Implementation of STEAM Gamification in Science Learning: A Systematic Literature Review

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Abstract

The advancement of science and technology in the 21st century calls for integrated and innovative educational approaches to ensure meaningful learning. STEAM—Science, Technology, Engineering, Arts, and Mathematics—offers an interdisciplinary structure, while gamification effectively rejuvenates science education. This systematic review, covering 2016 to 2024 and guided by PRISMA, examined 21 Scopus and Google Scholar studies. It explored key aspects such as research aims, methodologies, outcomes, levels of education targeted, integration models, and dominant disciplines. Findings revealed five main research designs—experimental, mixed methods, developmental, case studies, and qualitative—all showing positive impacts, with university settings being the most common. Science emerged as the core subject, with other STEAM components embedded contextually. Game elements like goals, badges, points, and leaderboards were prevalent, promoting engagement through challenge and reward dynamics. The study confirms the potential of STEAM gamification in enhancing creativity and critical thinking, particularly in higher education.

Keywords: *Literature Review, Science Gamification, Science Learning, STEAM.*

Introduction

Mastery of pedagogical competencies that strengthen the competencies required in the era of the Industrial Revolution 4.0 is a must to realize equitable and fair education for every student so that they can become lifelong learners (Likoko et al., 2023), including efforts to normalize the impact of educational decline post-covid-19 pandemic (González-Pérez et al., 2022). STEAM learning is more effective when students integrate information across disciplines. Project-Based Learning (PBL) plays a crucial role, providing an excellent opportunity for integrated learning by using student-directed problem-solving to produce products and gain mastery of concepts (Ubben, 2019). Its effectiveness in improving 21st-century skills is a reassuring fact. Several studies have shown that STEAM integration through Project-Based Learning (PjBL) models can effectively improve these skills (Zayyinah et al., 2022; Sigit et al., 2022; Al Wafi et al., 2022; Rizki et al., 2022; Wijayanti et al., 2018). Future research should explore the implementation of STEAM learning through project-based learning or other means.

STEAM, a truly unique learning approach, integrates art with science and technology to foster students' interest and passion. It combines science, technology, engineering, art, and mathematics, creating an inclusive learning environment that encourages all learners to engage and contribute. This holistic approach simultaneously stimulates the brain's left and right

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hemispheres, a feature that sets it apart from other learning methods (Martinez, 2017; Quigley et al., 2019; Khine & Areepattamannil, 2019).

STEAM education can facilitate teachers to integrate science, technology, engineering, arts, and mathematics through project-based learning and provide space for every student to inclusively actively contribute to the learning process (Alkhatib, 2025; Kuo, 2024). Unlike traditional learning models, STEAM bridges disciplines by leveraging synergies between process modeling and mathematics and science content, for example, to blur the lines between modeling methods and scientific/mathematical thinking (Al-Taie & Khattak, 2024). With this holistic approach, students can train both hemispheres of their brain at the same time (Sharipova, 2022; Herro & Quigley, 2017; Harrison & Parks, 2017; Liao, 2019).

Integrating STEM in learning prepares students to master 21st-century competencies, including problem-solving, critical thinking, creativity, and collaboration (Azriyanti, 2023; Chen et al., 2023). In implementing STEM or STEAM, teachers require support and professional development to ensure meaningful STEM or STEAM learning (Livers, 2022). Collaboration is not just beneficial, but it is essential for the success of STEAM. While subject integration in the curriculum has been advocated in recent years, there are limited opportunities for different subject teachers to implement an integrated curriculum through STEAM learning in schools collaboratively (Park & Cho, 2022).

The important role of information technology in the lives of the younger generation is the openness of access to its use in various areas of life, including education. In a pedagogical context, gamification that integrates game design principles into non-game activities to encourage certain behaviors is believed to increase students' psychological resilience and emotional stability (Varina et al., 2022). This mechanism facilitates a digital game design-based simulation experience, allowing active participation of students as users. Its implementation in the educational process is expected to answer the demands of adapting learning methods through educational play activities for students (Luo, 2022; González-Fernández et al., 2022).

