MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2024, 20(6), em2459
ISSN:1305-8223 (online)
OPEN ACCESS Review Article https://doi.org/10.29333/ejmste/14658

Learn biology using digital game-based learning: A systematic literature review

Risya Pramana Situmorang [1,2], Hadi Suwono [1*], Munzil [3], Hendra Susanto [1], Chun-Yen Chang [1,4,5], Shan-Yu Liu [5,6]

[1] Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Malang, INDONESIA
[2] Biology Education Program, Faculty of Biology, Universitas Kristen Satya Wacana, Salatiga, INDONESIA
[3] Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Malang, INDONESIA
[4] Department of Earth Sciences, National Taiwan Normal University, 88, Section 4, Ting-Jou Rd., Taipei 116, TAIWAN
[5] Graduate Institute of Science Education, National Taiwan Normal University, 88, Section 4, Ting-Jou Rd., Taipei 116, TAIWAN
[6] National Taiwan Science Education Center, Taipei, TAIWAN

Received 27 June 2023 ▪ Accepted 24 November 2023

Abstract

The implementation of digital games in biology education has steadily increased over the past decade. The utilization of simulation-based learning tools, such as digital games, is anticipated to be further enhanced due to the increasing shift toward virtual learning. This review aims to explore the existing scientific evidence and analyze the effectiveness of incorporating digital games as a learning tool in biology education. The research methodology was a systematic literature review of existing digital game-based learning (DGBL) in biology education. The term "digital game-based learning and education" was utilized in the search interface of the Scopus database, identifying 1,241 articles. However, only 56 articles adhered to the stipulated criteria for subsequent analysis. Preferred reporting items for systematic reviews and meta-analyses framework was employed for the process of inclusion and exclusion. A discernible trend of escalating publications has been observed over the past decade. The review findings indicate that DGBL has expanded widely, encompassing all levels of education, from elementary to higher education, and has even been applied in professional education. Researchers primarily utilize quantitative research methods, although qualitative methods are employed. This research found that the complexity of DGBL research requires interdisciplinary collaboration involving science, biomedical, education, and technology experts. In terms of content, DGBL has been used to teach students about basic biology and practical applications of biology, such as biomedical science. Genetics, environment, and healthcare emerged as the most frequently addressed subjects taught using DGBL. Trends in DGBL technology usage include various platforms like computer-based, internet-based, and mobile-based, with elements of gaming and social interaction that align with the demands of 21st century skills. DGBL integrates with several constructivist learning approaches like experiential learning, problem-based, inquiry-based, and inquiry-lab. Research showed that DGBL encourages development of 21st century skills in simulated settings and real-life situations.

Keywords: game, digital, education, biology

INTRODUCTION

Digital game-based learning (DGBL) is a contemporary teaching method that involves using digital games or game-based environments to provide enjoyable, stimulating, and challenging educational experiences for students (Chen, 2017, 2021; Supriana et al., 2018). This approach facilitates students' understanding of intricate concepts while keeping them engaged and promoting knowledge retention. It is a novel educational approach that employs game

✉ risya.pramana.2103419@students.um.ac.id ✉ hadi.suwono.fmipa@um.ac.id **(*Correspondence)** ✉ munzil.fmipa@um.ac.id
✉ hendrabio@um.ac.id ✉ changcy@ntnu.edu.tw ✉ inoyr2025@mail.ntsec.gov.tw

Contribution to the literature

- The researchers concentrate on primary publications concerning implementing DGBL in biology education and its implications within the field. Additionally, they investigate unexplored aspects, setting themselves apart from other scholars and establishing a foundational framework for further studies.
- A comprehensive overview of the materials utilized solely encompasses original research and publications, presenting a synopsis of the researchers' focus and alignment with this particular theme. The information sources employed by the researchers are confined to original research articles, thereby depicting or explaining the researchers' emphasis and standpoint regarding this theme.
- The researchers develop appropriate learning strategies or models for applying DGBL in biology education, intending to provide guidance or a foundation for the biology learning process and catalyze innovation in biology education.

elements to create a playful atmosphere, emphasizing using digital games as educational tools. DGBL can be applied in various fields, including programming, work, education, and leisure activities (Aguilera & de Roock, 2022; Hartt et al., 2020).

DGBL has been extensively researched and is an effective method for improving learning outcomes. For example, a study indicated that digital games are a promising pedagogical approach in STEM education that effectively enhances learning gains (Arztmann et al., 2022; Hacioglu & Donmez Usta, 2020). Similarly, competition in DGBL has been demonstrated to be effective for math, science, and language learning (Go et al., 2022; Huang et al., 2014; Khan et al., 2017; Lee & Zhu, 2022; Yu & Tsuei, 2022). Furthermore, ongoing research explores which types of digital games and game-based instruction are most effective (All et al., 2013). Various types of games have been shown to be efficient for different educational purposes. For example, research by Novoseltseva et al. (2022) revealed that the simulation features in digital games designed for specific academic subjects have proven beneficial in imparting content information and boosting learning. In addition, research by Hartt et al. (2020) discovered that game elements that inspire delight, facilitate peer engagement, and allow the opportunity to share ideas have become increasingly beneficial in game design.

DGBL is a highly effective teaching tool for biology education (Jones, 2019). The study identified emerging trends in gamification in science education and addressed literature gaps, challenges, and potential research directions (Indriasari et al., 2020; Khaldi et al., 2023). Moreover, a two-part review synthesized digital game-based interventions' effectiveness and critical features for cognitive training in healthy adults (Lancaster et al., 2020; Merriman et al., 2018). Ultimately, the findings suggest that DGBL has gradually emerged as a trend and can potentially enhance students' learning performance.

Although DGBL is increasingly being utilized as an alternative teaching tool in higher education for science subjects, there need to be review studies on its application in biology. According to the available research, 60.00% of implementations are digital games, 36.00% are non-digital games, and 4.00% are gamification-based (Adita et al., 2021). Despite its potential benefits, the current DGBL environment in science education faces challenges and barriers, particularly in higher education (Kalogiannakis et al., 2021). One of the game's drawbacks is that not all biological concepts can be effectively taught (Sadler, 2015). Complex or highly specialized subjects may transition poorly into game-based formats, restricting the coverage of particular content (Sadler, 2013). Hence, it is vital to study prospective trends in the information that might be packaged in the form of digital games.

Central questions revolve around assessing the degree to which digital games bolster the understanding of biological concepts and exploring potential preferences for more engaging game elements. Through the creation of immersive and interactive environments, simulation games hold the potential to assist students in comprehending biological concepts more efficiently. For example, game genres like UbiqBio Games (Perry & Klopfer, 2014), Hay Day Game (Cole & Stewart, 2017), and Great Falls Park (Howard et al., 2021) facilitate repeated student interactions with foundational systems across multiple sessions and days. DGBL is increasingly used as an alternative learning tool to teach science in higher and further education (Brown et al., 2018). Although some studies have examined the effects of DGBL on learning and motivation, there still needs to be a systematic demonstration of its benefits (Erhel & Jamet, 2013). Overall, there is supportive evidence of the effectiveness of DGBL in diverse fields.

In biology education, numerous digital games make learning more engaging and fun. Examples of digital games used in biology education include Immune Defense, Operation: Ebola!, Code Fred: Survival Mode, and other multiplayer games (Abidin et al., 2020; Addy et al., 2018; Kanyapasit & Srisawasdi, 2014; Price et al., 2016; Wu et al., 2014). Additionally, DGBL is increasingly used as an alternative learning tool to teach science in further and higher education (Abidin et al., 2020; Khan et al., 2017; Yeo, 2022). Digital games can help students learn by providing an interactive, immersive

experience that encourages exploration and experimentation. Additionally, they can increase student engagement and motivation while providing a platform for collaboration and communication (Bouzid et al., 2021; Kao, 2020).

The use of digital games for learning biology has been gaining attention in recent years. A systematic literature review (SLR) of biology game-based learning identified 47 final papers published between 2010 and 2019 from the Scopus database (Adita, 2020). Another systematic review focused on gamification in science education highlighted the latest emerging trends while identifying literature gaps, challenges, impediments, and potential areas for future research (Subhash, 2018). Furthermore, a research study was conducted to illustrate the patterns of instructional research involving using digital and non-digital biology games in the Scopus database-indexed literature from 2010 to 2019 (Kalogiannakis et al., 2021). An SLR examined the methodologies used to evaluate the effectiveness of DGBL (Chen, 2021). These studies suggest a growing trend toward utilizing digital games for educational purposes in various fields, including biology. This literature review plays a crucial role in identifying new areas by summarizing existing studies on implementing DGBL in education. In this study, we conducted an SLR of studies focusing on implementing DGBL in biology education from 2014 to 2023. This research outlines various aspects. For example, when designing DGBL for biology education, researchers can leverage the latest technologies, such as mobile games, to connect to the Internet or web-based to facilitate student social interaction. This approach aligns with 21st century learning, which aims to develop students' collaboration. Therefore, this study's findings are valuable for stakeholders in biology education planning to adopt DGBL and future researchers.

