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GAMIFICATION IN BIOLOGY EDUCATION: A SYSTEMATIC REVIEW ANALYSIS[1,2]

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ABSTRACT

The aim of this research is to systematically review the effectiveness of gamification technologies in biology education, which have been explored in various research studies conducted in different fields in recent years. Within this objective, a general overview of gamification usage in the field of biology education has been provided, focusing on research articles published in nationally and internationally important journals indexed in relevant databases. The research approach is a descriptive qualitative systematic review. To accomplish the research aim, articles related to "biology," "biology learning," "biology teaching," "game," "gamification," and "game-based learning" were examined using various combinations of keywords between January 2010 and December 2022 in databases such as Web of Science (WoS), SCOPUS, and TR index. The data obtained in the research were analyzed using both inductive analysis of descriptive data and analytic themes. According to the results obtained from the research, gamification has been found to have a significant impact on biology education. It has been observed that gamification technologies have positive effects on students' cognitive, social, and personal skills, enhancing motivation and supporting the learning processes in biology education. Furthermore, gamification technologies have been highlighted for their advantages in increasing learning effectiveness by providing student-centered and interactive learning experiences. However, it was also determined that gamification practices have certain disadvantages and challenges. It is believed that this systematic review will shed light on further studies and applications related to gamification practices in biology education, contributing to the field of educational sciences and technologies.

Anahtar kelimeler: Biology education, game, gamification, systematic review.

[1] This study has been derived from the master's thesis prepared by the first author under the supervision of the second author.

[2] This study was presented as an oral presentation at the EJERCongress:10th International Eurasian Educational Research Congress in Ankara on June 8-11, 2023.

INTRODUCTION

The novelty of gamification occasionally leads to its confusion with games. While the English terms "Play" and "Game" convey distinct meanings, in Turkish, both are represented by the single term "oyun." "Play" refers to freely engaged activities without specific boundaries or rules. In contrast, "Game" distinguishes itself with a competitive structure defined by rules and objectives. Activities such as a child playing ball improvisationally can be described as "Play," whereas structured games like football, tennis, checkers, chess, dodgeball, hide and seek, and tag are examples of activities that align with the term "Game."

In Turkish, a game is defined as "an entertaining activity that develops skills and intelligence, has certain rules, and serves as a means of spending time enjoyably" (TDK, 2016). This definition indicates that the Turkish concept of "oyun" is more closely related to the "Game" aspect. McGonigal (2011) defines a game as "a voluntary struggle players engage in within a framework of restricted rules, accompanied by feedback, aimed at reaching a goal." Salen and Zimmerman (2004) describe a game as "a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome." Gamification emphasizes the rule-based and objective-oriented structure derived from the "Game" concept (Salen & Zimmerman, 2004).

From a marketing perspective, gamification is defined as "a rule-based service system with interactive mechanisms and feedback designed to create value (importance) for users" (Huotari & Hamari, 2012), while from an educational standpoint, it is described as "the use of game-based mechanics, aesthetics, and thought processes to engage learners, increase motivation, support learning, or solve problems" (Kapp, 2012). Although the literature on gamification presents various definitions, such as "the use of game mechanics and thought processes to solve problems and engage users" (Zichermann & Cunningham, 2011) and "the use of game mechanics, dynamics, and components to encourage desired behaviors" (Lee & Hammer, 2011), the definition by Deterding, Dixon, Khaled, & Nacke (2011), "The use of game design elements in non-game contexts," is the most widely accepted definition of gamification.

Despite differences in definitions according to their purposes, these definitions shape non-gaming areas through the motivational qualities derived from games' mechanics, dynamics, components, and thought processes. Hence, gamification can be articulated as "the use of games' entertaining and motivational characteristics in non-gaming contexts." The use of game design elements in various fields to enhance user experience emerges as a topic of study within "Human-Computer Interaction (HCI)" (Malone, 1982). In this context, HCI researchers have proposed design principles based on video games' motivational effects to enhance motivation in computer-supported work (Zhang, 2008; Ryan, Rigby, & Przybylski, 2006). Thus, reward and prestige systems encountered in gamification have previously been suggested and employed as motivational conditions (Deterding et al., 2011).

The term gamification was first coined in 2002 by game designer Nick Pelling, referring to a user interface he designed to make electronic transactions more enjoyable and efficient (Park & Bae, 2014). Although the term was first used in the literature in 2008, it did not gain significant attention until the late 2010s (Deterding et al.,

2011). The success of the location-based social networking application Foursquare (Swarm) over time attracted the digital media industry's attention, leading many companies to adopt game design elements like points, badges, levels, and leaderboards to motivate and increase user loyalty. These developments have extended game technology beyond traditional boundaries, positioning game design elements as a contemporary phenomenon (Deterding et al., 2011).

With the proliferation of online environments, the digital marketing paradigm emerged, diminishing the effectiveness of traditional advertisements. Gamification has breathed new life into marketing activities, aiding businesses in achieving their goals (Rauch, 2013; Bayraktar, 2015). Over time, it has been chosen as a method for accomplishing tasks or increasing product sales (Lee & Hammer, 2011). This approach has made persuasion, inherent to marketing, more straightforward and faster by leveraging gamification's motivational effect (Zichermann & Cunningham, 2011).

The focal point of the research, gamification, is a multifaceted concept with the potential to be adapted across a multitude of interdisciplinary subjects. For this adaptability potential to be realized, the design of new structures, tools, or objects is required (Ayastuy, Torres & Fernández, 2021). Consequently, the subject of gamification has garnered interest from researchers worldwide, leading to the emergence of numerous studies addressing applications, perspectives, possibilities, and limitations in various fields (Ayastuy, Torres & Fernández, 2021; Kasurinen & Knutas, 2018; Kim & Castelli, 2021; Lopes et al., 2019). Technological advancements, globalization, and increasing digitization have resulted in a majority of developed applications focusing on gamification in digital media (Alzahrani, 2020; Montagni, Mabchour, and Tzourio, 2020; Vigoroso et al., 2021; Williams & Ayres, 2020).

In the context of biology education, gamification has gained popularity through the emergence of "biotic games" (Cira et al., 2015; Kim et al., 2016; Riedel-Kruse et al., 2011). These games, while offering an entertaining and interactive approach to the subject matter by simulating the manipulation of living organisms in the classroom, impose a technological limitation due to their development for digital platforms (i.e., in video game format) (Coil, Ettinger & Eisen, 2017). This leads to a lack of use of motivational strategies affecting young people in the field of biology education (Fahnert, 2016; Finger et al., 2020; Sancho et al., 2006). Researchers in the relevant literature have addressed many aspects of this issue, indicating a need for more creative solutions to overcome learning barriers. Narratives or objects that make science more noticeable and enjoyable, due to its often abstract nature for students, can facilitate learning (Dieser & Bogner, 2016). Additionally, educational strategies that provide an intense and enjoyable emotional experience for users can be associated with cognitive gains (Allen, 2010; Beylefeld & Struwig, 2014). Thus, the gamification provided by games has a positive effect as an outcome of this situation.

The use of gamification in teaching holds the potential to encourage active participation, increase motivation, and enhance the learning experience (Huizenga, Admiraal, & Dam, 2009; Landers & Landers, 2014). The application of gamification in biology teaching can enable students to explore and understand biological

concepts (Barata, Gama, & Jorge, 2017; Kapp, 2012). Through games, students can actively participate, develop strategies to solve biology-related problems, and apply concepts in practice (McMillan, PopMus & Hons, 2011; Nacke, Bateman, & Mandryk, 2014). However, there are several factors to consider for the effective implementation of gamification in biology teaching. It is important that the games are aligned with teaching objectives and can effectively convey biological concepts (Rahimi, van den Berg, & Veen, 2015; Sardi, 2017). Moreover, the games should engage students, encourage participation, and increase motivation (de Sousa Borges et al., 2014; Seaborn & Fels, 2015).