The application of game mechanisms in a pedagogical context has long been implemented, especially at the elementary education level, to support acquiring knowledge and developing student competencies. Although learning is student-centered, the role of educators remains crucial. Teachers are required to understand individual needs, provide relevant materials, and evaluate the learning process holistically. This study proposes an exploration of the design and integration of adaptive gamification environments in science education by teachers (Zourmpakis et al., 2022). Although the potential of gamification in increasing motivation, engagement, and modifying learning behavior has been recognized by academics, its application in formal education is still limited (Sajinčič et al., 2022). This mechanism is increasingly adopted as an effective learning instrument to create interactive learning experiences where its elements encourage active student participation. The interactive nature of gamification ensures that educators are not just observers, but active participants in the learning process. Gamification-based approaches offer an alternative to conventional methods while expanding the capacity of assessment for learning outside the school environment (Saleem & Ozdamli, 2021; Kim & Castelli, 2021; Fleischman & Ariel, 2016; Hursen & Bas, 2019; Rivas et al., 2019).

The problem formulation, which serves as the foundation for a systematic review of the implementation of STEAM Gamification in science learning, has the potential to impact our field significantly.

1.	What are the objectives, methods, and results of research on the application of STEAM gamification in science learning?

2.	How is the integration of models/approaches/learning tools and education levels in applying STEAM gamification in science learning?

3.	What are the fields of study for implementing STEAM gamification in science learning?

4.	What are the elements of STEAM gamification used in science learning?

Method

This study targets academics and practitioners of STEAM education and gamification to conduct a systematic literature mapping related to implementing STEAM Gamification in science learning. Data was collected by searching for scientific documents for 2016-2024 using the key terms 'STEAM education,' 'STEAM gamification,' and 'science learning' in the Scopus and Google Scholar databases accessed via the Publish or Perish application. The systematic literature review (SLR) method was applied to provide a comprehensive analysis of the application of the concept. The article selection process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol to ensure the validity of source selection (Page et al., 2021; Yepes-Nuñez et al., 2021).

The procedure for implementing a systematic literature review in this study can be seen in Figure 1 below:
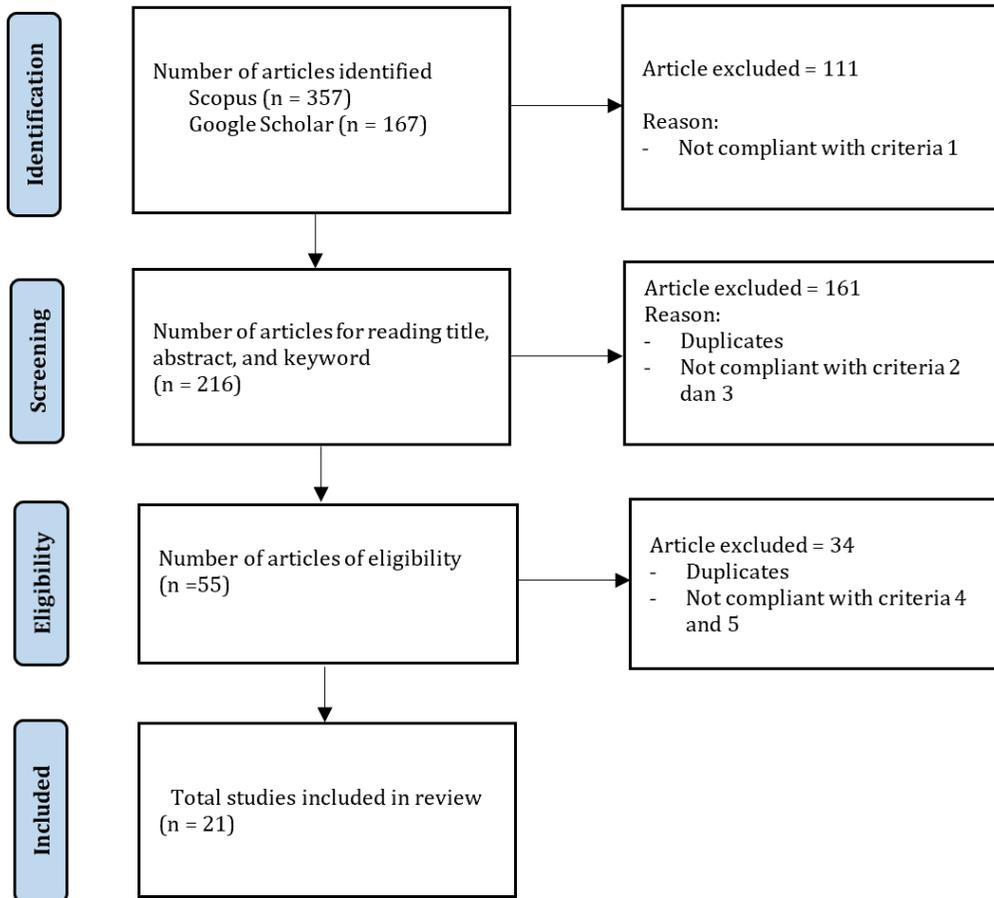
Figure 1. Systematic Literature Review Framework

