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Gamifying Science Education: A Bibliometric Review of Gamification Practices in Science Teaching and Learning

Dandy V. Alcido[1]*, Romalyn L. Talla[2], Joshua T. Soriano[3]
Technological University of the Philippines
Corresponding Author: Dandy V. Alcido dandy.alcido@deped.gov.ph

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A B S T R A C T
This bibliometric study maps gamification trends in science education—instructional modes (online, face-to-face, blended), content areas, educational levels, and philosophical foundations—to address gaps in empirical perspectives beyond descriptive/quantitative analyses. We systematically analyzed 15 peer-reviewed, open- access Scopus-indexed papers published 2015– 2025, classifying them by delivery mode, science discipline, learner level, and theoretical frameworks. Findings reveal dominant trends in blended/online modalities, secondary-level chemistry/physics applications, and pragmatist and constructivist philosophies, highlighting underexplored areas like primary education and face-to-face implementation. These insights guide educators and policymakers toward targeted gamification strategies, enhancing science learning engagement and outcomes.

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INTRODUCTION

Education stands at a crossroads, tasked with the vital mission of providing inclusive, equitable, and quality learning for all—a core aim of the United Nations' Sustainable Development Goal 4 (SDG 4). Achieving this goal in our rapidly digitizing world requires more than just access to technology; it demands teaching methods that truly captivate and inspire students. As traditional classrooms evolve, finding strategies that spark curiosity and sustain engagement across diverse learning styles has never been more crucial. A "gamification": the deliberate use of game-like elements such as earning points, unlocking badges, and overcoming challenges within educational settings. This approach is proving to be far more than a mere trend. A robust and growing collection of studies indicates that when applied thoughtfully, gamification can significantly boost students' motivation, deepen their engagement, and clarify complex scientific concepts (Fan et al., 2015; Fleischman & Ariel, 2016; Kalogiannakis et al., 2021).

This potential is being unlocked just as our learning environments are becoming fundamentally more innovative and digital (Jiménez-Valverde et al., 2025; Indiaka et al., n.d.). Consequently, researchers are increasingly exploring how this playful, game-based lens can reshape the experience of learning science itself (Chans & Portuguez Castro, 2021). The global shift toward flexible learning, accelerated by the recent pandemic, has dramatically widened the playing field. Digital platforms now offer rich opportunities to weave gamification not only into fully online courses but also into blended formats and traditional in-person science classrooms (Capinding, 2022; Zourmpakis et al., 2023; Gaurina et al., 2025). With these new possibilities, however, comes a need for clarity. The research landscape has become vast and varied, calling for a systematic effort to understand "how" gamification is being studied, "where" it is being implemented, and "what theories" are guiding its use in science education.

In response to this need, and to contribute meaningfully to the objectives of SDG 4, our study seeks to determine which mode of instruction: online, blended, or face-to-face modality, utilises the most use of gamification in science education. It will also explore the philosophical foundations that underlie the gamification in science education by content analysis as well as the most common Science learning area and the student educational level on which this gamified element is applied. The result of this will support educators, teachers, and policymakers in understanding the current state of gamification research and in identifying the promising pathways for future advancement in science education

LITERATURE REVIEW

Gamification brings game elements—points, badges, challenges, leaderboards, instant feedback into science classrooms to spark motivation and deeper learning (Kalogiannakis et al., 2021). Early work showed real promise: Fan et al. (2015) matched gamified health lessons to students' learning styles, while Fleischman and Ariel (2016) made microscopic lab processes engaging and fun.

Digital shifts supercharged this trend. Post-pandemic, tools like Quizizz transformed secondary science assessments (Capinding, 2022), Minecraft trained future teachers (Cózar-Gutiérrez & Sáez-López, 2016), and chemistry classes saw motivation soar through gamified platforms (Chans & Portuguez Castro, 2021; Lutfi et al., 2023). Physics students stayed hooked through playful challenges (Gaurina et al., 2025), and biology comprehension improved with digital games (Indiaka et al., n.d.).

Recent reviews paint a clear picture: gamification works across STEM, but gaps remain (Alahmari et al., 2023; Nurfadilah et al., 2025). We know little about which works best online, blended, or face-to-face and how philosophical foundations shape implementation. Adaptive games boosted motivation further (Zourmpakis et al., 2023), preservice teachers warmed to physics/chemistry through fantasy platforms (Jiménez-Valverde et al., 2024), and even early childhood gained science-positive attitudes (Fabre-Mitjans et al., 2025). Flipped classrooms, escape rooms, AR, and low-cost STEM tools pushed boundaries (Zamora-Polo et al., 2019; Pozo-Sánchez et al., 2022; Lampropoulos et al., 2023; Marin-Mantilla & Moscoso-Barrera, 2025).