Some studies examining the impact of gamification in biology teaching have shown that games can have positive effects on student achievement (Eisenkraft, 2018; Heinze, 2013). Research in the relevant literature found that a game covering the topic of genetics improved students' understanding and application of genetic concepts (Clark et al., 2015). Similarly, a game addressing the topic of ecology was found to enhance students' understanding of ecological concepts and their application (Honeycutt, 2016). However, there are also limitations and challenges associated with the effectiveness of gamification in biology teaching. Issues such as students misunderstanding the games, games deviating from teaching objectives, or distracting students' attention can arise (Dicheva et al., 2015; Kebritchi, Hirumi, & Bai, 2010). Additionally, cost factors related to the teaching material and resource requirements of games should also be considered (Denny, 2013; Kafai & Burke, 2013).

Building on the above explanations, the aim of the research is to systematically review the effectiveness of gamification, a technology tool increasingly investigated in recent years across various topics, in biology teaching and to present the current state of the literature on the development of gamification-based systems in biology education. Therefore, the research focuses on providing an overview of the use of gamification in the field of biology education in the literature and concentrates on studies published in national and international journals indexed in significant databases. This systematic review study is expected to shed light on new studies and practices related to the topic, contributing to the field of biology education.

METHOD

Model of the Study

The method of the study is a descriptive type of qualitative systematic review. The descriptive type qualitative systematic review method is defined as a systematic review method conducted by the researcher to reveal the general trend and research results related to any subject or discipline (Calik & Sözbilir, 2014). In other words, this systematic review method is based on the selection of literature related to the subject of interest, regardless of whether it is quantitative, qualitative, or mixed, based on certain criteria, the extraction of descriptive data related to the selected literature, and the interpretation of the data obtained. In this research method, the main goal is to reveal how the subject of interest is addressed by researchers and the trend over time through various themes created before or after the review, starting from descriptive data. In this method,

the researcher primarily aims to present the objectives of academic studies related to the chosen subject, the theoretical framework and method they are based on, and the findings of the research (Hallinger, 2018).

Determining the method on which the examined research (articles, theses, or reports) is based is one of the primary goals of descriptive type qualitative analysis in this research method. The researcher can reveal the extent to which these studies are based on quantitative, qualitative, mixed methods, and literature review by examining all the studies related to the subject within a certain time period and a limited number of journals previously defined. Therefore, limiting the studies to be included in the systematic review in terms of time and journals is also important for the feasibility of the study (Hallinger, 2013). Based on this information, this research identified and analyzed the studies related to gamification in biology education in the relevant literature.

Data Collection Process

In the data collection phase for the research, a search was conducted using the Web of Science (WoS), SCOPUS, and TR Index databases on December 30, 2022. The reason for conducting the search in the WoS, SCOPUS, and TR Index databases is that they are databases used by the international and national scientific community and are recognized for academic advancements. Within the scope of the research objective, a comprehensive literature review was conducted to identify studies related to gamification in biology education and to determine the current state of the field. The inclusion criteria for the studies included in the research were limited to the use of advanced search options with different combinations of the words/word groups "biology", "biology learning", "biology teaching", "game", "gamification", and "game-based learning" in the title and abstract areas, and the document type being restricted to articles (article). The search was limited to the dates between January 2010 and December 2022.

Inclusion and exclusion criteria

The inclusion and exclusion criteria for the research are as follows.

Inclusion criteria for the research:

- Being aimed at educators and/or learners in the field of educational sciences.
- The publication language being Turkish or English.
- The full text of the research being accessible.
- The title and abstract areas including the words/word groups "Biology", "Biology Learning", "Biology Teaching", "Game", "Gamification", "Game-Based Learning" as per the inclusion criteria.
- The studies being articles (article) published between January 2010 and December 2022.

Exclusion criteria for the research:

- Non-experimental research methodologies.
- Reviews, case reports, meta-analyses, editorial materials, brief survey studies, and duplicated articles are excluded from the scope of the research.

The publications evaluated as a result of the search were recorded in a table prepared in the Microsoft Office Excel Program. The prepared table includes the authors of the publications, publication name, year, purpose, universe and sample/study group, method, results, publication link, and bibliography entry (Appendix 2). Query links for each set of keywords have also been added to this Excel file. This is intended to increase the reproducibility and validity of the research process. For the reliability of the study, all screening and review activities have been conducted by two independent researchers.

During the screening process, the "Educational Sciences" research area was selected in the WoS database, ensuring that the studies focused on educational sciences and the specific dynamics of learning and teaching in this field. In the SCOPUS database, the "Social Sciences" category was chosen to provide a broad social sciences perspective. The TR Index database was accessed through https://trdizin.gov.tr/ using the "Publication Search" tab and "Advanced Search" in the "search area" section, adding title and abstract queries for "Biology", "Biology Learning", "Biology Teaching", "Game", "Gamification", "Game-Based Learning" word/word groups.

Finally, articles obtained from the WoS, SCOPUS, and TR Index databases were compared and duplicates were filtered. This filtering process is important in ensuring that the dataset has a unique and pluralistic coverage. After this stage, articles from both databases that did not match were compiled in an Excel file for analysis and review.

The identification and scanning of articles in the designated three databases for the studies addressed were conducted using the PRISMA (2020) methodology for suitability criteria. The research process flowchart according to PRISMA (2020) is shown in Figure 1.

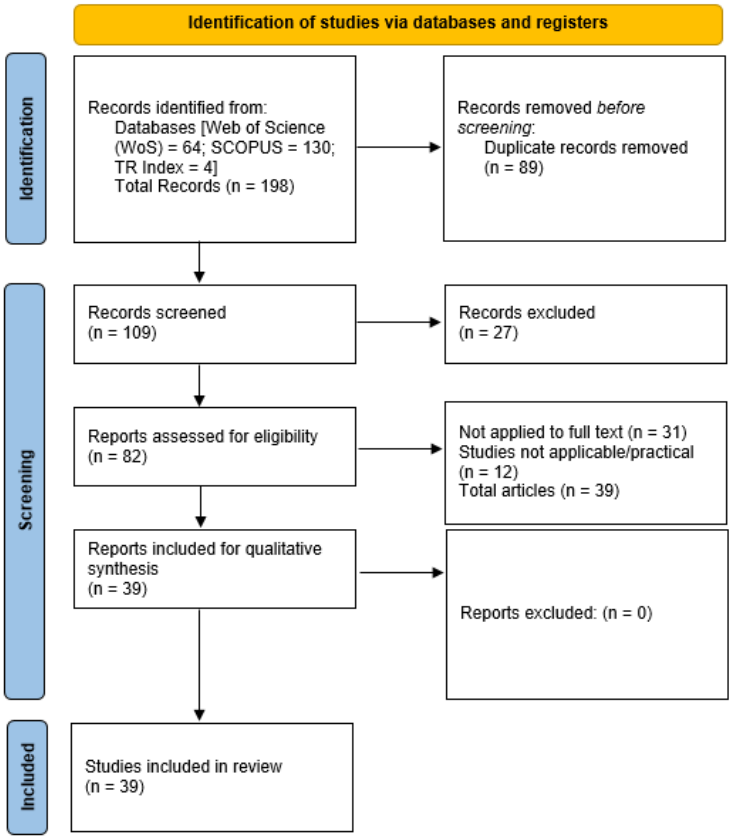

Figure 1. PRISMA (2020) Flow Diagram

As shown in Figure 1., between January 2010 and December 2022, a total of 198 studies were identified using the determined keywords/keyword groups in databases such as Web of Science (WoS) (n=64), Scopus (n=130), and TR Index (n=4). The identified articles were transferred to an Excel file, and duplicates were checked. After removing duplicates, 109 articles remained for which the titles and abstracts were examined. The titles and abstracts of the articles were read by two researchers. After reading the titles and abstracts of the 109 articles, criteria were established to determine the planning, execution, and reporting stages in the analysis review of gamification, using the method developed by Kitchenham (2004). Considering the characteristics of gamification mentioned by Kitchenham (2004), a framework was determined for the progress of research on the subject of gamification. Accordingly, 27 records that were included in the search results but did not contain the determined keywords/keyword groups in their titles and abstracts were excluded. Only those studies that dealt with gamification in biology education in their titles and abstracts were included. Thus, a total of 82 records remained for full-text reading. Out of these 82 records, 31 were excluded from the review because the full texts could not be accessed. After reading the full texts of the remaining 51 articles, 12 were excluded from the study because they were not practical/empirical. A total of 39 articles were reached for the scope of the research. The characteristics of the studies identified through databases and registers (author, main theme or objective, sample, implementation time/duration, and main findings) are provided in Appendix 1.