A review of DGBL conducted from 2000 to 2013 identified several high-quality empirical studies related to DGBL (Erhel & Jamet, 2013). Based on the above study and to the best of our knowledge, DGBL in biology education from 2014 to 2023 has not been reviewed by any publication. Despite some research on DGBL in biology education, there remains a need for additional review studies in this area. This research encompasses the trends in DGBL studies, with a specific focus on its implementation in the field of biology. Additionally, it examines all related games, levels of education, research methods, collaborations, biology topics, types of technology, game elements, and learning strategies. Five research questions served as the basis for this study:

1. Is DGBL implemented at various levels of education?
2. What are the research methods in DGBL studies?
3. What collaborations of academic background and biology topics are used to promote DGBL studies?
4. Which kinds of technology and gaming elements were employed?
5. What are the game strategies and their implications when using DGBL in the context of biology education?

METHOD

Research Framework

This study in question employed an SLR method, which involved using identification, evaluation, and analysis techniques to collect pertinent information from existing literature and references to address a research question (Carrera-Rivera et al., 2022; Mengist et al., 2020). This research method encompasses various steps, such as framing the research question, identifying relevant publications through a comprehensive search, assessing the quality of the selected studies, analyzing and extracting data from them, and summarizing the results to answer the research question (Xiao & Watson, 2019). By following a rigorous and systematic process, the study aimed to provide a comprehensive and objective overview of the available evidence related to the research question.

This systematic review aims to examine the research papers in English published between January 2014 and March 2023 that investigate the use of DGBL in biology education. This systematic review follows preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines and flowcharts to ensure the quality and transparency of the review process. PRISMA guide provides a comprehensive checklist and flowchart for the four stages of a literature review, outlining essential items that need to be considered to ensure transparency and completeness of the review process (Page et al., 2021).

Search for relevant research articles using the Scopus database and randomly obtained from several official databases (EBSCO and ProQuest) from two popular indexing databases covering various social science disciplines. The search strategy includes using relevant keywords and phrases related to DGBL, biology education, and pedagogy. The inclusion criteria for this review were that papers must be in English, published between 2014 and 2023, and related to DGBL in education. This systematic review presents a comprehensive and up-to-date literature summary on DGBL in biology education. Adhering to PRISMA guidelines ensures the systematic, transparent, and replicable review process provides a reasonable basis for further research and implementation.

Search Term

A series of keywords about learning biology is combined using the "AND" Boolean operator. We utilize the keyword "digital game-based learning and

education" in the search option within the Scopus database. Through the Scopus database, we received a total of 2,319 articles. The data we acquired were recorded in *CSV and *RIS formats, which were subsequently synchronized into Mendeley. We used VOSviewer software to visualize the data so that the information could be presented in a more conversational, engaging, and straightforward manner. The search term used includes possible terms for digital games, namely: TITTLE–KEY (digital AND game AND based AND learning AND in AND education) AND (LIMIT-TO) SUBJAREA, "SOCI")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (DOCTYPE, "ar")) AND LIMIT-TO (LANGUAGE, "English") AND (LIMIT-TO (OA, "all")) AND LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) AND (LIMIT-TO (PUBSTAGE, "final")).

Selection of Papers for Inclusion in Review

After a keyword search, the researcher reads the title and abstract of the article to select target papers that meet the following criteria:

(1) implement at least one particular digital game,

(2) the use of digital games must be related to biology education,

(3) provide an empirical evaluation or overview about the learning process or outcomes, and

(4) the full text of the article must be available in either paper or electronic format.

Suppose sufficient information to select an article is not available in the abstract. In that case, the researcher then goes through the article's main body (e.g., methodology and results) to make a judgment.

Some exclusion criteria listed below were also used to filter out articles not reviewed in this study:

1. This study did not target student groups. If a study investigates different groups of participants, only the instructions and outcomes related to student learning are reviewed.
2. Digital games are used explicitly for professional learning in computer science and engineering.
3. The main focus of the research is game development, and no essential outcome data is provided (e.g., only citing some conversations between students or stating in a few sentences the implementation of the results).
4. The authors of the article do not identify the software or environment as a digital game or provide sufficient information to verify the characteristics of the game.

Figure 1 shows the flowchart of systematic review, which is adapted from Haddaway et al. (2022).

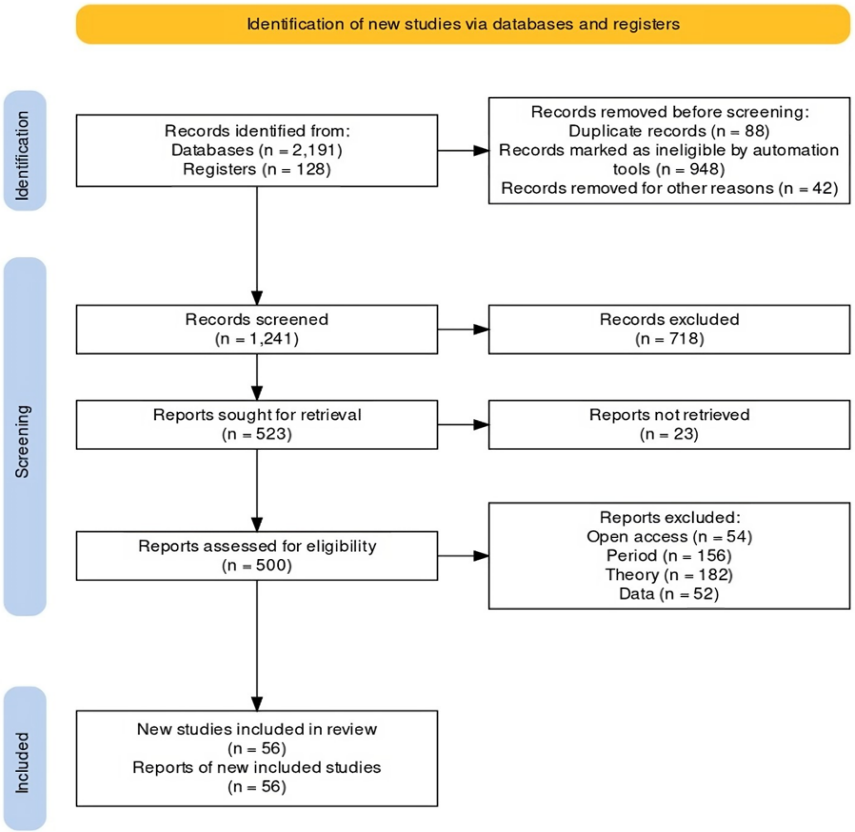

Figure 1. Flowchart of systematic review (adapted from Haddaway et al., 2022)

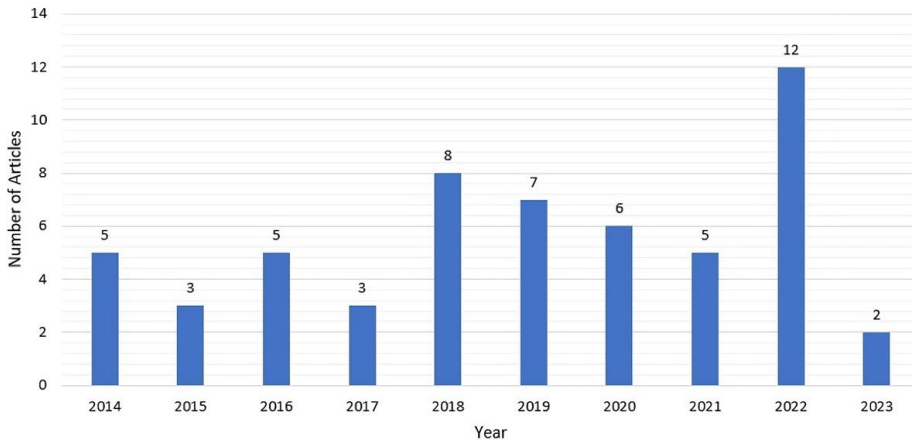

Figure 2. Distribution of articles each year (Source: Authors' own elaboration)