METHODOLOGY

This study is a quantitative bibliometric research design, which will analyze patterns, frequencies, and structures in collected references. Bibliometric analysis is applicable for this study because it allows the identification of research focus areas, implicit and explicit philosophical frameworks, and instructional modes in gamification research within science education.

The design is descriptive and quantitative, as it quantitatively summarises data such as the number of identified areas, frequency of keywords, distribution across different modes of instruction, and the prevalent philosophical foundations. This design also enables visualisation of networks and clusters to highlight the development and structure of research in the field.

Data Source

All open-access and peer-reviewed research journals and articles retrieved from various publications were checked to confirm that these are Scopus indexed; this served as the primary database for conducting this bibliometric analysis. Initial searching was done using the Google Scholar search engine, and ResearchRabbit AI was used as well in aid of efficiently finding relative sources.

Search Strategy

The search was conducted using the following keyword combinations:

1. “gamification” AND “science education”
2. “Gamify science”
3. “gamification” AND “Science Teaching”

Boolean operators were applied in searching to narrow the search and increase the relevance of results.

This Limits to:

a) Papers published from 2015 to 2025
b) Papers categorised as articles, journals, or research papers.
c) Publications written in English

Inclusion and Exclusion Criteria Inclusion criteria:

1. The study was related to a science content area such as chemistry, physics, biology, health education, natural sciences, etc.).
2. The study showcased gamified practice with at least one utilized game sample in any format, such as tools, sites, apps, web designs, teacher-made, etc.
3. The study was conducted in an educational environment (primary, secondary or higher education).
4. Peer-reviewed, open-access publications.
5. Scopus-indexed papers

Exclusion criteria:

1. Study on general game-based learning without gamification elements.
2. Study that focused on non-science disciplines.
3. Study that was not Scopus-indexed.
4. Studies that are not written in English

Data Analysis Tools

In aid of analysing the collected sources, researchers utilised software tools such as:

a) Microsoft Excel – for descriptive statistics (frequencies, percentages, etc.)
b) Zotero – for annotating and referencing.
c) Gemini Ai - for visualization of networks and clusters.

Data Analysis Extraction

Table 1: Papers Included in the Bibliometric Analysis

No	Title of Journal / Article	Featured Gamified Education al Context	Science Learning Area	Educational Level where the study was conducted	Game Elements
1	Gamification in Science Education: Gamifying Learning of Microscopic Processes in the Laboratory	Enzyme Linked Immunoso rbent Assays (ELISA)	Biology	Higher	task - oriented, challenges, rewards
2	The Game as a Strategy of Learning Chemistry Among High School Students	Webquest	Chemistr y	Secondary	badges, points , progression, role-playing

3	Student Assessment of the Use of Kahoot in the Learning Process of Science and Mathematics	Kahoot	General Sciences	Secondary	leaderboard s, competition , score
4	Gamification: Game as a Medium for Learning Chemistry to Motivate and Increase Retention of Students Learning Outcomes	CHEM-RUSH	Chemistr y	Secondary	role-playing score-based
5	Utilization of 'Quizizz' a Game-based Assessment: An Instructional Strategy in Secondary Education Science 10	QUIZIZZ	Physics	Higher	leaderboard s,competitio n, score
6	Gut Check: The evolution of an educational board game	GUT CHECK	Biology	Secondary	challenges, win-lose
7	The Effects of Learning Styles and Meaningful Learning on the Learning Achievement of Gamification Health Education Curriculum	Meaningfu l Bloo d Circulation Learning System (MMBCLS)	Biology	Secondary	role selection, progression
8	Adaptive Gamification in Science Education: An Analysis of the Impact of Implementation and Adapted Game Elements on Students' Motivation	Water cycle app	Natural Sciences	Primary	challenges, badges and currency/ storytelling, points, gifting , collaboratio n
9	Effectiveness of Digital Gamification in Biology Concept Comprehension and Learner Motivation in Secondary Schools	Kahoot	Biology	Secondary	leaderboard s,competitio n, score
10	Development of a STEM Teaching Strategy to Foster 21st-Century Skills in High School Students Through Gamification and Low-Cost Biomedical Technologies	BioSen electronic board and space exploratio n booklet	Space Explorati on	Secondary	challenging mission/ badge system

