science education.

S/N	State of adoption of mobile technologies	N	Total Score	Percentage Score	Mean Score	Mean Ranking
1.	My previous knowledge of science affects the level at which gamified activities improve my critical thinking skills.	600	1847	76.96	3.08	3
2.	A high level of motivation helps me engage critically with gamified science tasks.	600	1943	80.96	3.24	1
3.	Gamified activities in science education benefit my critical thinking when familiar with the topic.	600	1649	68.71	2.75	5
4.	My interest in science impacts how gamification influences my thinking process.	600	1698	70.75	2.83	4
5.	Gamification in science education has more impact on my critical thinking when I am motivated to attain high scores.	600	1891	78.79	3.15	2

Table 3 evaluates the influence of student characteristics on the effectiveness of gamification in promoting critical thinking. Motivation was the most significant factor, with "High level of motivation helps me engage critically with gamified science tasks", scoring the highest mean of 3.24 (80.96%), highlighting the crucial role of motivation in critical thinking. Similarly, "Gamification in science education has more impact on my critical thinking when I am motivated to attain high scores" had a high mean of 3.15 (78.79%), emphasising that score-driven motivation enhances gamification outcomes. Prior knowledge and familiarity with the topic moderately impacted critical thinking (3.08, 76.96% for prior knowledge and 2.75, 68.71% for familiarity), suggesting that students' background knowledge aids gamification's effectiveness. Finally, interest in science had

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a mean of 2.83 (70.75%), indicating that students' inherent interest in science moderately influences how gamification affects their critical thinking skills.

DISCUSSION OF FINDINGS

The findings indicate that gamification significantly enhances critical thinking skills in online science education, aligning with the literature on gamified learning's effectiveness in promoting higher-order thinking. According to Correia and Lobo (2024), gamification elements, like reflective tasks, can deepen critical thinking by engaging students in self-assessment and iterative learning. In this study, the highest-rated statement, "Gamification has improved my ability to reflect critically on my understanding of scientific topics," supports this by showing that students found reflection notably beneficial, echoing Ryan and Ryan's (2013) findings that reflective tasks enable students to evaluate their learning progress critically. However, the relatively lower mean scores for decision-making and perspective evaluation suggest gamification may be less effective in facilitating these aspects, contrary to general assumptions about the broad utility of gamification in fostering all dimensions of critical thinking (Kalogiannakis et al., 2021). Regarding gamification features, progress tracking emerged as the most impactful, indicating that students benefit from consistent feedback on their progress. This aligns with the findings by Hamari et al. (2014), which highlight that tracking mechanisms foster engagement and reflective analysis, which is vital for critical thinking. Points and rewards also scored highly, emphasising that achievement-based elements effectively motivate students to think critically to reach goals. However, the relatively low ranking of leaderboards as a motivational tool indicates potential drawbacks to competitive gamification features. Smirani and Yamani's (2024) research suggests that competitive elements may detract from intrinsic motivation and discourage critical engagement for students less inclined towards competition. Thus, while gamification promotes critical engagement, the effectiveness of specific elements varies, and competitive features may need reconsideration.

Student characteristics, including motivation and prior knowledge, significantly influence how gamification impacts critical thinking. Motivation was the most influential factor, supporting Bircan's (2015) self-efficacy theory, which posits that high motivation enhances cognitive engagement. The findings show that students motivated by high scores or personal interest benefit more from gamified tasks, mirroring Barata et al. (2015) findings that motivated students tend to engage deeply with critical tasks. However, this also raises questions about gamification's efficacy for less motivated students, as Hung (2017) argues that gamification may primarily reinforce existing motivation rather than create it. Prior knowledge also appeared significant, suggesting that gamified learning may be more effective for students with foundational knowledge. This perspective is consistent with the findings of Sailer et al. (2017), who argue that gamification benefits are amplified for students already familiar with the subject matter.

CONCLUSION

This study has provided valuable insights into the role of gamification in enhancing critical thinking skills within online science education. By examining various game-based elements and their effects on learner cognitive behaviour, we have identified specific features that significantly contribute to developing critical thinking skills among students. The findings indicate that gamification strategies, particularly those involving structured reflection tasks and progress-tracking mechanisms, foster

self-assessment and increase student engagement. These elements encourage deeper cognitive processing and promote a reflective approach to learning, which is essential for critical thinking. Conversely, the research highlighted that competitive gamification aspects like leaderboards may not universally enhance critical thinking skills. This suggests their effectiveness can vary based on individual student motivations and learning styles. This underscores the importance of a balanced approach when integrating gamified elements into educational practices. Moreover, the study emphasises the need for educators to tailor gamification strategies to accommodate diverse learner profiles. By doing so, they can create a more inclusive and effective learning environment that enhances critical thinking across different student demographics. In conclusion, this research contributes to the growing body of literature on gamification in education and highlights its potential as a transformative tool for enhancing critical thinking skills. As educational technology continues to evolve, further exploration of gamification's impact on different aspects of learning will be essential in informing best practices and advancing the quality of online education. Future studies should consider longitudinal approaches and diverse educational contexts to deepen our understanding of how gamification can be effectively leveraged to support critical thinking and overall student success.

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