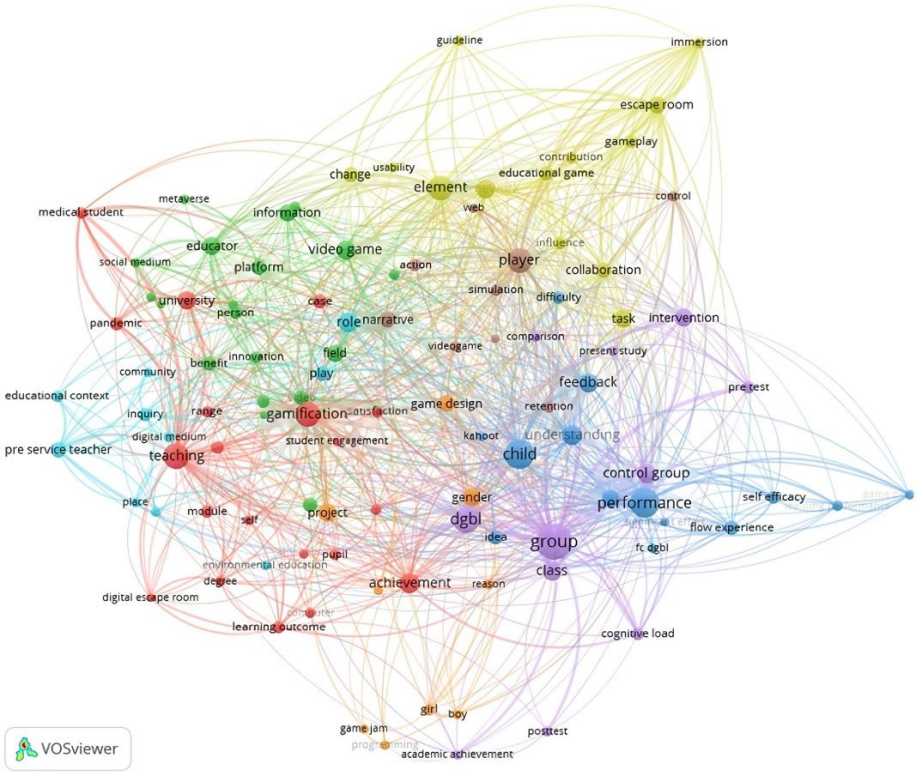

Figure 3. Authors' depiction of VOSviewer analysis using "co-occurrence→keywords" type of analysis (Source: Authors' own elaboration, using VOSviewer software)

RESULTS

Distribution Year

The search results yield numerous valuable insights into the research on DGBL in biology education over the past 10 years. By analyzing the articles published during this period, researchers can identify emerging trends and the number of publications in the field. As such, the search results serve as a crucial foundation for further research and development in this exciting and rapidly expanding field of study.

Figure 2 displays a timeline of articles on DGBL in biology education published from 2014 to 2023. The graph highlights the consistent research activity in this field over the past decade, although there is a need for more studies to be published. At least two articles have been published yearly, indicating a sustained interest in DGBL in biology education.

Although the number of publications has declined since 2018, there was a significant increase in 2022, indicating a renewed interest in this area of research. This surge in publications made DGBL in biology education a popular research topic last year. As of March 2023, two articles have been published, but the number will likely increase for 11 months remain in the year. Therefore, it is expected that there will be more publications on DGBL in biology education in 2023.

Figure 3 illustrates the trends of keywords most frequently used by authors in writing the theme "Digital Game and Biology Education."

Table 1. Distribution of educational level across each article

No	Participants	f	%	References
1	Elementary school	8	14.81	Chang and Hwang (2017), Chin and Tsuei (2014), Hwang and Chen (2016), Kostenius et al. (2018), Li et al. (2021), Price et al. (2016), Wang et al. (2022), and Yeo et al. (2022)
2	Middle school	9	16.67	Bouris et al. (2016), Culp et al. (2015), Pombo and Marques (2019), Puttick (2018), Ristanto (2022), Schneider and Schaal (2018), Tucker-raymond et al. (2019), Wallin (2022), and Wommer (2021)
3	High school	11	20.37	Addy et al. (2018), Barwood et al. (2020), Cheng et al. (2022), Christopoulos et al. (2022), Ciloglu and Ustun (2023), Janakiraman et al. (2018), Oliver et al. (2019), Perry and Klopfer (2014), Rosenheck et al. (2021), von Kotzebue et al. (2022), and Wang (2019)
4	Undergraduate	7	12.96	Alrehaili and Al Osman (2022), Antón-Solanas et al. (2022), Chen (2019), de Almeida et al. (2021), Lawson et al. (2019), Lookadoo et al. (2017), and Maddison (2018)
5	Medical students	2	3.70	Gauthier et al. (2015), and Tsopra et al. (2020)
6	Nursing students	2	3.70	Chang et al. (2020), and Foss (2014)
7	Dental students	2	1.85	Felszeghy et al. (2019), and Lin and Yang (2023)
8	Student pharmacists	1	1.85	Lam et al. (2019)
9	Experts	2	3.70	Klit (2020), and Razali et al. (2022)
10	Healthcare professionals	1	1.85	Yeo et al. (2020)
11	Agriscience teachers	1	1.85	Webb (2015)
12	Pre-service primary teacher	1	1.85	Casanoves et al. (2017)
13	Primary & secondary school biology teachers	1	1.85	Aivelo and Uitto (2016)
14	Pre-service primary teacher	1	1.85	Solé-Llussà et al. (2021)
15	High school & teachers	1	1.85	Wilson (2018)
16	Community	4	7.41	de la Vega et al. (2022), Hawkins et al. (2023), Radhakrishnan (2016), and Silva et al. (2019)

Based on **Figure 3**, research on DGBL is divided into seven clusters: blue, red, yellow, brown, purple, orange, and green. The clusters demonstrated a connection between different topics. The thickness of the connecting line indicated the strength of the pairs of topic areas or keywords. In addition to clusters and lines, the size of the nodes also revealed how frequently a keyword or topic occurred. **Figure 3** shows that the prevailing subjects or key terms included group, project, child, performance, teaching, and gamification. This information suggests that these themes garnered the most attention among researchers from 2014 to 2023. Also, nodes or critical terms that exhibited connections with other keywords indicated the potential to emerge as new research topics, such as DGBL and project.

Distribution of Educational Levels

Table 1 displays the preferred participants in DGBL research in biology education. The data showed that high school students were the most significant proportion of participants at 16.67%, followed by elementary school students (14.81%) and middle school students (16.67%). The undergraduate group is also often used by researchers as participants in research, namely 12.96%.

The information presented in **Table 1** highlights the importance of understanding the impact of digital games on student engagement in various educational settings. A significant proportion of high school students engaged in DGBL research indicates that these games are recognized as an effective tool for engaging this age group. Meanwhile, the involvement of elementary and junior high school students shows that digital games can also stimulate learning in younger students. In addition, the participation of undergraduate students in DGBL research shows that digital games can involve learning at the higher education level through digital game strategies.

Research Method

DGBL research has been extensively conducted. Trends in research on DGBL through research methods indicate increased interest in this type of research to explore the effectiveness of DGBL in biology education. **Table 2** presents the current trends in research focused on "digital game-based learning in biology education."