11	Gamification as a Strategy to Increase Motivation and Engagement in Higher Education Chemistry students	Mastering Chemistry (MC) platform from Pearson. / Canvas	Chemistr y	Higher	challenges, reward points,
		learning manageme nt system			
12	Digital Gamification to Foster Attitudes Toward Science in Early Childhood Teacher Education	FANTASY CLASS	Natural Science	Higher	point, challenges rewards, avatars
13	Gamifying Teacher Education with FantasyClass: Effects on Attitudes towards Physics and Chemistry among Preservice Primary Teachers	FANTASY CLASS	Chemistr y and Physics	Higher	point, challenges, rewards, avatars
14	Narrative-Driven Digital Gamification for Motivation and Presence: Preservice Teachers' Experiences in a Science Education Course	FANTASY CLASS	Natural Science	Higher	avatars, themes, points, leaderboard s,rewards and progression system
15	The Power of Play: Investigating the Effects of Gamification on Motivation and Engagement in Physics Classroom	Self-made gamified platform	Physics	Secondary	points, rewards, badge, leaderboard s

Table 1:

Thorough reading and keyword analysis were done to collect data across all retrieved papers while maintaining their credibility. The following necessary information was extracted from each paper:

1. mode of instructions
2. rooted Philosophical Foundation
3. Science Learning Area
4. Educational Level where the study was conductedname of the educational context
5. gaming elements
6. methods
7. findings

The philosophical foundations of learning presented were derived through a comprehensive analysis of articles' results, conclusions, and discourse. They were not explicitly stated in the reviewed articles aside from constructivism. Instead these classifications were derived based on the identification of hallmark keywords and phrases associated with each school of thought.

RESEARCH RESULT

Mode of learning

A quantitative content analysis of the journal articles was made to identify which mode of learning gamification in science is frequently used. The figure shows the percentage share of each learning modality within the provided list of 15 articles.

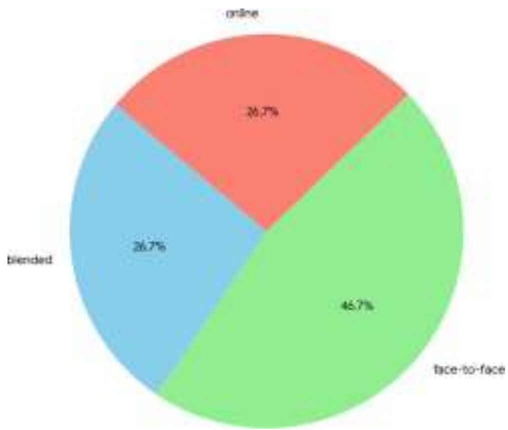

Figure 1: Frequency of Learning Modalities in Gamification Articles

Table 2: Summary of the reviewed articles, such as the title, author and type of learning modality.

	Title of Journal / Article	Authors	Learning Modality
1	Gamification in Science Education: Gamifying Learning of Microscopic Processes in the Laboratory	Katja Fleischmann, & Ellen Ariel	online
2	The Game as a Strategy of Learning Chemistry Among High School Students	Álvarez-Herrero, J.-F., & Valls-Bautista, C. (2021).	online

3	Student Assessment of the Use of Kahoot in the Learning Process of Science and Mathematics	Marta Curto Prieto *, Lara Orcos Palma, Pedro Jesús Blázquez Tobías and Francisco Javier Molina León	face to face
4	Gamification: Game as a Medium for Learning Chemistry to Motivate and Increase Retention of Students Learning Outcomes	Lutfi, A., Aftinia, F., & Permani, B.E. (2023).	face to face
5	Utilization of 'Quizizz' a Game-based Assessment: An Instructional Strategy in Secondary Education Science 10	Capinding, A. T. (2022).	blended
6	Gut Check: The evolution of an educational board game	Coil DA, Ettinger CL, Eisen JA (2017)	face to face
7	The Effects of Learning Styles and Meaningful Learning on the Learning Achievement of Gamification Health Education Curriculum	Kuo-Kuang Fan, Peng-wei Xiao, & Chung-Ho Su	blended
8	Adaptive Gamification in Science Education: An Analysis of the Impact of Implementation and Adapted Game Elements on Students'	Zourmpakis, A.-I.; Kalogiannakis, M.; Papadakis, S.	face to face
	Motivation		
9	Effectiveness of Digital Gamification in Biology Concept Comprehension and Learner Motivation in Secondary Schools	Indiaka, S., Mwangi, W., & Sanyanda, J. (2025).	online
10	Development of a STEM Teaching Strategy to Foster 21st-Century Skills in High School Students Through Gamification and Low-Cost Biomedical Technologies	Marin-Mantilla, K. J., & Moscoso-Barrera, W. D. (2025)	face to face
11	Gamification as a Strategy to Increase Motivation and Engagement in Higher Education Chemistry students	Chans, G.M.; Portuguez Castro, M.	Face to face and Online
12	Digital Gamification to Foster Attitudes Toward Science in Early Childhood Teacher Education	Fabre-Mitjans, N.; Jiménez-Valverde, G.; Guimerà-Ballesta, G.; Calafell-Subirà, G.	online
13	Gamifying Teacher Education with FantasyClass: Effects on Attitudes towards Physics and Chemistry among Preservice Primary Teachers	Jiménez-Valverde, G.; Heras-Paniagua, C.; Fabre-Mitjans, N.; Calafell-Subirà, G	Face to face and Online
14	Narrative-Driven Digital		