Data Analysis

In the analysis of the articles considered according to the determined criteria in the study, descriptive analysis was utilized. Accordingly, the coding in the descriptive analysis benefited from the theoretical framework in the relevant literature (Miles & Huberman, 2015). Accordingly, the codes were compared based on their similarities and differences to create descriptive themes in a hierarchical tree structure. Each group formed is named as a theme. Each theme is created to encompass the definitions and meanings of the grouped codes. Additionally, alongside the themes created by utilizing the theoretical framework in the relevant literature in the context of the questions addressed in the research, new interpretative structures and explanations have also been produced (Thomas & Hardene, 2008). Accordingly, analytical themes were formed using the descriptive themes obtained as a result of inductive analysis.

RESULTS

The findings from the analysis of data obtained from the research were examined according to the descriptive characteristics (such as purpose, sample size) of the articles reviewed and the sub-questions of the research.

Descriptive Characteristics of the Reviewed Articles

Within the scope of the research's aim, articles obtained from journals indexed in WoS, SCOPUS, and TR Index databases were examined based on their descriptive characteristics using different combinations of the words/word groups "biology", "biology learning", "biology teaching", "game", "gamification", "game-based learning". The descriptive characteristics utilized in the examination of the articles include publication year,

research topics, sample/study group, sample size, levels of education, the interaction dynamics of technological tools used in gamification, research method, and main findings.

Publication year

The distribution of the publication years of the articles reviewed within the scope of the research is presented in Figure 2.

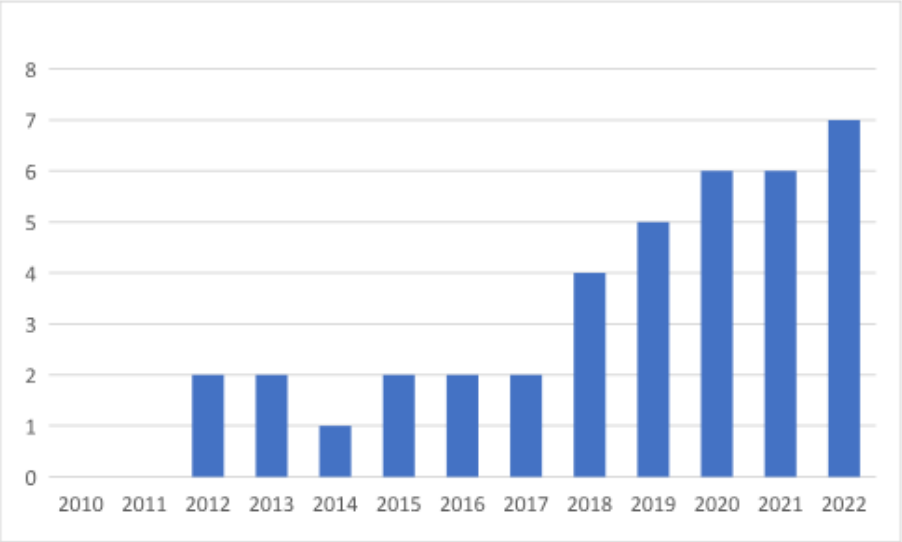

Figure 2. Distribution of Articles by Year

Of the 39 articles reviewed, 2 were published in 2013, 1 in 2014, 2 in 2015, 2 in 2016, 2 in 2017, 4 in 2018, 5 in 2019, 6 in 2020, 6 in 2021, and 7 in 2022. It is observed that there is a significant increase in the number of articles reviewed, especially between the years 2018-2022.

Research topics

The distribution of the articles reviewed within the scope of the research according to biology teaching topics is presented in Table 1.

Table 1. Distribution of Articles by Research Topics

Biology Topics	Educational Game Themes	Key Research Points	n	Percentage (%)
Genetics	Structure and functions of DNA	DNA replication, protein synthesis	10	20%
	Genetic mutations and evolution	Natural selection, theories of evolution	8	16%
	Genetic diseases and treatments	Genetic treatments, genetic counseling	7	14%
Cell Biology	Cell structure and functions	Organelles, cell membrane	9	18%
	Cell division and reproduction	Mitosis, meiosis, reproduction strategies	6	12%
	Cell energy and metabolism	Photosynthesis, respiration, energy transformation	5	10%
Ecology	Population dynamics	Population growth, interspecies interaction	8	16%
	Climate change and ecosystems	Global warming, carbon footprint, habitat loss	7	14%

	Endangered species and conservation	Conservation biology, species restoration	5	10%
Anatomy and Physiology	Organs and systems of the human body	Organ systems, anatomical structures	10	20%
	Respiratory and circulatory system	Blood flow, oxygen transport, gas exchange	8	16%
	Nervous system and brain functions	Neurology, brain regions, brain plasticity	7	14%
Botany	Plant structure and functions	Photosynthesis, cell wall, plant growth	8	16%
	Plant reproduction and genetics	Pollen transport, seed dispersal, plant genetics	7	14%
	Plant and environmental interactions	Ecosystem services, plant-environment interactions	5	10%
Microbiology	Microorganisms and diseases	Pathogens, disease spread	9	18%
	Antibiotic resistance and new treatments	Resistance mechanisms, new antibiotics	7	14%
	Structure and functions of bacteria and viruses	Viral replication, bacterial structure	4	8%
Total			123	100%

The examined articles are observed to be oriented towards various subjects of biology education. The predominant topics can be classified as genetics, cell biology, ecology, anatomy and physiology, botany, and microbiology. These subjects are further divided into specific subtopics such as genetic variation and evolution, the structure and functions of DNA, genetic diseases and treatments, the structure and functions of cells, cell division and reproduction, cell energy and metabolism, population dynamics, climate change and ecosystems, endangered species and conservation, the organs and systems of the human body, respiratory and circulatory system, nervous system and brain functions, the structure and functions of plants, plant reproduction and genetics, plant and environmental interaction, microorganisms and diseases, antibiotic resistance and new treatments, and lastly, the structure and functions of bacteria and viruses.

The topic of genetics covers themes such as genetic variation and evolution, the structure and functions of DNA, and genetic diseases and treatments, with each of these subjects being examined at rates of 20.5%, 16.3%, and 14.3%, respectively. In addition, subtopics such as the structure and functions of cells, cell division and reproduction, and cell energy and metabolism are grouped under the title of cell biology. These subjects have been studied at rates of 18.4%, 12.2%, and 10.2%, respectively. Subtopics like population dynamics, climate change and ecosystems, and endangered species and conservation are categorized under the ecology topic. These titles have been examined at rates of 16.3%, 14.3%, and 10.2%, respectively. The topic of anatomy and physiology includes subtopics like the organs and systems of the human body, the respiratory and circulatory system, and the nervous system and brain functions. These subjects have been studied at rates of 20.5%, 16.3%, and 14.3%, respectively. The botany topic contains subtopics such as the structure and functions of plants, plant reproduction and genetics, and plant and environmental interaction. These subjects have been examined at rates of 16.3%, 14.3%, and 10.2%, respectively. Lastly, subtopics like microorganisms and diseases, antibiotic resistance and new treatments, and the structure and functions of bacteria and viruses fall under the microbiology title. Each of these topics has been studied at rates of 18.4%, 14.3%, and 8.2%, respectively.

Accordingly, it is observed that articles focusing on various subjects of biology education predominantly concentrate on topics such as genetics, cell biology, and anatomy and physiology (Table 2).