Most studies on this topic employ a quantitative approach (40 articles), while a few utilize qualitative methods (nine articles). This finding indicates that digital games are predominantly studied using quantitative research. Quantitative methods are ideal for large-scale research, as they enable researchers to collect and analyze data from various people. This information aligns with Culp (2015) research, which included 914 students from 25 schools in New York, to ensure that the results could be generalized to a broader student population. Additionally, quantitative methods allow researchers to generalize the general population or

Table 2. Different categories of research on DGBL in biology education topics

No	Type of research	f	References
1	Mixed method	2	Chen (2019), and Janakiraman et al. (2018)
2	Qualitative	9	Chin and Tsuei (2014), Kostenius et al. (2018), Leith et al. (2016), Puttick (2018), Sandbrook (2015), Tucker-raymond et al. (2019), Webb, (2015), Wallin (2022), and Wilson (2018)
3	Quantitative	40	Addy et al. (2018), Aivelo and Uitto (2016), Alrehaili and Al Osman (2022), Antón-Solanas et al. (2022), Barwood et al. (2020), Bouris et al. (2016), Casanoves et al. (2017), Chang et al. (2020), Chen (2019, 2020), Cheng et al. (2022), Christopoulos et al. (2022), Ciloglu and Ustun (2023), Culp et al. (2015), de la Vega et al. (2022), Felszeghy et al. (2019), Foss (2014), Gauthier et al. (2015), Hwang and Chen (2016), Lam et al. (2019), Li et al. (2021), Lin and Yang (2023), Lookadoo et al. (2017), Maddison (2018), Oliver et al. (2019), Perry and Klopfer (2014), Pombo and Marques (2019), Price et al. (2016), Radhakrishnan (2016), Ristanto (2022), Rosenheck et al. (2021), Schneider and Schaal (2018), Silva et al. (2019), Solé-Llussà et al. (2021), Tsopra et al. (2020), von Kotzebue et al. (2022), Wang et al. (2022), Wommer (2021), and Yeo et al. (2020, 2022)
4	Research & development	5	de Almeida et al. (2021), Hawkins et al. (2023), Klit (2020), Razali et al. (2022), and Wang et al. (2019)

educational context (Polit & Beck, 2010). This condition is crucial for demonstrating the broader applicability and potential impact of DGBL intervention. For instance, the development of the spotted-stop-it game could serve as a model for creating similar educational tools for other invasive pest species, given that the game has effectively conveyed concepts and practices related to integrated pest management and sustainable plant protection (de la Vega et al., 2022). These advantages generally make quantitative research the preferred choice for DGBL studies. The quantitative approach offers unique advantages in analyzing the effectiveness and impact of DGBL in the educational context.

Other studies exhibit methodological variations, conducting qualitative research, with some even employing mixed methods. Researchers also explore mixed methods (two articles) to understand better how digital games can enhance biology education (de Almeida et al., 2021; Hawkins et al., 2023). Another noteworthy trend is the focus on design-based research (four articles) and research and development (one article) of digital games. This information underscores the importance of creating interactive and educational games that address critical social issues and actively promote scientific concepts (Ishak et al., 2023). Ultimately, it aims to develop digital games that make biology learning more enjoyable and accessible.

The issue of DGBL in education can be explored by qualitative, quantitative, or mixed-method, depending on the researchers' aims, objectives, and demands.

Collaboration of Academic Backgrounds & Biology Topic

The analysis of authors' backgrounds revealed that just about five (5.89%) of the 56 papers examined were written by specialists with a similar academic background. This finding emphasizes how most of this field's research involves authors working together with different academic backgrounds.

Table 3 summarizes the academic backgrounds of authors collaborating collaboratively in well-known DGBL publications on biology education. Numerous authors who have contributed to the subject of DGBL in biology teaching are shown in **Table 3** to have a variety of academic backgrounds.

Observations indicate that within basic biology research group, most authors had a biology background (7.44%). On the other hand, in the education sector, two fields particularly stood out as actively publishing research on digital games and collaborating with other

Table 3. Academic backgrounds of researchers contributing to DGBL publications in biology education

Study group	Academic background	f	%
Basic biology	Biology	9	7.44
	Biochemistry	3	2.48
	Anatomy & embryology	1	0.83
	Cell biology	1	0.83
	Immunology	1	0.83
	Metabolism	1	0.83
	Molecular, cellular, & developmental biology	1	0.83
Applied biology	Veterinary & animal sciences	3	2.48
	Environmental conservation	3	2.48
	Biotechnology	2	1.65
	Biomedicine	1	0.83
	Agricultural pests	1	0.83
	Water & environmental health	1	0.83

Table 3 (Continued). Academic backgrounds of researchers contributing to DGBL publications in biology education

Study group	Academic background	f	%
Education	Biology education	5	4.13
	Science education	2	1.65
	Curriculum & pedagogy	1	0.83
	Educational psychology	3	2.48
	Educational technology	19	15.70
	Teacher education	12	9.92
	STEM education	1	0.83
	Early childhood	2	1.65
Biomedical	Health sciences	5	4.13
	Biomedical communications	1	0.83
	Dentistry	1	0.83
	Neonatal & developmental medicine	1	0.83
	Sexual & reproductive health	1	0.83
	Neurosciences	1	0.83
	Nursing & health sciences	6	4.96
	Obstetrics & gynecology	1	0.83
	Pharmaceutical sciences	4	3.31
	Physiotherapy	1	0.83
	Psychology	4	3.31
	Public health	1	0.83
	Surgical oncologist	1	0.83
Technology	Informatics	4	3.31
	Electrical & computer engineering	3	2.48
	Human communication	1	0.83
	Digital multimedia design	4	3.31
	Comparative media studies	1	0.83
	Computer science	7	5.79

fields to investigate DGBL, namely educational technology (15.70%) and teacher education (9.92%). Additionally, the biomedical science field showed a higher frequency of research conducted by authors with backgrounds in nursing and health science (4.96%). Finally, the technology field was represented by authors with experience in computer science (5.79%). Given its link with the digitization of games, which aligns with their area of competence, computer science demonstrated a percentage that is more extensive than other technology-related fields in DGBL study.

These findings emphasize the cross-disciplinary areas and diverse academic backgrounds that have contributed to the development of DGBL research. The authors' ability to work together more effectively is substantially enhanced by their diversity, which is excellent for advancing DGBL in biology teaching. By merging information and approaches from various fields, such interdisciplinary collaboration enables research to address complicated challenges from various angles. This condition can result in greater comprehension, invention, and discoveries that advance the subject of DGBL and assist in addressing fresh difficulties in biology teaching.

The trends evident in **Table 4** clarify that there are two main categories: basic biology and applied biology. This classification highlights the connection between the findings of academic backgrounds (**Table 3**) and trends in biological topics used in DGBL. Specifically, the trend of teaching biology using DGBL has been widely applied to applied biology topics such as biomedical science. This information aligns with the finding that some researchers have backgrounds in nursing and health science (**Table 3**).

Table 4 reveals 56 articles on various topics related to digital games and that genetics and healthcare are the most extensively studied, with each having a usage rate of 8.83%. The statement suggests that researchers use digital games to disseminate knowledge and effectively teach complex topics like genetics and healthcare engagingly. In general, digital games have been increasingly used as educational tools in various fields, including healthcare and genetics. They offer an interactive and engaging way to learn complex topics and can effectively engage younger audiences.

Digital games are frequently used to educate players about various natural world and environmental topics. These topics include ecosystems, with a usage rate of 7.14%, and animal science and environmental topics, at 5.36%. Games focused on these topics can teach players about interrelationships between species, human impact on the planet, and how to reduce ecological footprints. Incorporating such content can enhance educational value and make games more engaging and enjoyable. Furthermore, environmental and ecological games can promote awareness and encourage sustainable practices in players' daily lives (Tan & Nurul-Asna, 2023).

Table 4. Digital games are identified within scope of topic used for biology education

Group	Topic	f	%	References
Basic biology	Photosynthesis	1	1.79	Culp et al. (2015)
	Animal science	3	5.36	Chang et al. (2020), Oliver et al. (2019), and Webb (2015)
	Biodiversity	2	3.57	Sandbrook (2015), and Wallin (2022)
	Cellular biology	3	5.36	Hawkins et al. (2023), Silva et al. (2019), and Wang et al. (2019)
	Climate change	3	5.36	Puttick (2018), Razali et al. (2022), and Tucker-raymond et al. (2019)
	Digestion & nutrition	2	3.57	Barwood et al. (2020), and Li et al. (2021)
	Ecosystem	4	7.14	Hwang and Chen (2016), Perry and Klopfer (2014), Pombo and Marques (2019), and Yeo (2022)
	Environmental	3	5.36	Janakiraman et al. (2018), Schneider and Schaal (2018), and Wang et al. (2022)
	Enzyme	1	1.79	Christopoulos et al. (2022)
	Ethology: Animal behavior	1	1.79	Alrehaili and Al Osman (2022)
	Evolution	3	5.36	Aivelo and Uitto (2016), Leith et al. (2016), and Lookadoo et al. (2017)
	Genetic	5	8.93	Casanoves et al. (2022), Llussà et al., (2021), Ristanto (2022), Rosenheck et al. (2021), and Wilson (2018)
	Human biological system	2	3.57	Ciloglu and Ustun (2023), and Price et al. (2016)
	Human histology	1	1.79	Felszeghy et al. (2019)
	Human vascular anatomy	2	3.57	Gauthier et al. (2015), and Hwang and Chang (2020)
	Immunology	1	1.79	Addy et al. (2018)
	Insect	2	3.57	Wommer (2021), and de la Vega et al. (2022)
	Mycorrhizal ecology	1	1.79	Maddison (2018)
	Neurology	1	1.79	Lam et al. (2019)
	Phylogenetic tree of animal	1	1.79	Cheng et al. (2022)
	Plant	1	1.79	Chen (2020)
Applied biology	Sex education	1	1.79	von Kotzebue et al. (2022)
	Veterinary education	1	1.79	Klit (2020)
	Viral diseases	1	1.79	de Almeida et al. (2021)
	Neonatal resuscitation	1	1.79	Yeo et al. (2020)
	Healthcare	5	3.57	Antón-Solanas et al. (2022), Bouris et al. (2016), Foss (2014), Kostenius et al. (2018), and Radhakrishnan (2016)
	Dental treatment	1	1.79	Lin and Yang (2023)
	Antibiotic	1	1.79	Tsopra et al. (2020)
	Chronic illness	1	1.79	Chin and Tsuei (2014)
	Energy conservation	1	1.79	Chen (2019)

Technology Types & Game Elements in Digital Game-Based Learning

When addressing devices used for gaming, different possibilities are accessible in today's technologically evolved digital world. These gaming gadgets have seen considerable technical improvements, giving players numerous gaming experiences and opportunities to engage in various types of interactive contact.