	Gamification for Motivation and Presence: Preservice Teachers' Experiences in a Science Education Course	Michail Kalogiannakis and Kalliopi Kanak	face to face
15	The Power of Play: Investigating the Effects of Gamification on Motivation and Engagement in Physics Classroom	Gaurina, M., Alajbeg, A., & Weber, I. (2025).	face to face

Based on the figure 1 and table 2 analysis, Face-to-face learning is the most frequent modality discussed in the provided articles, accounting for nearly half or 7 articles (46.67%) of the studies, On the other hand, Online and Blended learning modalities are equally represented, each constituting 4 or 26.67% of the articles. The table 2 shows the summary of the titles of the articles, authors and modality.

Distribution of Gamification Across Science Disciplines and Educational Levels

Table 3: Cross Tabulation between Science Area and Educational level that uses gamification

Science Area	Frequency	Percentages	Educational Level		
			Primary	Secondary	Higher
Biology	4	26.7%	0.0	75.0	25.0
Chemistry	4	26.7%	0.0	50.0	50.0
General/Natural Sciences	4	26.7%	25.0	25.0	50.0
Physics	2	13.3%	0.0	50.0	50.0
Space Exploration	1	6.7%	0.0	100.0	100.0

Based on the result of the cross-tabulation analysis, it shows that Biology, Chemistry and General/Natural sciences appeared each four times or it constitutes 26.7 percent each are the most frequent science disciplines where gamification is used in science education.

a. Biology: Gamification in this discipline is predominantly focused on Secondary education, with 75% of its applications (3 out of 4 articles) targeting this level. The remaining 25% are in Higher education.
b. Chemistry: The application is evenly split, with 50% of the studies (2 articles) conducted at the Secondary level and 50% (2 articles) at the Higher education level.
c. General/Natural Sciences: This is the most broadly applied discipline, appearing across all three educational levels. It is also the only

discipline from the reviewed articles where gamification was used in a Primary education setting (25%, or 1 article).

d. Physics: Appeared in two articles (13.3% of the sample), with applications split evenly between Secondary and Higher education.
e. Space Exploration: Appeared in one article (6.7% of the sample), which was conducted exclusively at the Secondary education level.

Embedded Philosophical Foundation of Learnings

The Philosophical foundations of learning presented were derived through a comprehensive analysis of articles, discussions, results, and conclusions.. They were not explicitly stated in the reviewed articles aside from Constructivism. Instead these classifications were derived based on the identification of hallmark keywords and phrases associated with each school of thought.

A network graph was made to illustrate the philosophical foundations of learning as reflected in the 15 reviewed journal articles.