Sample/study group

To facilitate the categorization of the reviewed studies according to their sample/study group distribution, the following target groups have been considered: children (ages 0-12); adolescents (ages 13-17); and adults (ages 18 and above) (Samson et al., 2021). Depending on the selected age group, there has been a diversity ranging from studies with a specific target age group of 11-12 years to those encompassing a broader age range of 24-40 years (Buaraphan et al., 2020; Skukan et al., 2020). According to Figure 5, research conducted on children represents a total of 24%, highlighting the extent of children's exposure to gamification technologies in biology education and the importance of the impact of these studies on children. The proportion of studies conducted on adolescents is determined to be 21%. This rate, similar to that of children, investigates the interest of young individuals in gamification methods in biology education and the contribution of these methods to the learning process of adolescents. Research on adult samples holds the highest value at 32%, indicating that gamification technologies are not only effective teaching methods for younger age groups but also for adults in biology education. The proportion of studies conducted jointly on children and adolescents is 10%. This represents studies that consider both age groups together and compare the effects of gamification techniques on these groups. Finally, the proportion of studies that involve both adolescents and adults is 13%. This rate reflects research examining the effect of gamification techniques between young and adult individuals, thereby highlighting a trend towards understanding the effectiveness of gamification technologies in biology education across different age groups. Especially, the high proportion of research on adults demonstrates that gamification is not only for younger age groups but can be an effective tool throughout the lifelong learning process.

Sample size

The distribution of the reviewed articles according to their sample sizes shows that studies with 1-100 participants constitute approximately 48.72%, representing the highest ratio. This ratio indicates that nearly half of the reviewed articles fall into this category. Studies within the 101-200 participant range represent about 10.26% of the overall distribution, suggesting that relatively fewer studies have this sample size. Studies with 201-300, 301-400, and over 400 participants make up a total of 5.13% of the distribution, indicating that studies with these participant numbers are rarer. In 25.64% of the studies, the sample size is not specified.

Education levels

When examining the distribution of the articles within the scope of the research according to their education levels, it is observed that there are no articles at the preschool level (0%). This indicates that sufficient research has not yet been conducted on gamification at the preschool level. The number of articles addressing gamification at the primary education level is 6, constituting 15.38% of the total articles. The number of articles

dealing with gamification at the high school level has been identified as 10 (25.64%). The majority of the reviewed articles, i.e., 61.53% (n=24), focus on learning processes at the university level. This situation indicates that gamification is extensively addressed and researched at the university level. According to the findings, it is evident that gamification in biology education is particularly concentrated at the university level and applied less in other educational levels. The absence of articles on gamification at the preschool level may indicate potential research gaps in this area.

The interaction dynamics of technology tools used in gamification

The findings related to the interaction dynamics of technology tools utilized for teaching biology, as examined in the articles within the scope of the research, are presented in Table 2.

Table 2. Distribution of Technology Tools Used in Gamification by Interaction Dynamics

Interaction Dynamics of Technology Tools Used in Gamification	n	Percentage (%)
Collaborative	6	15.4
Non-interactive	1	2.5
Not Specified	2	5.1
Competitive	24	61.5
Collaborative and Competitive	6	15.4
Total	39	100

According to Table 2., the interaction dynamics of technology tools used for biology teaching in the articles examined within the scope of the research are classified into five different categories based on the interaction dynamics used in gamification: "collaborative," "non-interactive," "unspecified," "competitive," and "both collaborative and competitive." The category with the highest frequency is "competitive," with 61.5%. The "collaborative" and "both collaborative and competitive" categories are in second place with 15.4%, while the "non-interactive" category is the least used dynamic with 2.5%. The "unspecified" category has been determined as 5.1%.

Research method

Studies utilizing qualitative research methods represent the most used method with 56.4%, constituting 22 of the total studies. These studies contain detailed reports about the development and application contexts, objectives, results obtained, limitations, and perspectives of educational games. On the other hand, studies using quantitative research methods make up 17 of the total studies, having a rate of 43.8%. These studies are generally experimental studies conducted using control groups and sample randomization and whose results are of a generalizable nature.

Main findings

The main findings related to the articles examined within the scope of the research are presented in Table 3.

Table 3. Distribution According to Main Findings in the Articles

Biology Topics	Main Findings	n	Percentage (%)
Genetics	Research on the structure and functions of DNA has contributed to the understanding of DNA replication and protein synthesis processes.	10	25.6%
	Studies on gene mutations and evolution have facilitated deeper insights into natural selection and evolutionary theories.	8	20.5%
	Research in genetic diseases and treatments has contributed to the development of genetic therapies and genetic counseling.	7	17.9%
Cell Biology	Studies on cell structure and functions have provided important information about the functions of organelles and the cell membrane.	9	23.1%
	Research on cell division and reproduction has aided in understanding processes like mitosis, meiosis, and reproductive strategies.	6	15.4%
	Studies related to cell energy and metabolism have contributed to the understanding of fundamental processes such as photosynthesis, respiration, and energy conversion.	5	12.8%
Ecology	Studies on population dynamics have helped us understand the importance of population growth and interspecies interactions in ecosystems.	8	20.5%
	Research aiming to understand the relationship between climate change and ecosystems has covered topics like global warming, carbon footprint, and habitat loss.	7	17.9%
	Studies on endangered species and conservation have presented significant insights into conservation biology and species restoration.	5	12.8%
Anatomy and Physiology	Research on human body organs and systems has provided detailed information about organ systems and anatomical structures.	10	25.6%
	Studies on the respiratory and circulatory systems have illuminated basic physiological processes such as blood flow, oxygen transport, and gas exchange.	8	20.5%
	Research in the area of the nervous system and brain functions has offered significant findings on neurology, brain regions, and brain plasticity.	7	17.9%
Botany	Research on plant structure and functions has contributed to our understanding of basic processes like photosynthesis, cell wall, and plant growth.	8	20.5%
	Studies on plant reproduction and genetics have provided in-depth knowledge on pollen transport, seed dispersal, and plant genetics.	7	17.9%
	Research investigating plant and environmental interactions has presented significant findings on ecosystem services and plant-environment interactions.	5	12.8%
Microbiology	Studies on microorganisms and diseases have contributed to understanding pathogens and the spread of diseases.	9	23.1%
	Research on antibiotic resistance and new treatments has addressed resistance mechanisms and the development of new antibiotics.	7	17.9%
	Studies on the structure and functions of bacteria and viruses have aided in understanding viral replication and bacterial structure.	4	10.3%
	Total	39	100%

According to Table 3, the distribution of the main findings from the articles reviewed within the scope of the research demonstrates that studies in the field of biology have focused on various subjects. The highest proportion (25.6%) of research is found in genetics. These studies have contributed to understanding the structure and functions of DNA, processes of DNA replication and protein synthesis, and have facilitated deeper insights into genetic mutations and theories of evolution. Additionally, research in genetic diseases and treatments holds a significant share (17.9%). Studies in cell biology, making up 23.1% of the total articles, have provided critical information about cell structure and functions, organelles, and the cell membrane. Research on cell division and reproduction (15.4%) and cell energy and metabolism (12.8%) are other vital elements in this field. Research in ecology accounts for 20.5% of the total, emphasizing the significance of population dynamics, population growth, and interspecies interactions in ecosystems. Studies aimed at understanding the relationship between climate change and ecosystems (17.9%) and research on endangered species and conservation (12.8%) also hold a crucial place in the ecology field. Anatomy and Physiology research has the

highest rate at 25.6%, offering detailed information on the organs and systems of the human body. Studies on the respiratory and circulatory system (20.5%) and the nervous system and brain functions (17.9%) represent significant contributions in this area. Botanical research comprises 20.5% of the total articles, with studies on plant structure and functions providing essential insights. Research on plant reproduction and genetics (17.9%) and plant-environment interactions (12.8%) reflect significant work in this field. Lastly, microbiology research has a slightly higher proportion (23.1%) compared to other topics. These studies represent research on microorganisms and diseases, while research on antibiotic resistance and new treatments (17.9%) and the structure and functions of bacteria and viruses (10.3%) also occupy an important share.

Examination of Related Research According to Sub-research Questions

Below is the examination of the sub-research questions of the studies addressed, concerning the outcomes of gamification in biology education.