The literature search process involved a comprehensive strategy through electronic databases and manual searches of selected journals to maximize coverage. Articles that did not contain practical implementations of STEAM/gamification in science learning were excluded. A total of 524 documents were identified from Scopus and Google Scholar, then filtered into 21 articles that met the following inclusion criteria:

1. Publication of international journals or proceedings in English;

2. Containing the terms 'STEAM/STEM gamification' and 'science learning' in the title, abstract, keywords, or body of the article;

3. Presenting the application of gamification in formal education/training for learning outcomes or development of gamification systems;

4. Containing measuring instruments for dependent variables related to learning outcomes (conceptual understanding, motivation, creativity, etc.);

5. Concluding the impact of gamification on the dependent variables.

Results

Table 1 presents a synthesis of data from 21 studies on the implementation of STEAM gamification in science learning included in this systematic review. The table contains the following columns: author and year of publication, country of origin of the study, study objectives, learning models/media/tools used, educational level, teaching materials, research design, gamification elements applied, and research achievements.

Code	Authors and Year	Country	Learning models/approaches/tools	Level Education	Subject	Research design	Gamification Element	Goals
S1	Kummanee et al. (2020)	Taiwan	Digital learning ecosystem involving STEAM gamification	Senior high school	Biology Ecosystem	article review, experiment pretest posttest	a. Goals, b. Rules, c. Reinforcement, d. Times, and e. Feedback.	Strengthening the ability to innovate and think creatively in vocational students.
S2	Wannapiroon & Pimdee (2022)	Thailand	Virtual classroom learning environment (VCLE) STEAM	University	STEAM	Qualitative and quantitative research methods	Gamification structurally contains two core components: a. game mechanics (goals, points, levels, badges, leaderboard) and b.	The creativity and innovation capacity of students using the VCLE STEAM-Gamification method is significantly higher

Code	Authors and Year	Country	Learning models/approaches/tools	Level Education	Subject	Research design	Gamification Element	Goals
							game dynamics (rewards, achievements, challenges, competition).	than students in the regular curriculum.
S3	López Serentill et al. (2021)	Brasil and Spain	Gamification in STEAM Education	Primary School Teacher	Mathematics	It is descriptive research with a mixed design, integrating quantitative and qualitative approaches simultaneously.		Examining mathematics teachers' perceptions of the implementation of gamified activities in STEAM education.
S4	Balci et al. (2022)	USA	Learning management system	University	Physics	Experiment	Badges and leader board	The study compared the effectiveness of badges and

Code	Authors and Year	Country	Learning models/approaches/tools	Level Education	Subject	Research design	Gamification Element	Goals
								leader boards (two of the most common gamification mechanisms) on students' academic achievement and motivation levels to evaluate their relative impact.
S5	Uanhoro & Young (2022)	Taiwan	This assignment system is operated through the Moodle Learning Management System (LMS) platform.	University	Physics	Experiment	Badges	Encourage timely submission of assignments while implementing distributed

Code	Authors and Year	Country	Learning models/approaches/tools	Level Education	Subject	Research design	Gamification Element	Goals
								practice strategies in student assignment completion.
S6	Araújo & Carvalho (2022)	Portugal	Platforms like Educaplay, Kahoot, Quizizz, Nearpod, Edpuzzle, Playposit, Plickers, Class Craft, Habitica, Bluerabbit, Edmodo, ActivelyLearn, Classflow, Pear Deck, and Thinglink fall into this category.	Teacher	Biology and Geology, History, Physical Education, and Special Education	Case Study	Participants had to choose platforms that could respond to their gamification goals.	Inventorying supporting elements and difficulties that impact learning planning, including personal characteristics, time availability, and technical room facilities.