Figure 4 shows the different types of technologies used to implement DGBL. Trends in technology usage were categorized into three segments: computer-based technology (blue), Internet-based technology (orange), and mobile games (green). Based on **Figure 4**, the number of computer-based technology and mobile games used in research has varied over the last ten years until reaching a peak in 2022, with five publications.

As of 2023, no publications in DGBL that utilize computer-based technology have been found, even though this study collected articles up until April 2023. This condition indicates a potential decline in the trend compared to mobile games.

Furthermore, internet-based technology has become a trend in recent years, with a stable usage rate. This condition indicates a consistent trend and has been favored by researchers. The utilization of mobile games has become an appealing element in digital game packaging, enabling broader access to all students and flexibility in their implementation.

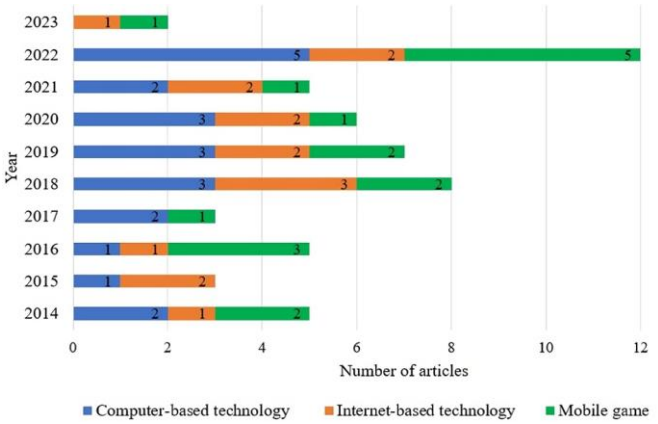

Figure 4. Distribution of technology used in DGBL (Source: Authors' own elaboration)

Based on the findings of this study, it is essential to consider a shift from computer-based to mobile game-based DGBL integrated with the Internet in future

Table 5. Incorporation of gaming elements

Dominate game elements	f	Description	References
Advancement & completion	5	Commitment to grow toward a fulfilling finish	Chang et al. (2020), Hawkins et al. (2023), Puttick (2018), Tucker-raymond et al. (2019), and Wallin (2022)
Application of a skill	6	Employing tangible expertise	Aivelo and Uitto (2016), Casanoves et al. (2017), Klit (2020), Perry and Klopfer (2014), Wilson (2018), and Yeo et al. (2020)
Assessment	4	By gathering data, evaluation evaluates quality of user	Felszeghy et al. (2019), Li et al. (2021), Lookadoo et al. (2017), and Wang et al. (2022)
Competition	1	Tasks that foster personal brilliance	Razali et al. (2022)
Creation	2	Create something new	Janakiraman et al. (2018), and Silva et al. (2019)
Exploration	2	Venturing game's world to learn about & engage with its many components, settings, & contents	Pombo and Marques (2019), and Rosenheck et al. (2021)
Gamification	2	Settings or activities outside of games that increase involvement	Tsopra et al. (2020), and Wommer (2021)
Immersion	3	Experiencing an alternative existence amid a new setting	Barwood et al. (2020), de la Vega et al. (2022), and Hwang and Chang (2020)
Intellectual problem solving	11	Discovering remedies for contemporary concerns	Chen (2020), Christopoulos et al. (2022), Culp et al. (2015), Gauthier et al. (2015), Leith et al. (2016), Li et al. (2021), Llussà et al., (2021), Price et al. (2016), Sandbrook (2015), von Kotzebue et al. (2022), and Yeo et al. (2020)
Physical activity	2	Tasks involving intense body motions	Cheng et al. (2022), and Kostenius et al. (2018)
Power	2	Exhibiting rising or falling levels of force	Foss (2014), and Maddison (2018)
Social interaction	16	Engage collaboratively with fellow humans	Addy et al. (2018), Alrehaili and Al Osman (2022), Bouris et al. (2016), Chen (2019), Chin and Tsuei (2014), Ciloglu and Ustun (2023), de Almeida et al. (2021), Lam et al. (2019), Lin and Yang (2023), Oliver et al. (2019), Radhakrishnan (2016), Ristanto (2022), Solanas et al. (2022), Schneider and Schaal (2018), von Kotzebue et al. (2022), and Wang et al. (2022)

research. This shift aimed to facilitate flexible gaming activities, including player-social interactions.

The game elements (**Table 5**) refer to the components, activities, or mechanisms that make a game entertaining and enjoyable. Games typically consider the dominance of these elements, making them the core of the game (Guan et al., 2022).

As shown in **Table 5**, social interaction is the most popular game element, followed by intellectual problem-solving, the application of a skill, and advancement and completion. Future research in DGBL should focus on social interaction because it enhances collaboration skills that are crucial in the 21st century (Ibharim, 2019; Roukouni et al., 2020; Sardone & Devlin-Scherer, 2010). Social interaction in learning allows students to practice working together (Buyukozturk & Shay, 2022), listening to different perspectives (Li et al., 2022), and reaching a consensus (Noroozi, 2018), which significantly impacts their workplace and daily life. Further exploration of digital games can be optimized to strengthen students' collaboration skills is required.

Game Strategy & Its Implications

The concept of game strategy in the context of DGBL reflects an essential integration of pedagogical elements with the gaming experience.

As students assume the role of players in the game, game strategy is essential for directing their actions and choices. Understanding and using game strategies has a big impact on creating meaningful and efficient learning. In DGBL, winning the game is just one aspect of game strategy. How the students use their newly gained information and abilities in the game setting is more critical. This process allows students to comprehend and internalize the concepts presented in the learning material interactively and enjoyably.

Table 6 shows a variety of learning strategies/models used in various types of digital games and relates how they impact learning. Based on **Table 6**, experiential learning is the most common and widely used strategy in DGBL. This approach directly explores ideas and constructs meaning through active experimentation, reflective observation, abstract conceptualization, and concrete learning.

Table 6. Use of game strategy & its implication in biology learning

LMS	Digital game	Practical implication
Scratch programming platform	Visual programming environment called Scratch	Educators should consider game-based approaches in curriculum as they can be attractive for students of all ability levels, including beginners, to learn essential computer science, programming, & data analysis skills.