The effect of gamification on students' learning efficiency

The findings related to the impact of gamification used in biology education on students' learning activity, as discussed in the reviewed articles, are categorized into cognitive skills, personality and psychological skills, and social skills and engagement learning areas. Cognitive skills encompass 61.54% of the total number of articles reviewed. This percentage highlights the potential impact of gamification techniques on enhancing cognitive abilities such as thinking and problem-solving in students. On the basis of personality and psychological skills, 15 articles discuss the positive effects of gamification on students' personality development and motivation, constituting 38.46% of all articles. These findings suggest that gamification can be an effective strategy for improving students' personality and psychological skills. Regarding social skills and engagement, there are 22 articles indicating that gamification enhances social skills and participation in activities, accounting for 56.41% of the total articles. These results demonstrate that gamification can support the development of social skills and encourage participation in group activities. Overall, the findings from the 39 articles reviewed reveal that gamification plays a significant role in enhancing students' cognitive, personality, and psychological skills, as well as their social skills and participation in activities. These findings support the use of gamification as a comprehensive tool in the learning and teaching process.

Trends and tools used in gamification

The findings related to the trends and tools used in gamification in the scope of the research are presented in Table 4.

Table 4. Trends and Tools Used in Gamification in the Articles

Learning Tools	n	Percentage (%)
Individually Tailored	20	51.28
E-Learning Platforms	7	17.94
Platforms	6	15.38
Badges	2	5.12
Kahoot	3	7.69
Puzzles	1	2.56
Total	39	100

According to Table 10, the most prominent trend regarding the gamification tools used in the reviewed articles is the high proportion of individually tailored gamification tools. These 20 articles, constituting 51.28% of the reviewed articles, indicate the potential of gamification to make education more effective and meaningful by considering students' personal needs and individual differences. Additionally, 7 articles focusing on e-learning platforms, highlighting the importance of digital technologies in education, represent 17.94% of the reviewed articles. This signifies the universality of education in the digital age and the increasing opportunities for interactive learning. Six articles focusing on gamification platforms, representing 15.38% of all articles, typically analyze the features, applicability, and gamification potential of a platform, emphasizing the need to understand how different platforms can be used for gamification in education. On the other hand, studies on more specific gamification tools such as badges and Kahoot are fewer. However, the 2 articles on badges (5.12%) and 3 on Kahoot (7.69%) highlight the potential of such tools to increase student motivation and make the learning process more enjoyable and engaging. A single article focusing on puzzles (2.56%) may suggest that more research and attention are needed to understand the role of puzzles in enhancing problem-solving and analytical thinking skills.

Skills used in gamification

The skills used in gamification within the scope of biology education in the examined articles are discussed in Table 5.

Table 5. Skills Used in Gamification in the Articles

Skills	Number	Percentage (%)
Learning Skills	21	53.84
Cognitive Skills	5	12.82
Social Skills	9	23.07
Personal-Psychological Skills	4	10.25
Total	39	100

According to Table 5., the findings regarding the skills used in gamification within the scope of biology education in the examined articles indicate that 9 articles (53.84%) emphasize learning skills, focusing on helping students better understand the subject matter and quickly grasp concepts. This suggests that gamification generally contributes significantly to the process of internalizing knowledge and concepts. The development of social skills is addressed in 9 articles (23.07%), demonstrating how gamification supports students' ability to interact and collaborate. In a section representing 12.82% of the articles, where cognitive skills are supported by gamification, the potential of gamification to enhance students' problem-solving, critical thinking, and analytical skills is highlighted. Finally, 4 articles (10.25%) examine the impact of gamification on personal-psychological skills, with a focus on areas such as motivation, self-confidence, and self-regulation. The findings suggest that gamification can play an important role in enhancing various skills in biology education, with each skill area serving as an indicator of the comprehensive applicability and impact of gamification in education.

Advantages of using gamification

Based on the distribution of findings regarding the advantages of using gamification in biology education in the examined articles, the highest percentage advantage is seen in increasing learning activities (25.64%). Effectively integrating gamification into learning processes can help students better understand biology topics and learn the material more permanently. Another significant advantage is increasing motivational outcomes (20.51%). Gamification can keep students engaged in biology lessons, making them more willing to participate in learning. Additionally, there are significant contributions such as promoting positive attitudes (17.95%) and increasing participation (15.38%). Encouraging students' positive attitudes towards biology classes can lead to more active participation in lessons. Other advantages such as improving learning success (15.38%) and enhancing thinking skills and problem-solving ability (12.82%) also demonstrate the positive effects of gamification on biology education. In conclusion, gamification offers many advantages in biology education. Gamification can provide a more effective learning experience in biology classes and increase students' participation, motivation, and success. Further academic research in this direction could support the more widespread use of gamification in biology education.

Disadvantages and challenges of using gamification in biology education

The most common disadvantage encountered in the implementation of gamification in biology education, with a percentage of 25.64%, is concerns about short-term effects and time usage. Expectations of achieving rapid results with gamification may lead students to deviate from long-term learning goals. The second significant challenge is technical issues, representing a percentage of 20.51%. Technical barriers such as students' internet speed, computer equipment, and deficiencies in game designs can hinder the efficient implementation and negatively impact gamification. Additionally, problems with task evaluation and system design (15.38%) may lead to difficulties in measuring students' actual learning levels. Furthermore, the lack of students' preparation level and technological skills (12.82%) is another factor affecting the success of gamification processes. The insufficient experiences of educators and students with gamification (10.26%) may also hinder the effective use of this educational method. Similarly, the inadequate consideration of cognitive, social, and personal skills (7.69%) may prevent students from fully utilizing their potential. However, based on these results, it can be said that more research is needed to evaluate the potential advantages and challenges of using gamification in biology education. Such research could comprehensively assess the impact of gamification on student achievement, motivation, and learning experience and compare the effectiveness of different gamification strategies (Hamari, Koivisto, & Sarsa, 2014; Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013).

DISCUSSION and CONCLUSION

The purpose of this study is to examine the effectiveness of gamification method in biology education through a systematic review. A total of 39 articles from journals indexed in WoS, SCOPUS, and TR Index databases were examined using different combinations of the keywords "biology," "biology learning," "biology teaching," "game," "gamification," and "game-based learning." The study aimed to identify the descriptive characteristics

of the examined articles and to reveal the effects of gamification applications in biology education, as well as the commonly used trends in these applications. Additionally, it examined the skills focused on by gamification in biology education and its impact on student achievement, as well as addressing the advantages, disadvantages, and challenges encountered.

Based on the descriptive characteristics of the gamification studies, there has been a significant increase, particularly between 2018 and 2022. It was determined that the articles primarily focused on genetics, cell biology, ecology, anatomy and physiology, botany, and microbiology. Among these topics, genetics, cell biology, and anatomy and physiology have a significant share. Most of the research focused on learning processes at the university level. Gamification, leveraging the psychological advantages of games, has been used in various fields such as human resources, health, social communities, research, commerce, and education to increase engagement, motivation, and induce behavioral changes. Despite being used for a long time to enhance user experience and regulate the routine functioning of social life and schools, the recent emergence of gamification can be attributed to the development and widespread use of online environments and mobile devices. Successful applications in digital and mobile environments have prompted a desire to leverage the contributions of gamification pedagogically.

Gamification is mainly concentrated on increasing engagement and motivation in learning environments to address participation and motivation issues. It aims to increase the time spent by learners in online learning environments, the number of visits, content reviews, and contributions. Gamification offers an opportunity to transform learning environments perceived as dull or challenging into engaging ones, thereby potentially changing learners' perspectives on learning. It has been observed that learners participating in gamified environments engage in more challenging tasks, spend more time in the environment, and demonstrate successful learning outcomes. Moreover, by making learning environments more enjoyable, gamification can change learners' attitudes towards learning. While gamification studies in the literature have primarily focused on engagement and motivation and have been found to be effective in learning processes, the impact on learning environments and learners has not been clearly established yet. This is mainly due to gamification being a relatively new approach that became feasible only in 2014, despite its wide application scope. Its rapid development has not received sufficient support from experimental research due to the lack of studies investigating the effectiveness of gamification integrated into online learning environments. Despite its theoretical foundation being based on motivation, the number of studies demonstrating the effects of intrinsic and extrinsic motivational mechanisms in gamified systems is quite limited. Furthermore, the integration of motivation principles with gamification applications and the effects of gamification on individuals with different motivation levels have not yet been fully understood. Studies on gamification have generally focused on examining the effects of multiple elements, and the connection between each element and motivation and performance outcomes has not been clearly established. While there is a trend towards designs that prioritize the target audience in recent gamification applications, little is known about the impact of designs tailored to different user types. Experimental studies by Dominguez et al. (2013) and Hanus and Fox (2015) have shown a decrease in the effectiveness of gamification over time, but its short, medium, and long-term effects are still

not well understood. Behaviors starting with a small user group can evolve over time to meet a general need and become widespread, provided they satisfy a general requirement. Despite initially being seen and performed by very few people, new behaviors can open the door to creating new habits in the future.