Code	Authors and Year	Country	Learning models/approaches/tools	Level Education	Subject	Research design	Gamification Element	Goals
S7	Ricoy & Sánchez-Martínez (2022)	Spain		Primary School Children	Science, Environmental Education	A qualitative approach		Examining the impact of a gamification-based educational program for elementary school students in expanding ecological awareness and improving digital literacy.
S8	Fleischman & Ariel (2016)	Australia	Enzyme Linked Immunosorbent Assays (ELISAs) in a digital laboratory.	University	Biology	Experiment		To improve their understanding of Enzyme Linked Immunosorbent

Code	Authors and Year	Country	Learning models/approaches/tools	Level Education	Subject	Research design	Gamification Element	Goals
								Assays (ELISA).
S9	Saprudin et al. (2020)	Indonesia	PBL-Optical Gamification (OG)	Pre-service physics teachers	Physics, Wave and Optics	Quasi-experimental research with pretest posttest nonequivalent multiple group design		The implementation of gamified problem-based learning design in teaching materials (theory-practice) confirmed the achievement of very good categories for learning effectiveness and

Code	Authors and Year	Country	Learning models/approaches/tools	Level Education	Subject	Research design	Gamification Element	Goals
								interest.
S10	Dela Cruz et al. (2020)	Philippine	Gamified Instruction	University	Physics, Electricity and Magnetism	Sequential explanatory research design with a mixed methods approach	Experience points (XP), badges, leader boards, and search	Examining the effect of gamification mechanisms on the academic motivation of new students in the department of applied physics.

Code	Authors and Year	Country	Learning models/approaches/tools	Level Education	Subject	Research design	Gamification Element	Goals
S11	Panthalookaran (2018)	India	Digital Game	University	a. Swing and Grab Game (Oscillations) b. Wave Maker Arena (Waves) c. Wave Surfing Simulation (Interference) d. Shoot Right on Target (Diffraction) e. Archer Game (Polarization) f. Acoustic Kites (Acoustics)	Research and Development	Badges, collecting points, going to the new levels or winning the prizes	Building a conceptual knowledge base of physics through an engineering lens and examining the implementation of gamification on elementary concepts in depth.

Code	Authors and Year	Country	Learning models/approaches/tools	Level Education	Subject	Research design	Gamification Element	Goals
S12	Sakulkueakulsuk et al (2018)	Thailand	Rapid Miner, a UI-based software for machine learning.	Middle school level (grade 7 to 9)	Biology	Machine learning workshop		Designing innovative educational models that encourage learners to connect cutting-edge technology solutions (such as AI) with pressing real-world problems through fun approaches.
S13	Ibarra-Herrera et al. (2019)	Mexico	Gamification strategy in the Bio3D app	University	Biology	Experiment	Avatar, badges, puzzle, create story, minigames	Strengthening the motivation of students in engineering school

Code	Authors and Year	Country	Learning models/approaches/tools	Level Education	Subject	Research design	Gamification Element	Goals
								s to be interested in biology courses.
S14	Dustman, et al. (2021)	USA	Through virtual, gamified, multimodal laboratory simulations that combine the strengths of traditional labs with interactive platforms to increase student engagement.	University	Biology	Experiment	Power Point (PPt), online discussions and quizzes	Analyze the implementation of various gamification features in the Power Point presentation system.
S15	Borsos (2019)	Szerbia	PPT with 30 plant pictures, wordcards	Elementary school fifth-grade	Science, Plant	Experiment	'Which plant am I?' game wordcard	To help improve students' plant knowledge, while motivating them to learn

Code	Authors and Year	Country	Learning models/approaches/tools	Level Education	Subject	Research design	Gamification Element	Goals
								more about plants
S16	Siswati et al. (2021)	Indonesia	Modul Gamification	Senior high school	Biology	Development of the Plomp Model		Generate valid gamification modules
S17	Jones et al. (2019)	USA	KAHOOT!	Senior high school	Biology, Transcription and Translation	Experiment	Quiz	Evaluating the impact of gamification in AP (Advanced Placement) Biology learning through the integration of the online game 'KAHOOT!' as a complement to conventional

Code	Authors and Year	Country	Learning models/approaches/tools	Level Education	Subject	Research design	Gamification Element	Goals
								teacher-centered teaching methods.
S18	Sánchez-Martín et al. (2017)	Canada		Primary Education prospective teachers	Science, Matter and Energy	Experiment	Kahoot, G-Index	Increase student motivation and consequently improve academic grades.
S19	López Carrillo et al. (2019)	Spain	KAHOOT!, class dojo	Pre-service teachers	Science Practical Training	Mix method	Level and mission, avatar insignia, score, progress bar or story board	Gamification influences motivation through elements specifically designed for the implementat

Code	Authors and Year	Country	Learning models/approaches/tools	Level Education	Subject	Research design	Gamification Element	Goals
								ion of learning activities.
S20	Ares et al. (2018).	Spain	KAHOOT!,	University	Chemistry of mixed materials	Experiment	Quiz	Examining the use of the Kahoot! platform as a gamification instrument to explore blended learning strategies.
S21	Tolentin & Roleda (2019).	Philippine		High school, Grade 8	Physics	Sequential explanatory research design with a mixed methods approach	Experience points (XP), Badges, Leaderboards	Testing the significance of the influence of gamification on students' learning motivation.