Table 6 (Continued). Use of game strategy & its implication in biology learning

LMS	Digital game	Practical implication
Authentic learning	EduPARK game	This research has important practical implications in context of formal/non-formal education & beyond it–Including tourism sector, where AR technology can effectively promote cultural heritage sites among visitors while providing interactive/engaging experiences through techniques gamification.
Bauman's layered learning model	Kahoot®	It proves that gamification can be an effective tool for teaching histology to medical & dental students, resulting in better grades & increased motivation. It suggests incorporating multimedia educational technologies into traditional didactic presentation of material can increase student engagement in learning process.
Case-based learning (CBL)	Ebola wars: Mission immune evasion	Serious games can be integrated into case-based learning to increase student engagement & enhance their understanding of complex topics. This study found that students enjoyed CBL activities with educational games, which resulted in improved learning gains indicated by higher post-knowledge assessment scores.
Collaborative knowledge strategy	Concept mapping-based two-tier test gaming (CM-TTG)	It investigates effectiveness of CM-TTG approach in improving student learning achievement in integrative activities.
Complex biological interactions	Simulation digital game about food chain concept	There is an influence of gender & prior knowledge on learning performance and student motivation in using digital simulation games about food chains for elementary school students. Integrating gameplay and augmented reality technologies in educational applications can increase students' interest in learning.
Complex casual games	Mobile Plant	Combining gameplay and augmented reality technology in educational applications can increase students' interest in education.
Computer-generated models or simulations	Video games: Fallout & outer worlds	Encourage educators to incorporate critical analysis of popular cultures, such as video games, into their teaching practice to develop students' abilities to think critically about representation & treatment of non-human beings. Raise awareness among game developers & players about how representation of animals in video games can perpetuate harmful attitudes toward animals or reinforce speciesism.
Cooperative gameplay	Tabletopia: Board game called outbreak	Educators need to encourage critical analysis of popular culture, including video games, to enhance students' necessary thinking skills about treatment of non-human beings. Game developers & players aware that representations of animals in video games can reinforce harmful attitudes toward animals or speciesism.
Evidence-centered design	Vascular invaders	Performance of learning aids using games was an essential factor in predicting improvement on anatomy tests, especially in game group compared to non-game control group. This condition suggests that a well-designed e-learning environment can be an effective tool for evaluating student knowledge acquisition over time & providing feedback mechanisms tailored to individual student performance levels.
Experiential learning	Digital e-health game	It shows that developing & testing digital game prototypes can seriously improve knowledge about heart failure self-management in community-dwelling adults. Game-based learning strategies also have potential to motivate behavior modification in older people & lead to better health outcomes. Thus, it is advisable to seriously consider using games in patient education programs for chronic conditions such as heart failure. It has proven effective in patients who prefer an interactive process or playing games over traditional educational materials.
	Digital escape rooms	Using digital educational escape room games (DEERs) as a game-based learning environment can be an effective and motivating approach to teaching science, especially in sex education.
	Immersive virtual reality role-playing game (RPG)	VR RPGs can be practical tools for experiential learning, as shown by a study using a VR RPG to teach about honeybee behavior and ecology. All tested approaches resulted in knowledge acquisition, but the desktop-based non-immersive version had better information retention than conventional methods like reading.
	Parasite race	An effective way to teach complex science concepts; engage students of various age groups and backgrounds to determine how well digital games can improve learning outcomes in subjects other than biology education.
	Game for climate change awareness	Engaging game experts and environmentalists during development will create practical solutions with contextualized experiences.
	Shroomroot	Digital games like Shroomroot can effectively teach undergraduate students concepts of mycorrhizal ecology. It found that playing Shroomroot increased students' knowledge acquisition & engagement with mycorrhizal content. Students reported increased learning & interest in mycorrhizae & networks after using it. It suggests that plant ecology action-oriented digital games have positive potential in university science curricula, where traditional methods may not be effective.

Table 6 (Continued). Use of game strategy & its implication in biology learning

LMS	Digital game	Practical implication
Exploration & experimentation	Mobile augmented reality (AR) applications	AR mobile application can enhance online biology learning and increase students' self-efficacy. This study found that AR materials were considered innovative, discreet, successful in knowledge acquisition, engaging, attention-grabbing, and fun by students. This finding suggests that incorporating AR technology in teaching can make subjects more concrete for learners while facilitating their understanding of complex concepts.
Flipped classroom	Kahoot!	FC-DGBL learning model can be used as an alternative learning method to increase awareness of the concept of Genetics.
Game-based & location-based learning	Geo-game	Location-based smartphone games can effectively promote a sense of connection with nature, encouraging better environmental attitudes and behaviors. The study found that complex geo games and simpler treasure-seeking games were equally effective at building those connections. Therefore, designers and educators can focus on creating engaging activities in real-world contexts where players must interact directly with their surroundings using mobile devices.
Incidental learning	Serious games: Proteingo	Proteingo, an educational game designed to teach protein-protein interactions in biochemistry, can be a valuable tool for incidental learning. The study found that users who played the game showed progress and improvement over time and provided positive feedback about their experiences. This finding suggests that games like Proteingo could be used in the classroom or other educational settings to complement traditional teaching methods and more effectively engage students. Additionally, databases created through play (such as those built by Proteingo players) can be valuable for scientific research outside of education.
Inquiry-based laboratory	Educational game called Scialience	It found that educational games can increase student engagement in science learning & laboratory activities. Science, a combined approach between play & physical experimentation, has successfully increased understanding of material among high school students. Teachers may consider using a similar method to integrate educational games into their teaching. This condition can increase student engagement & increase long-term retention. Narrative-driven game design like Science model can help overcome challenges associated with implementing investigative practices in traditional classroom settings.
Inquiry-based learning	Digital games like Geniverse	Digital games such as Geniverse are used to teach complex scientific concepts in high school biology classes, which is a dynamic and novel way of teaching science. Geniverse is an excellent illustration of a game-based learning tool that was created to engage students in genetics and genomics. Thus, it is an entertaining and effective platform for teaching complex scientific ideas.
	Inquiry-based ubiquitous gaming	Inquiry-based game approach can be used to improve student performance in real-world learning activities. Experiments show that it improves student achievement, intrinsic motivation, problem-solving, & critical thinking skills. Incorporating it into educational settings can improve student outcomes.
Interactive gaming	Serious game development triangle (SDT)	Development of digital game-based learning for veterinary education is a complex process that requires collaboration between professionals from various disciplines. Practical implications indicate that using virtual game technology can enhance learning & involvement of pharmacist students. It found that college students benefited from increased familiarity with virtual & educational game concepts through their experiences with Mimycx quests. But no statistically significant differences were found regarding their attitude toward communication & teamwork. Thus, incorporating more interactive activities such as these games into traditional teaching methods may be beneficial for increasing student engagement and understanding in health education courses.
	Mimycx quests	Development of digital game-based learning for veterinary education is a complex process that requires collaboration between professionals from various disciplines. Practical implications indicate that using virtual game technology can enhance learning & involvement of pharmacist students. It found that college students benefited from increased familiarity with virtual & educational game concepts through their experiences with Mimycx quests. But no statistically significant differences were found regarding their attitude toward communication & teamwork. Thus, incorporating more interactive activities such as these games into traditional teaching methods may be beneficial for increasing student engagement and understanding in health education courses.

Table 6 (Continued). Use of game strategy & its implication in biology learning

LMS	Digital game	Practical implication
Problem-based learning	Annapurna expedition	Annapurna expedition activity can be used as an effective educational tool to teach basic concepts in genetics to prospective teachers and secondary school students. The game-based science learning methodology used in this activity provides a more engaging environment than traditional classroom-based approaches, which can help increase student knowledge retention rates.
	Computer games for healthy food choices	Computer games that promote healthy eating provide an immersive educational experience that enables players to experiment with various meal alternatives and see the effects of their decisions in a virtual setting. The need for a balanced diet, portion control, and nutritional value of foods is better understood owing to this practical approach.
Role-playing	IVR-Honeybee	The use of immersive VR-RPG games, such as IVR-Honeybee, can be an effective tool for promoting experiential learning in educational settings. Students who engage with educational content through serious role play may experience higher levels of motivation and engagement than those using conventional methods or desktop VR RPGs. The results showed that students who studied material through a desktop VR-RPG approach showed an increased capacity to retain learned information compared to those who used a traditional textbook-based approach.
ARCS model	Insects GO	Gamification can effectively increase engagement & motivation in science education, especially among high school students. Insects GO game designed by researchers improved students' performance in multiple-choice tests related to entomology & increased their interest & motivation towards learning about insects. These findings may have important implications for educators who wish to create engaging instructional materials or curricula focused on STEM subjects such as biology or environmental sciences, where hands-on experience with real-world phenomena may not always be possible due to logistical constraints such as time, cost, problems, & security.

Note. LMS: Learning model/strategy

Digital games are a motivating and engaging learning approach and can help increase students' interest and concentration in learning material. By enabling students to make decisions and manage the process, teachers or instructors can become facilitators in the learning process (Suwono et al., 2022).

Problem-based learning (PBL) model is combined with DGBL. For example, the problems presented in the game become challenges based on learning objectives, which are the essence of this model. PBL integrated with digital games can be an optimal strategy as a content delivery mechanism and an interesting way to use technology in the classroom. Apart from PBL model, inquiry is also a learning model that is of interest to be used with DGBL. Inquiry learning has great potential when combined with digital games. The use of inquiry helps games so that students can be more involved and motivated to learn. Combining inquiry learning with DGBL fosters and unlocks spirit of inquiry, risk-taking, experimentation, curiosity, problem-solving, and creativity all of which are 21st century skills.