Competitive interaction dynamics have been identified as the most commonly used dynamic in gamification. Other dynamics include "collaborative," "both collaborative and competitive," "unspecified," and "non-interactive."

Gamification in biology education has positive effects on students' learning effectiveness. The findings indicate that gamification is effective in enhancing students' cognitive, personality, and psychological skills, as well as increasing their social skills and participation.

It is noteworthy that gamification tools are created according to individual characteristics. The importance of digital technologies in education is emphasized in studies conducted on e-learning platforms.

Among the advantages of gamification in biology education are increasing learning activities, enhancing motivation, promoting positive attitudes, and increasing participation. However, disadvantages encountered in gamification applications are also noteworthy. Short-term effects, concerns about time usage, and technical issues are significant challenges. Additionally, students' lack of preparedness and technological skills are factors that affect the effectiveness of gamification.

In conclusion, gamification plays a significant role in increasing student participation, motivation, and learning effectiveness in biology education. However, considering the challenges and shortcomings in the implementation processes, educators and researchers need to conduct further studies to use gamification methods more effectively. Progress in this field will facilitate the more widespread use of gamification in biology education and enhance students' learning experiences. Finally, content and material deficiencies in gamification may not adequately cover the fundamental topics of biology courses, potentially resulting in students receiving incomplete education. In summary, it is a fact that there are various challenges and disadvantages in the implementation of gamification in biology education. To overcome these challenges, it is important for educators to identify these challenges and develop various strategies to integrate gamification more effectively. The articles reviewed highlight student achievement and student motivation as prominent results regarding the effectiveness of gamification used in biology education. It is observed that gamification increases students' academic achievements and encourages their participation in learning processes. Additionally, it has been noted that gamification increases students' interest in the course and their participation in course materials. By providing students with a fun and interactive learning experience, gamification can help make course content perceived as boring or challenging more appealing. Moreover, by increasing student participation through gamification, it can contribute to active participation in the course. It is indicated that students' participation in more difficult tasks, increased duration in the environment, and successful learning outcomes are observed in gamified environments. Furthermore, by making learning environments enjoyable, gamification can play an important role in changing students' perspectives on

learning. It is stated that gamification enhances students' collaboration and communication skills and increases social interaction. This also indicates that gamification can be a tool to strengthen students' social skills. Collaborative projects and interactive games where students work together and share knowledge can increase social interaction and improve students' collaboration skills. It has been observed that gamification increases student feedback and participation in course materials. Students' increased interest in gamified course materials and interactive feedback can enhance student learning and improve student-teacher interaction. Gamification can be an effective tool in providing feedback to students. These results indicate that gamification is one of the effective strategies in biology education and can play an important role in increasing student achievement and motivation. Based on the reviewed articles, it is concluded that gamification in biology education has potential shortcomings in terms of the distribution of findings related to its potential shortcomings. The most common deficiency is seen as gamification being disconnected from real-life contexts. Gamified educational applications often lack real-life situations, which can hinder the transfer of knowledge and skills gained through these applications to real-life contexts. Another drawback is the potential for technical problems. Technical problems such as server crashes, application malfunctions, and slow internet connection can disrupt the gamified learning process. Additionally, the lack of technical infrastructure in educational institutions can be a challenge for the implementation of gamified educational applications. The issue of content and material deficiencies is also among the drawbacks of gamification. It is stated that gamified educational applications may not adequately cover the fundamental topics of courses, which can lead to incomplete education. This indicates that gamified educational applications may not provide students with comprehensive knowledge and skills. Finally, the potential for addiction is also mentioned as a drawback of gamification. Gamified educational applications can be addictive, which can lead to negative consequences such as decreased academic performance and increased health problems. Overall, while gamification in biology education has many advantages, it is also important to consider potential shortcomings and challenges in its implementation.

RECOMMENDATION

Based on the results of this study, here are some recommendations for the use of gamification in biology education:

- **Gamification of instructional materials:** Gamifying instructional materials for biology classes can be an effective method to capture students' interest and increase their engagement. Presenting biology topics to students through games, interactive simulations, or digital applications can make the learning experience more enjoyable and help students deepen their understanding and develop their skills.

- **Content and design diversity:** It is important for the games used in biology classes to be diverse and suitable for different learning styles and skill levels. Different types of games can include visual, auditory, and tactile elements, providing students with opportunities to develop skills such as problem-solving, analytical thinking, and collaboration. Adjustable difficulty levels in games will allow students to adapt to their own learning pace.

- **Feedback mechanisms:** Using feedback mechanisms in gamified biology classes can help students assess and improve their performance. Games can provide instant feedback with correct and incorrect answers, helping students understand their mistakes and make corrections. Additionally, integrating elements such as progress tracking and reward systems into games can motivate students.

- **Collaborative learning opportunities:** Biology games can include elements that encourage collaboration and teamwork among students. Activities such as solving problems together, sharing knowledge, and improving communication skills can be facilitated. Activities like group projects, competitions, or virtual laboratory experiments can contribute to the creation of collaborative learning environments.

- **Increasing student motivation:** In gamified biology classes, motivation tools such as reward systems, scoring systems, or leaderboards can be used to increase student motivation. Encouraging students to track their achievements, strive to reach goals, and compete can be effective. Additionally, designing games to align with students' interests and daily lives is important for increasing motivation.

- **Evaluation of long-term effects:** Further research is needed to evaluate the long-term effects of gamification in biology education. These studies should be designed to demonstrate whether gamification methods are effective in sustainably improving students' biology knowledge, long-term learning outcomes, and skill acquisition.

Ethics Statement

This article adheres to the journal's writing standards, publication principles, research and publication ethics rules, and journal ethical guidelines. The author is responsible for any and all violations related to the article. "The ethical approval for the article was obtained with decision no. E.586752 by the Gazi University Ethics Committee on 13.02.2023."

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APPENDIX

Appendix 1. Characteristics of Articles

Author	Main Theme or Purpose	Age	Group/Size	Time/Duration	Main Outcome
Wanyama vd. (2012)	Evaluation of an educational game developed to increase knowledge levels about HIV and sexually transmitted infections.	>18	180	45 minutes	It was determined that the knowledge level of participants in the game group was 3.2 points higher than that of the control group, with a statistically significant difference observed ($p<0.001$). Additionally, participants and trainers have reported that the educational game was more effective than health lectures.
Karbownik vd. (2016)	Evaluation of an educational game developed to teach the pharmacology of antimicrobial drugs.	22-24	124	70 minutes	The participants' knowledge levels on the subject after the application were found to be high (ANOVA, $p = 0.035$). A retention test conducted 14 days post-application showed a significant increase in retained knowledge (ANOVA, $p = 0.007$).
Coil, Ettinger ve Eisen (2017)	Development and evaluation of an entertaining educational game about beneficial microorganisms.	14 ≈ 20	No information provided.	1 year	The developed educational game has been described as an impactful educational model for biology learning. Participants have evaluated the game about honey bees as a fun and effective educational model.
Lauren (2016)	Development and evaluation of an educational game for raising awareness about honeybees.	14-18	54	1 term/session duration: No information provided	Participants have rated the game about honey bees as a fun and effective educational model. Furthermore, it has been found that the game is effective in relating basic concepts of biology to everyday life.
GarcíaBarrios, Perfecto ve Vandermeer (2016)	An educational board game has been developed to assess the effectiveness of shade coffee cultivation methods (a farming method where coffee plants are grown under tree shades to protect them from sunlight. In this method, coffee plants are cultivated under natural tree shades or artificially created shades to protect them from the harmful effects of the sun). This game aims to teach students the methods and benefits used in shade coffee farming.	14-18	42	1 year/session duration: No information provided	It has been determined that the success average of the post-test conducted after the application has significantly increased compared to the pre-test. Accordingly, the educational game has been proven to be an effective tool for understanding and learning the shade coffee farming method. In summary, the game has been observed to increase participants' knowledge level regarding the shade coffee farming method and to positively contribute to the learning process.
Bassey ve diğerleri (2020)	Evaluation of the effectiveness of an educational game developed to increase knowledge, attitudes, and practices towards soil-transmitted helminthiasis, a group of infections caused by intestinal parasites.	5-15	372	1 month/session duration: No information provided	The research findings indicate that in the experimental group, the prevalence of infection decreased from 25.0% to 10.4% three months after the intervention, as measured by a retention test, while in the control group, it decreased from 49.4% to 33.3%. In a retention test conducted six months later, the infection prevalence further dropped to 5.6% in the experimental group, whereas it increased to 37.2% in the control group. Additionally, a statistically significant difference was found in the spread of