Table 1. Research Article Data Synthesis

Based on Table 1 inform research related to the application of gamification started from 2016 to 2022. To have a broader view, the literature study was grouped based on the continent of origin, so that 48% were Asia, 28% America, and 24% Europe.

1.   Objectives, methods, and results of research on the application of gamification in science learning

Table 1 shows that the research objectives are divided into five categories of research methods or designs: experimental methods, mixed methods, development, case studies, and qualitative research.

Research design	Literature	Total
Experiment	S4, S5, S8, S9, S13, S14, S15, S17, S18, S20	10
Mix method	S1, S2, S3, S10, S19, S21	6
Development	S11, S12, S16	3
Case Study	S6	1
A qualitative approach	S7	1
	Total	21

Table 2. Research Method Recapitulation

2.   Integration of learning models/approaches/tools and education levels in applying STEAM gamification in science learning

Level Education	Literature	Total
Primary school	S7, S15	2
Middle school	S12, S21	2
Senior high school	S1, S16, S17	3
University	S2, S4, S5, S8, S9, S10, S11, S13, S14, S18, S19, S20	12
Teacher	S3, S6	2
	Total	21

Table 3. Education Level Recapitulation

Table 3 shows that the level of education that is most widely used in the implementation of STEAM gamification in science learning is at the college or university level.

3.   Field of study on the implementation of STEAM gamification in science learning

Table 4 shows how the field of study on the implementation of STEAM gamification in science learning is used to observe trends in applying gamification in specific fields of study.

STEAM Field of Study	Literature	Total
STEAM	S1, S2, S3	3
Science	S17, S19	2
	Physics (S4, S5, S9, S10, S11, S18, S21)	7
	Chemistry (S20)	1
	Biology (S7, S8, S12, S13, S14, S15, S16)	7
	Physics and Biology (S6)	1
Technology	-	-
Engineering	-	-
Art	-	-
Mathematics	-	-
	Total	21

Table 4. Field of Study on STEAM Gamification Implementation

Table 4 underscores the practical application of gamification in STEAM education, particularly in science. The 18 articles, divided into four categories-science, physics, chemistry and biology-demonstrate the potential of gamification to enhance learning.

4.   STEAM gamification elements used in science learning

STEAM gamification elements in science learning research are dynamic and adaptive. Of the 21 studies, 14 explicitly included these components in the analysis. Game mechanics (goals, points, leveling, badges, leaderboards) and game dynamics (rewards, achievements, challenges, competitions) can be flexibly modified. These elements are modular and can be combined and customized according to learning targets, academic achievements, and unique characteristics of learners at different levels. This flexibility underscores the practical value of gamification in educational contexts.

Discussion

Table 1 shows several Asian countries that have published research on gamification, including the Philippines, India, Indonesia, Taiwan, Thailand, and Australia. In the Americas, countries that have published research on gamification include the United States, Mexico, and Canada. Meanwhile, from Europe, publications on similar topics come from Spain and Portugal. The research trend on the use of gamification in learning increased between 2016 and 2019, decreased in 2020, and increased again in 2022. The decline is likely due to insufficient research that meets the inclusion criteria.

Table 2 shows that the most common research method used in the application of STEAM gamification in science learning is experiments, either with two classes (experimental class and control class) or only one experimental class. The objectives of experimental research in this field include improving the timeliness of assignment submission and distribution of practical assignments by students (Uanhoro & Young, 2022). In addition, this experiment was also conducted to assess the relative influence of two popular gamification tools—badges and leaderboards—on students' academic achievement, learning motivation, and interest in Biology materials such as plant knowledge, ELISA in digital laboratories, Chemistry materials, and

others (Balci et al., 2022; Fleischman & Ariel, 2016; Saprudin et al., 2020; Ibarra-Herrera et al., 2019; Borsos, 2019; Jones et al., 2019; Sánchez-Martín et al., 2017; Ares et al., 2018).