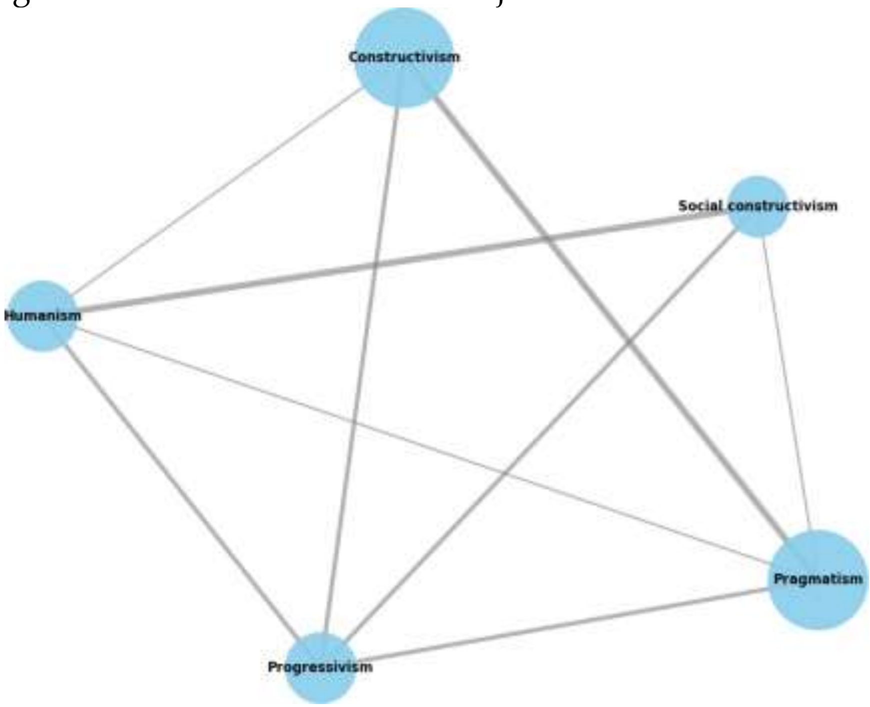

Figure 2. Network of Philosophical Foundations in the 15 reviewed papers (Circle, Sized by frequency, lines by co-occurence)

This map represents the implicit theoretical framework that drives the successful learning outcomes reported in the studies.

In this network graph, each circle represents a learning philosophy, and its size corresponds to the frequency of its occurrence across the articles. The lines connect philosophies that co-occur within the same article, the thicker lines indicating more frequent co-occurrence. It shows that Pragmatism and constructivism are the most prominent philosophies appearing in eight (8) articles, each showing the strongest co-occurrence. It shows that the research landscape focused on the individual learner's cognitive process, favored active and experiential learning. Progressivism and Humanism appear moderately in a total of four (4) articles, often linked with Pragmatism or Constructivism.

Social constructivism on the other hand, occurs less, in three (3) articles, but connects meaningfully with Humanism and Progressivism, emphasizing collaborative and socially oriented learning perspectives.

DISCUSSION

The bibliometric review reveals that research on gamification in Science education has a consistent place evidently from 15 retrieved published articles within the identified period. Although the number is relatively small the distribution indicates a continuous interest in intensifying Science learning through integrating gamified deliveries. The data suggest that researchers are continuously investigating gamification as a strategy to improve in learning aspects such as motivation, engagement, performance and assessment in science classrooms across education level and content area.

The study showed that science gamification has been implemented across face-to-face, online, and blended learning settings but differs in terms of number and application frequency. A notable proportion of the collected studies were conducted in face-to-face settings, implying that traditional classroom settings remain a valuable option for gamified science learning experiences (Pozo-Sánchez, 2022) This indicates that teachers may efficiently integrate game elements, such as competitions, challenges, rewards point systems, etc., within physical classroom interactions and involvement.

Furthermore, online and blended modalities showed equal frequency. This gives the idea that Science learning through gamification can also be suited with digital and hybrid learning arrangements due to the availability of various learning management systems and the accessibility of different self-made or pre- existed gamified digital platforms. The results in terms of mode of instructions connote that this strategy is viable with regard to flexibility and adaptability in many instructional contexts, especially in the evolving post-pandemic educational landscape (Nurfadilah, et al., 2025).

In Table 3, Gamification showed that it is suited across all Science learning areas primarily Biology as its contents are applicable to be gamified. Biological processes and parts naturally require visualisations, diagrams, simulations and interactivity, which elements of gamification provide. The same with Chemistry and Natural Science equally contains a gamified-friendly approach, with one to easily enhance understanding of concepts and procedures about matter and reactions and the other to leverage learnings in terms of phenomena, cycles and the like. Disciplines that involve complex concepts and processes like Biology, Chemistry and Natural Science are often being gamified, this can be deduced from the fact that interactive and game element strategies are well suited to keeping motivation and understanding towards this specific learning areas.These findings are in line with the claim that gamification is applied in areas where active engagement and experiential learning are needed to avoid retention difficulties. (Kalogiannakis, et al., 2021).