					infection post-intervention between the experimental group and the control group ($p < 0.05$). It was also determined that knowledge, attitudes, and practices regarding infection transmission, control, and prevention in the participants of the experimental group significantly improved in a positive direction ($p < 0.05$).
Sen ve diğerleri (2018)	Evaluation of the effectiveness of the Kaledo educational game in family-involved group therapy for childhood obesity.	9-12	24	6 hours	
Viggiano ve diğerleri (2015)	Evaluation of the effectiveness of an educational game developed to promote nutrition education and improve dietary habits using the Adolescent Food Habits Checklist (AFHC).	9-19	3,110	20 weeks/session duration: No information provided	Following the intervention, both the experimental and control groups observed a significant reduction in body mass index (BMI) and BMI z-scores compared to baseline measurements. In the control group, the change in BMI was -1.01 (from 25.44 to 24.43, $p = 0.03$), and the change in BMI z-score was -0.17 (from 2.07 to 1.90, $p = 0.000$). In the experimental group, the change in BMI was -0.74 (from 26.98 to 26.24, $p = 0.007$), and the change in BMI z-score was -0.09 (from 2.07 to 1.98, $p = 0.003$). However, no significant difference was found between the control and experimental groups in terms of BMI and BMI z-scores ($p = 0.130$ and $p = 0.706$, respectively).
Struwig ve Beylefeld (2014)	Development and evaluation of an educational game aimed at increasing participants' knowledge level in medical microbiology.	>18	No information provided.	1 hour/ 5 sessions	The results obtained indicate that the implementation of the educational game, involving active participation from the participants, yielded positive feedback. Additionally, it has been determined that integrating this application into educational programs enhances participants' learning experiences in medical microbiology topics.
Ferreira da Silva, da Silva Costa, Castro (2017)	Development and evaluation of an educational game aimed at increasing knowledge levels about taste physiology.	14-18	No information provided.	No information provided.	The evaluation conducted within the scope of the application suggests that the game will provide educators with the opportunity to explore the taste perception process and the transformation of tastes into nerve impulses in an enjoyable and holistic manner. Through this approach, an increase in participants' knowledge about taste physiology is anticipated. With this game, teachers can interact with students in a comprehensive manner by playing through the taste perception process, adhering to the rules of the game, and explaining how tastes are perceived and transformed into nerve impulses.
Cavalho, Beltramini ve Bossolan, (2018)	Development and evaluation of an educational game on protein synthesis based on Vygotsky's socio-constructivist theory.	14-18	15	No information provided.	According to the research findings, the application has been found to assist participants in better understanding and grasping the process of protein synthesis. Furthermore, it has been determined that the interactions conducted by the participants, in accordance with the rules of the game, were effective in concretizing the

					process of protein synthesis.
Argo (2018)	Development and evaluation of an educational game aimed at increasing knowledge about the climate-related challenges faced by migratory birds.	8-12	No information provided.	15 minutes	According to the research results, it has been determined that the application offers an interactive approach in learning how different bird species adapt to environmental changes. The application has been found to be effective in the process of acquiring knowledge on migratory birds and climate-related issues. Additionally, it has been observed to contribute to participants' ability to recognize migratory birds they may encounter in their immediate surroundings.
Chaves ve diğerleri (2020)	Investigating the effectiveness of using an educational game to better handle the design of mycorrhizal-friendly farming systems (agricultural practices that encourage and support a symbiotic relationship between plant roots and specific fungi called mycorrhiza) and contribute to agroecological approaches.	>18	50	Two half-day workshops	The results have shown that the game helps farmers to better understand how they can relate agricultural practices to mycorrhizal relationships and facilitates communication on agroecological issues. Additionally, the application aids farmers in connecting different agroecological networks and coordinating activities in this area. This study demonstrates that the game can be used as an effective methodological tool in the design of mycorrhiza-friendly farming systems and the transition to agroecological approaches, potentially increasing farmers' awareness in this field.
Holzmann ve diğerleri (2019)	Evaluation of the short-term effectiveness of an educational game designed to convey nutrition knowledge.	12-14	76	Three 15-minute sessions	According to the study results, a significant positive effect on nutritional knowledge was found in both the experimental and control groups ($p < 0.001$). Furthermore, when comparing the two groups, the increase in nutritional knowledge was higher in the experimental group than in the control group ($p = 0.01$). These results indicate that educational games are an effective method for transferring nutritional knowledge.
Wulanyani ve diğerleri (2019)	Evaluation of the effectiveness of an educational game aimed at increasing knowledge levels about taeniasis (tapeworm infection).	9-12	78	30 minutes	Before the implementation, the correct response rate of the participants to questions about infection was 40.3% in the pre-test. After the application, this rate was determined to be 58.8%. Consequently, the educational application developed was effective in increasing participants' knowledge level on taeniasis and had positive effects especially in increasing knowledge about transmission routes and types of infection.
McOwat (2018)	Evaluation of the effectiveness of Blast-a-Biofilm, an educational game on bacteria and biofilm formation.	8-12	No information provided.	No information provided.	According to the research findings, it has been determined that the topics of bacteria and biofilm formation arouse interest and curiosity in children.
Amelia ve Setiawan (2019)	Evaluation of the effectiveness of an educational game developed to increase	10-12	92	Two 40-minute sessions	According to the research results, statistically significant differences were found in the experimental group compared to

	knowledge levels about dengue fever, a disease caused by mosquitoes.				the control group regarding dengue fever symptoms and manifestations (p = 0.001), prevention strategies based on the guidelines of the Indonesian Ministry of Health (p = 0.001), chemical agents (p = 0.000), biological agents (p = 0.000), personal protection (p = 0.001), and immune system (p = 0.001). There was also a statistically significant difference in the level of knowledge between the experimental and control groups (p = 0.000). Based on these results, it has been determined that the method employed effectively increases children's knowledge level regarding the prevention of dengue fever.
Leelapreechalert ve diğerleri (2017)	Evaluation of the effectiveness of an educational game developed to increase knowledge levels about Type 1 diabetes.	8-25	107	30 minutes	The educational game's clinical utility assessment scores, evaluated by three different groups comprising patients, observers, and doctors, were determined to be 83%, 93%, and 100% respectively. These results indicate that the educational game can be used to verify participants' knowledge of diabetes and their self-management skills before discharge from the hospital, contributing to increasing their knowledge level about diabetes. Additionally, it has been determined that the game may contribute to improving relationships between healthcare providers, patients, and families.
Júnior (2020)	Evaluation of the effectiveness of an educational game developed to increase knowledge in entomology.	>18	92	20 minutes	According to the research results, when comparing the pre- and post-application test scores (18.09 ± 0.67 and 20.11 ± 0.66 respectively), a significant increase in learning outcomes was observed (t = 8.72, df = 91, p < 0.001). Therefore, it can be said that the educational game is effective in increasing the level of knowledge about entomology.
Wibking (2020)	Evaluation of the effectiveness of an educational game developed to increase knowledge levels about respiratory physiology.	17-24	No information provided.	30 minutes	The pilot implementation of the study aimed at increasing the knowledge level about respiratory physiology among participants aged 17-24 has been found to have a positive effect. This was evidenced by the pre-test and post-test scores (18.09 ± 0.67 and 20.11 ± 0.66 respectively) showing a significant improvement (t = 8.72, df = 91, p < 0.001). Additionally, based on participants' feedback about the implementation, it can be said that it could serve as an effective learning tool for respiratory physiology.
Buaraphan ve diğerleri (2020)	Investigation of the effectiveness of an educational game developed to increase nutrition knowledge.	11-12	102	60-90 minutes	According to the research results, the game has shown a positive impact on increasing participants' knowledge levels about nutrition.
Barnes (2020)	Development, use, and evaluation of the effectiveness of an educational game on protein purification techniques for a postgraduate sample group in molecular biology education.	>18	192	2 hours	The application has been found effective in assessing students' knowledge levels on the subject. Additionally, it has been noted that the game is beneficial in presenting communication and experimental planning skills in an enjoyable manner.
Chaves ve diğerleri (2020)	This study investigates the effectiveness of an educational game developed to support	17-20	40	1 hour	According to the results obtained, it has been determined that the