DISCUSSION

Year Distribution

The field of DGBL in biology education has experienced consistent growth over the past decade, as evidenced by numerous studies published between 2014 and early 2023 that investigated the effectiveness of DGBL applications. This trend reflects the growing interest of both biology researchers and educators in incorporating innovative technology tools, such as digital games, into the learning experience to enhance student engagement and learning outcomes (Abidin et al., 2020; Aguilera & de Roock, 2022).

The integration of games in biology education has rapidly gained popularity as a highly effective and engaging tool for enhancing the learning experience. Over the years, digital games have increasingly supported learning, and recent technological advancements have made them even more prevalent in educational settings. In online education, this area of research has generated significant interest from various stakeholders, including scientists, educators, game designers, tutors, and students (Behnamnia, 2022; Wang, 2022).

Educators and policymakers have recognized the potential of digital games in biology education, keen to incorporate innovative technology tools to create a more engaging and interactive learning experience. Digital games effectively engage learners, enhance their understanding of complex biological concepts, and foster critical thinking and problem-solving skills (Yang, 2013).

The search results reveal that gamification, teaching, group, and performance are the four main keywords commonly associated with using games in biology education. Gamification involves integrating game

elements, such as challenges, levels, and points, into non-game contexts, including educational settings, to enhance student motivation and engagement. Teaching with games refers to using games as teaching tools to foster active learning, boost interest, and encourage student collaboration. Group learning with games, on the other hand, focuses on using games to facilitate group interaction and cooperation among students, thus promoting a cooperative learning environment. Finally, the keyword performance describes using games to enhance academic performance, including learning achievement and self-efficacy, by providing students with immediate feedback and adaptive challenges (Luo, 2022; Smiderle et al., 2020). These keywords are commonly found in research exploring the effectiveness of DGBL in biology education and can assist in identifying relevant studies and refining research questions.

Educational Levels

The search results indicate that high school students are the most frequently studied group in DGBL research, accounting for 16.67% of the total participants, followed by elementary and junior high school students, each representing 9.26% of the total participants. However, it is worth noting that the age range of participants in DGBL research is diverse, from elementary to tertiary institutions.

Although high school students are the most studied group, digital games have been explored as a learning tool for learners of different ages. For example, some studies have investigated the effectiveness of digital games in teaching biology to elementary students, as they can make learning more interactive and exciting (Price et al., 2016; Sadler, 2015). Others have focused on using digital games to enhance learning outcomes for college students pursuing biology degrees (Aivelo & Uitto, 2016; Brown et al., 2018). The wide age range of participants in DGBL research highlights the potential of this approach to benefit learners across different age groups (Tucker-Raymond et al., 2019). It also underscores the importance of considering learners' developmental stages when designing and implementing DGBL applications.

Digital games are increasingly being used as educational tools for learners of all ages, from elementary to high school students. These games effectively promote student learning achievement, interest, and collaboration. Specifically, well-designed digital games can offer interactive experiences encouraging skill-building and healthy development among young children. Research indicates that digital games can impact preschool children's behavior and can also be used to teach 21st century skills. In addition to younger learners, DGBL has positively affected learning among older individuals, particularly those aged 60 and above (Zhang & Kaufman, 2016). As digital technologies become more widely used by people of all ages, the potential for DGBL to support lifelong learning continues to grow (Kanyapasit & Srisawasdi, 2014).

Research Method

Numerous research approaches have investigated integrating digital games into biology education. Most studies (40 articles) have utilized a quantitative approach, while a smaller number (nine) have opted for qualitative methods. However, researchers are growing interested in employing mixed methods (two articles) to understand better how digital games can effectively enhance learning in biology education. The findings from these studies highlight that digital games have the potential to facilitate biology education through both quantitative and qualitative research approaches. Various digital games, such as gamified simulations, mobile games, and location-based games, have been utilized in biology education.

Presently, ongoing research studies are utilizing digital biology games to investigate their capacity as a tool for biology education. These games have shown promise in fostering students' problem-solving abilities and improving their comprehension of intricate scientific concepts. The predominant games employed in these studies are digital simulations resembling real-life scenarios. Additionally, some research has incorporated non-digital games, including board games and tailor-made cards. Integrating digital games in biology education is an emerging trend, with researchers delving into their effectiveness in enhancing students' scientific thinking, biological understanding, and digital literacy.

Collaborations of Academic Background in Biology Topic

DGBL relies heavily on interdisciplinary teamwork. These collaborations bring specialists and researchers from diverse academic fields to develop DGBL theory, application, and implementation (Vlachopoulos, 2017). These partnerships increase the range and depth of study and make creating creative (Klaassen, 2018), multidisciplinary strategies for using digital games for education easier. As shown in **Table 3**, authors generally engage in multidisciplinary collaborations spanning four main fields: science, biology, education, and computer science. This collaborative process serves as a potential strategy to optimize the utilization of DGBL. For instance, education experts provide insights into effective teaching strategies and learning outcomes, while computer scientists and game developers contribute technical expertise in creating engaging and interactive digital environments.

Interdisciplinary collaborations in DGBL promote a holistic approach to research and development (Kurniati et al., 2022), ensuring that digital learning games are

entertaining, pedagogically sound, and aligned with educational goals. The synergy arising from diverse academic backgrounds enables the exploration of novel ideas, the assessment of learning outcomes, and the refinement of game-based learning experiences to better cater to the needs of learners across various educational contexts and age groups. By integrating a wide spectrum of skills, collaborations across varied academic backgrounds play a crucial role in promoting the area of DGBL by producing meaningful, efficient, and engaging digital learning experiences (Timmis & Williams, 2017).

In this research review, the collaborative processes among researchers also represent how biology topics are presented and explored. The trends in biology topics currently investigated by researchers have evolved significantly beyond basic biology, expanding into applied biology fields, such as biomedical science. A closer examination of **Table 4** reveals that specific biology topics, including genetics, environment, and healthcare, are the most favored by researchers for instructional purposes using DGBL. Consistent with findings in applied biology, healthcare is also a component that intersects with biomedical topics (Molero et al., 2021). These interdisciplinary efforts by DGBL scholars reflect the growing significance of applied biology in modern pedagogy and contribute to the diversification of biology education. The emphasis on genetics, the environment, and healthcare-related themes is particularly indicative of the use of DGBL as a method to communicate difficult biological concepts.

Genetics, as a prominent subject within biology, offers unique opportunities for learners to engage with concepts related to heredity, genetic variation, and biotechnological advancements (Brown et al., 2018). Environment-related topics enable learners to explore critical ecological issues, such as sustainability and conservation, through immersive digital experiences (Tan & Nurul-Asna, 2023). Healthcare-focused topics empower students to delve into vital subjects like medical advancements, disease prevention, and public health, enhancing their understanding of real-world applications of biology (Suwono et al., 2021a). Fundamentally, the collaborative character of DGBL research improves the flexibility of biology instruction to consider changing trends in the discipline. Researchers use the potential of DGBL to make biology instruction more engaging, pertinent, and practical to the problems facing today's society by prioritizing genetics, environment, and health themes.

Technology Types & Game Elements

Using digital games in an educational context highlights the need for learner engagement in screen-based technological activities. Based on **Figure 4**, considering the trends that researchers have been most excited about in recent years, it is crucial to consider transitioning from computer-based technology to mobile games integrated with internet connectivity in future research. This transition will enable more flexible gaming experiences, particularly facilitating player-social interactions.

Technological advancement, particularly in DGBL, has changed how we approach learning. The advantages of conventional computer-based DGBL are undeniable. Still, the development and widespread use of mobile devices, reinforced by internet access, offers a chance to change the face of digital learning. Integrating mobile devices and internet connectivity into DGBL can offer several advantages. Firstly, mobile devices are inherently portable, allowing learners to engage in gaming almost anywhere and anytime. This flexibility not only makes learning more accessible but also enhances the potential for spontaneous and on-the-go interactions among players (Li et al., 2022).

Secondly, internet integration facilitates seamless connectivity among players (Kim, 2022). This opens up opportunities for multiplayer gaming experiences, allowing learners to collaborate, compete, and engage in social interactions within the virtual learning environment (Yang, 2020). This social dimension is crucial for enhancing learner engagement and motivation, as it satisfies the human desire for connection and community (Ewell et al., 2020). Moreover, mobile games provide quick feedback and clear objectives. Integrating mobile devices and Internet connectivity allows the design of games that naturally possess features that support clear goals and feedback.