The following method is mixed, a combination of quantitative and qualitative approaches used to improve students' creativity and innovative skills (Kummanee et al., 2020; Wannapiroon & Pimdee, 2022). The application of gamification was also carried out to examine its effect on student and college student learning motivation (Dela Cruz et al., 2020; López Carrillo et al., 2019; Tolentino & Roleda, 2019). In addition, this study also aims to explore teachers' views on gamification-based learning activities in the context of STEAM education (López Serentill et al., 2021). In qualitative research, gamification was used to assess the impact of a learning program designed for elementary school students in increasing ecological awareness and digital literacy (Ricoy & Sánchez-Martínez, 2022). Meanwhile, in the case study, gamification was analyzed to identify various challenges in its planning, such as personal background, time availability, and technical conditions in the classroom (Araújo & Carvalho, 2022; Montiel-Ruiz et al., 2023; Sampedro-Martín et al., 2023). Research on development related to gamification in science learning includes the creation of gamification modules, the development of digital games for physics materials, and innovative educational models that connect cutting-edge technological solutions, such as artificial intelligence (AI), with real problems in a fun learning atmosphere (Siswati et al., 2021; Panthalookaran, 2018; Sakulkueakulsuk et al., 2018; Lorenzo-Lledó et al., 2023). The results of this study show positive achievements. They align with the planned objectives, so their success encourages further future research and development of gamification in science learning.

Table 4 reinforces the real use of gamification in STEAM education, especially in the science domain. From the 18 articles analyzed and categorized into four fields science, physics, chemistry, and biology it can be seen that gamification has excellent potential to improve the quality of learning. In physics materials, gamification is applied to topics such as waves and optics, electricity and magnetism, and swing games (oscillations), which provide a new approach to teaching complex concepts. For chemistry, gamification is used in mixed topics, while in biology, this approach enhances the understanding of ecosystems, dyeing processes, and plants. Integrating technology, engineering, art, and mathematics elements further strengthens the effectiveness of STEAM gamification in the learning process.

Conclusions

The results of the analysis and discussion show that the use of STEAM-based gamification in science learning is most dominantly applied at the tertiary level. However, its application is also possible for elementary, junior high, high school, and teacher training levels. Studies on STEAM gamification are primarily found in the realm of Natural Sciences. The integration of technology, engineering, art, and mathematics components is not just a complement but is the core of the appeal of this approach. These four fields are synergistically combined in applying STEAM gamification, making it a comprehensive and engaging learning method that instills confidence in educators. Some gamification elements commonly used in science learning include game features such as missions, points, levels, badges, scoreboards and game dynamics such as prizes, achievements, challenges, and competitions. These elements can be redesigned and adjusted to support learning outcomes and student characteristics at each level of education. This systematic literature review is expected to be a reference for designing research that examines the implementation of STEAM gamification in science learning so that it can be applied widely at various levels and learning topics. Referring to Table 3, higher education is the level of education

that most often implements the STEAM gamification approach in science learning. Its implementation is often combined with various learning models. It approaches such as the STEAM-based Virtual Classroom Learning Environment (VCLE), the Moodle learning management system, ELISA tests in digital laboratories, the PBL approach with a touch of Optical Gamification (OG), gamification-based instructions, digital games, gamification strategies in the Bio3D application, and multimodal laboratory simulations. These tools are used strategically to combine the advantages of conventional laboratories with digital technology that can increase student participation and engagement, including using applications such as Kahoot and ClassDojo. The primary focus of this approach is increasing student engagement, which is a crucial aspect of the success of STEAM gamification-based learning.

At the high school level, STEAM gamification seamlessly integrates into the digital learning environment through gamification modules and interactive platforms such as Kahoot! Similarly, at the junior high school level, the approach includes integrating user interface-based software such as RapidMiner to support data-based learning and artificial intelligence. Even at the elementary school level, there is innovation in using simple media such as PowerPoint presentations that display 30 plant images and word cards as part of the gamification activity. The adaptability of the STEAM gamification approach to various levels of education demonstrates its flexibility and effectiveness in sparking students' interest in learning at every stage of education.

In the context of teacher training, gamification in STEAM learning is also implemented by giving participants the freedom to choose their digital platform that suits their learning goals. Some of the platforms provided in the list of choices include Educaplay, Edmodo, Blue Rabbit, ClassCraft, Habitica, Kahoot, Quizizz, Plickers, Edpuzzle, PlayPosit, Nearpod, ActivelyLearn, ClassFlow, Pear Deck, Thinglink, and others. With this flexibility, teachers can adjust the tools used to their specific needs in developing gamification-based learning activities.

Acknowledgements

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