	the teaching-learning process in synaptic transport physiology.				application of synaptic transmission physiology contributed to the participants' learning.
Chagas (2020)	Investigation of the effectiveness of an educational game developed to understand the neurophysiological processes of drug addiction using neurological bases.	>12	No information provided.	No information provided.	According to the results obtained, it has been determined that participants acquired knowledge about the effects of drugs on the physiological structure of the brain through the application designed to reflect the neurophysiological processes of drug addiction. Therefore, it can be said that the application is an effective tool for creating awareness and providing information about drug addiction.
Lobo ve Viana (2020)	Investigation of the effectiveness of an educational game developed for teaching evolutionary topics in biology education.	>18	4	1,5 hours	According to the results obtained, the developed educational game demonstrates significant potential in teaching abstract and complex concepts such as evolution. Therefore, it can be said that the application can be evaluated as an effective supplementary resource in the learning processes of participants regarding evolution.
Espinoza, Orvis ve Brophy (2020)	Investigating the effectiveness of an educational game and video content developed for teaching the electron transport chain (ETC) process in photosynthesis.	13-14	120	20-25 minute sessions	According to the results obtained, it has been determined that after participants watched the video and used the application, misconceptions regarding concepts such as absorption of sunlight by chlorophyll, production of oxygen, ATP, and NADPH, and electron flow during the electron transport chain were effectively corrected. Therefore, it has been indicated that educational videos and games may be effective in deepening participants' understanding of photosynthesis.
Cheng ve diğerleri (2019)	Evaluation of an educational game developed based on the Water Resource Adaptation (WRA) theme to increase participants' knowledge levels about adapting to water resources and help improve their skills related to water resources.	>18	21	4,5 hours	According to the results obtained, the developed educational game has been considered an effective tool for increasing participants' knowledge and awareness regarding adaptation to water resources. Additionally, participants' adoption of social and community benefit-oriented strategies indicates that the game significantly contributes to water resource adaptation education.
Tsai ve diğerleri (2019)	Evaluation of an educational game developed on the impacts of environmental conservation on social development, a socio-scientific issue.	15-16	38	200 minutes	According to the results obtained, positive feedback was noted during individual interviews conducted after the application. Additionally, it was determined that participants became aware of the importance of the relationship between humans and animals and environmental conservation through the developed educational game.
Illingworth ve Wake (2019)	Development and evaluation of an educational game aimed at increasing knowledge levels about global warming.	No information provided.	65	No information provided.	According to the results obtained, the developed game was evaluated by sending it to domain experts on global warming in three different countries for usability testing.
Harikiran (2017)	Design, development, and beta testing evaluation of a fun and educational game aimed at increasing knowledge and attitudes about oral health.	12-13	45	20-25 minutes	The results of the beta test of the developed game indicated that the effectiveness of the game was statistically significant. Statistically significant differences were observed in the average overall score, knowledge score, and attitude score of the

					participants before and after the application (previously 14.7, 2.91 and afterwards 18.6, 4.35; P = 0.003; previously 11.8, 2.73 and afterwards 14.76, 4.0; p = 0.000; previously 2.93, 1.09 and afterwards 3.84, 1.02; p = 0.000). The average effect size was found to be 0.5. Additionally, participants reported enjoying playing the game and learning new things about oral health. Therefore, it was concluded that the developed oral health game is an effective tool in increasing participants' knowledge and attitudes.
Dieser ve Bogner (2016)	Investigation of the cognitive knowledge success of an interactive environmental program conducted within a National Park.	9-11	289	No information provided.	According to the results obtained, participating students in the environmental program showed an increase in their cognitive knowledge levels, and the experimental group performed better than the control group. As a result, it was concluded that this interactive environmental program is effective in improving participants' cognitive knowledge achievement, with the experimental group demonstrating higher success compared to the control group.
Burleson ve Olimpo (2016)	Evaluation of the effectiveness of an educational game developed to understand key concepts in basic anatomy and physiology courses.	No information provided.	36	60-90 minutes	Comparative pre-test / post-test / delayed post-test results in the application revealed that participants achieved significant learning gains after participating in the application following each unit of the relevant courses. Additionally, in the post-application survey, participants indicated that they received assistance from the application in learning key concepts and found it enjoyable.
Anyanwu (2014)	Evaluation of the effectiveness of an educational game developed to increase knowledge in anatomy courses.	>18	95	No information provided.	In the research, it was found that the post-test scores of the experimental group in the application conducted on a specific number of adult students differed significantly in a positive direction compared to those of the control group ($p < 0.05$). Based on student feedback, the application was determined to be an engaging, highly informative tool that encourages teamwork and facilitates significant learning outcomes for anatomy classes. Consequently, the developed educational game was observed to be effective in increasing knowledge in anatomy classes and received positive feedback from students.
Eterovic ve Santos (2013)	Evaluation of the effectiveness of an educational game developed to teach the role of mutation in evolution.	>18	109	1,5 hours	The application conducted on a specific number of adult students in the research revealed statistically significant differences in the scores concerning the role of mutation in evolution between the experimental and control groups. Additionally, participants provided positive feedback regarding the application. Consequently, it was concluded that the educational game is effective in teaching the role of mutation in evolution and contributes to increasing students' knowledge level.
Fiesco ve Leclercq (2013)	Evaluation of the effectiveness of an educational game developed for teaching basic nutrition concepts.	7-12	959	2 months	According to the results obtained, it was determined that the knowledge level of students in the experimental group increased from 49.4 to 61.8 on a scale of 0-100 over time ($p < 0.001$). No

					change was observed in the scores of students in the control group over time. Therefore, it was indicated that it is an effective tool in teaching basic nutrition concepts.
Schneider ve diğerleri (2012)	Development and evaluation of an educational game to assist medical students in interpreting the reference value of white blood cells.	>18	90	2 hours	According to the results obtained, a statistically significant difference has been observed in the post-application scores compared to the pre-test and post-test results. Additionally, students have reported that the application has helped them understand the topic and contributed to the clinical assessment processes.
Riechert, Leander ve Lenhart (2011)	Development and evaluation of an educational game addressing the process of evolution through natural selection.	No information provided.	No information provided.	No information provided.	The findings suggest that the educational game allows students to actively explore the process of evolution through natural selection. Therefore, it has been observed that the educational game can enrich participants' learning experiences related to evolution.
Skukan ve diğerleri (2020)	Development and evaluation of an educational game aimed at helping individuals aged 11-12 years to learn about seaweeds and introduce them to underwater science.	11-12	46	50 minutes	According to the results obtained, it has been stated that the developed educational game is an effective tool for participants to recognize invasive marine algae and gain awareness of underwater science. Additionally, it has been observed that the application has a positive impact on participants in learning and understanding environmental issues.
Dullius (2019)	Evaluation of the effectiveness of an educational game developed to familiarize with the tourist attractions of eight municipalities in the Serra Catarinense, a region in southern Brazil known for its natural beauty, mountains, rivers, lakes, and waterfalls.	No information provided.	No information provided.	No information provided.	According to the results obtained, it has been determined that the educational game effectively provides tourists, the target audience, with the opportunity to get to know the cultural heritage, natural beauty, and gastronomy of the region more closely. At the same time, it is noted that users can have a fun experience while learning basic information about viticulture (grape cultivation and cultivation science) and enology (wine making science) in biology education.