In contrast, Physics and Space Exploration are less represented. This is because these particular subjects are mathematically demanding with specific content and processes that require a high level of understanding, so applying gamified activities may be difficult and challenging. The same result yielded in (Alahmari, M., Jdaitawi, M. T., Rasheed, A., Abduljawad, R., Hussein, E., Alzahrani, M., & Awad, N. (2023), that the use of gamification in Physics is limited.

Gamifying Biology is mostly common in secondary level where concepts are complex and students are expected to be more engaging and involved. Chemistry and Physics shares distribution in secondary and tertiary levels, indicating that gamification on these stages can serve as both a motivational tool and strategy.

After systematic analysis of the retrieved research papers, it was found that the researchers of these papers used one or a combination of philosophical foundations to describe the value of applying gamification in teaching and learning Science concepts. However, Pragmatism surfaced as the most common Philosophical foundation, a sign that many researchers view gamification as a practical, problem-solving teaching tool that helps learners apply scientific concepts in meaningful and functional ways. In line with these perspectives, the positive gains observed in creativity, computational thinking, and critical thinking confirm that immersive, challenge-based strategies are effective in developing these competencies, particularly when they integrate real-world technological tools adapted to the school context (Marin-Mantilla, K. J., & Moscoso-Barrera, W. D., 2025). As well as Constructivism that also appeared significantly, suggesting an emphasis on active learning through interaction and exploration, processes that expectedly align with game-based strategy. Notably, while Social Constructivism was explicitly identified in only three articles, its emergence—particularly in tandem with Humanism and Progressivism—points toward an evolving recognition of gamification as a tool for fostering collaborative learning, social negotiation of meaning, and community-oriented engagement. This alignment reinforces a student-centered paradigm that values not only individual cognitive development but also social interaction and interpersonal growth within the learning process. Progressivism and humanism, points out that there are also studies that directly focused on student-centered, experiential learning and personal growth. It validates the findings of (Jiménez-Valverde, G., Heras-Paniagua, C., Fabre-Mitjans, N., & Calafell-Subirà, G. (2024)) suggest that integrating gamification in teacher education programs can effectively prepare future educators to employ innovative and engaging teaching strategies, thereby enhancing science education in primary and even in tertiary education.

Overall, these analysed anchored philosophical foundations highlight that gamification is not just part of technological development and 21st-century learning adjustments but also a pedagogical method that prioritises student learning experiences, problem-solving, and meaningful acquisition of knowledge in science education. This aligns with the present findings on how gamification fosters dynamic, engaging, and inclusive learning environments, paving the way for a more effective educational experience (Gaurina, M., Alajbeg, A., & Weber, I. (2025).

CONCLUSIONS AND RECOMMENDATIONS

This bibliometric analysis continuously proved that gamification is already an alternative part of science education in terms of transfer of knowledge and student-focused learning due to its adaptability and pedagogical capacity in raising student interest and performance. Gamified strategies are very flexible and can be successfully integrated into any educational context across different Science learning areas through any method of instruction possible, be it blended, online, or face-to-face instruction.

In the 15 papers we reviewed, the analysis on the distribution of Gamification across Science Disciplines and Educational Levels reveals that the application of gamification in science education is not uniform but is strategically concentrated where perceived needs are greatest: sustaining adolescent engagement in content-heavy life and chemical sciences. The dominance of Biology and Chemistry as gamified subjects is noteworthy. While this focus has yielded valuable models for secondary education, it has also led to relative neglect in other vital areas. This suggests that the structure of the subject matter itself may be particularly amenable to gamification. However, the significant under-representation of Physics and the near absence of Primary-level studies in specific disciplines point to critical gaps. This scarcity echoes concerns in the literature about the need for broader research across all educational levels and scientific fields (Alahmari et al., 2023).

Additionally, the analysis reveals that philosophical concepts such as pragmatism, constructivism, progressivism, and humanism are commonly used in gamifying science concepts, an indication that gamification is based on philosophical backgrounds that aim for active engagement, involvement, experiential learning, and acquisition of practical knowledge. It is also concluded that Philosophical foundation is naturally embedded in gamified science instruction in aid of meaningful cognitive and experiential learning aside from the purpose of motivation and interest. Nonetheless, a more intensive study with a larger number of publications over decades is needed in order to give an in- depth perspective of science gamification relative to its philosophical frameworks.

ADVANCED RESEARCH

This study reveals the gaps that future researchers could study. As this study reviewed 15 open access journal articles, future researchers may increase the number of reviewed papers for much more accurate data. This research is limited to the gamification in science education; other researchers could also map in which subject gamification is most frequently used.

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