The potential use of mobile games integrated with the internet aligns with the development trend of game elements that place greater emphasis on social interaction (**Table 5**). The use of the internet facilitates collaboration among students, enhancing the potential for optimizing the use of mobile games (Elsherbiny & Raya, 2021). For example, problems in biological learning often require solutions that involve student cooperation (Brown et al., 2018). Through social interactions, students can hone their collaborative problem-solving skills and participate in addressing considerable challenges through digital games. The collaborative process realized through social interaction is a vital strategy to facilitate students' acquiring 21st century skills (Thornhill-Miller et al., 2023).

Game Strategy & Its Implications

DGBL effectively teaches biology (Brown et al., 2018; Price et al., 2016). Designers can create games that tackle specific scientific problems and offer contextual learning experiences for students. Students who play and interact with games can act in the context of scientific issues that support their academic knowledge. There are various digital game formats for science learning and multiple methods for implementation and evaluation.

Digital games have proven to be a valuable tool for facilitating biological learning. Below are various formats of digital games that can be employed in biology education (Robinson et al., 2021):

1. Simulation games allow students to manipulate variables, conduct experiments, and observe realistic outcomes in a virtual environment.
2. Digital board games can involve adapting traditional games into digital versions. Students can engage with these games through electronic devices, tackling science concepts through challenges and assignments incorporated into the gameplay.
3. Puzzle games require students to solve puzzles, make decisions, and apply problem-solving strategies.
4. Real-life simulation games can present students with scenarios that reflect real-life situations, such as managing a zoo, city, or planet. Students can learn about ecosystems, human-environment interactions, and environmental issues through these games.

Digital games in biology learning have the potential to create an exciting and fun learning environment for students (Hou et al., 2022). Through the use of game elements such as challenges, goals, rewards, and competition, games can motivate students to be actively involved in the learning process (Alexiou, 2018; Fu et al., 2022). Additionally, using digital technology, games can present engaging visualizations, interactive simulations, and real-world situations, enabling students to understand complex biology concepts better (Suwono et al., 2017).

Implementing digital games in biology learning can also provide a contextual learning experience. In games, students can face situations or challenges that reflect fundamental problems in biology. They can apply their biology knowledge and skills in relevant contexts, enhancing their understanding and transferring their learning into everyday life. Empirical studies on using digital games in biology education have evolved to incorporate different technologies and will likely continue to do so. However, it is essential that research in this field is not limited to the technology itself but rather incorporate a didactic perspective that considers how the technology can be effectively used for teaching biology.

In recent years, there has been a growing emphasis on using digital technology to facilitate active learning, knowledge construction, and inquiry in the classroom (Suwono et al., 2021b). To effectively integrate digital technology into education, teachers must possess professional digital competence and the ability to incorporate technology to enhance learning outcomes (Falloon, 2020; Skantz-Åberg et al., 2022). This condition requires focusing on the technology and the pedagogical strategies to maximize effectiveness. Professional digital competence underscores the importance of teachers' abilities to use digital technology to support learning effectively (Fernández-Batanero et al., 2022). It highlights the need for ongoing professional development in this area.

The search results indicate that experiential learning is prominent in DGBL. The experiential gaming model is prevalent in designing and analyzing educational computer games. This model aligns with the principles of experiential learning theory, which emphasizes the importance of direct experience and reflective observation, making it a practical framework for integrating gameplay and pedagogy (Dabbous et al., 2022). In a game-based learning environment, users engage in immersive experiences, where they can learn new concepts and practice skills within a risk-free and safe setting. This condition fosters a sense of experiential learning, allowing learners to participate and apply their knowledge actively. By providing a fun, interactive, personalized, and challenging learning environment, game-based learning enables learners to acquire knowledge and experience its practical application.

Integrating experiential learning into DGBL enhances the educational experience by creating a dynamic and engaging platform for learners. Through gameplay, learners are immersed in virtual worlds, scenarios, and problem-solving tasks that stimulate their curiosity, critical thinking, and decision-making abilities. Digital games can be an excellent tool in cultivating 21st century skills such as critical thinking, cooperation, communication, and creativity (Kahila et al., 2020). Research has proven that games are a practical learning approach because they replicate adventure and involve pupils actively. For example, Perry and Klopfer (2014) used inquiry-based and immersive games to boost students' problem-solving and critical-thinking skills by integrating learning activities linked to the real world. The interactive nature of games promotes active participation and empowers learners to explore and experiment, leading to a deeper understanding of the subject matter.

Digital games designed based on relevant learning strategies or models have great potential to enrich the learning process. In creating this game, it is necessary to consider proven learning principles and effective learning strategies. By employing suitable approaches, digital games have the potential to offer players a captivating, interactive, and productive learning experience (Hou et al., 2022; Khan et al., 2017).

It is essential to create game activities that involve biology concepts in a comprehensive and relevant way. This case can be done by providing challenges related to biology material, bridging conceptual understanding with real life, and strengthening the link between theory and practice (Webb, 2015). By leveraging appropriate

learning strategies and models, games can facilitate students in comprehending biology concepts more profoundly, fostering analytical thinking and enhancing their problem-solving abilities.

In addition, it is also essential to ensure that the games are well-designed and match the needs of students (Alexiou, 2018). Good game design includes selecting challenging but achievable tasks; difficulty levels adapted to students' understanding levels, and feedback that provides clear guidance. In this regard, involving students in the game design and development process can be an effective strategy to ensure successful implementation.

The implementation of digital games in biology learning also provides several important implications. First, games can increase student involvement in education (Chau et al., 2023). Through engaging playing experiences, students tend to be more motivated to learn and more actively involved in the learning process (Yeo et al., 2022). In addition, games can also increase social interaction between students, either through collaboration in multiplayer games or discussions about game strategies. Furthermore, digital games can provide a personal and adaptive learning experience. By harnessing the power of technology, games can identify the unique learning requirements of individual students and deliver personalized feedback tailored to their needs. This condition allows students to learn at a rate and pace suited to their abilities and needs.

CONCLUSIONS, LIMITATIONS, & IMPLICATIONS

Conclusions

This SLR delivers intriguing findings. First, it is obvious that there has been a growing trend in the number of papers linked to DGBL in biology education themes during the previous decade. Second, the research trend in using DGBL in biology education indicates that high school students comprise the most significant proportion of educational level, followed by elementary and middle school students, community members, and university students. Third, the most commonly used research method for studying DGBL in biology education is quantitative, while qualitative methods are less frequently used. Fourth, research groups have diverse academic backgrounds. Collaboration based on academic backgrounds includes biology, applied biology, education, biomedicine, and technology. The research background that collaborates the most in DGBL in the field of biology education is teacher education and educational technology, followed by biology and computer science. Involving researchers from applied biology and biomedical fields provides an interrelated trend toward the topics used in DGBL research, especially researchers' attention to healthcare topics. Genetics, environment, and healthcare are the most frequently utilized subjects in DGBL. Fifth, this study revealed that the possible utilization of internet-integrated mobile games aligns with the emerging trend of game elements prioritizing social interaction. Internet usage fosters student collaboration, maximizing the potential for optimizing mobile game utilization. Sixth, the most commonly used learning models in DGBL, in order, are experiential learning, problem-based, inquiry-based and inquiry-lab. These learning strategies impact conceptual understanding, problem-solving, and strengthening the link between theory and practice. These findings can serve as essential references for researchers exploring topics related to DGBL in biology education, further connecting Biology topics with developing 21st century skills, particularly problem-solving, critical thinking, creativity, and cooperation.

Limitations

Our review contains numerous limitations that need to be considered. Firstly, although we made efforts to incorporate as many DGBL studies linked to biology learning as feasible, it is crucial to emphasize that the quality of these papers differs significantly. During our research process, we employed different filters and selection criteria. However, some papers may still need to reflect this topic accurately and comprehensively. With the expanding number of DGBL studies, future researchers may need to apply stricter selection criteria to ensure that only high-quality studies are included. Secondly, considering the diversity in DGBL research, these findings can also be studied from multiple angles. In addition to studying components of biology learning, these studies can be developed in terms of the efficiency of DGBL approaches, and the effect sizes of adopting technology in the learning process.

Implications

When examining the content of DGBL within the contemporary landscape of biology education, research patterns predominantly focus on particular domains, including genetics, healthcare, and cell biology. However, it is necessary to carry out further development in the future by containing more diverse content, for example, on contemporary environmental issues and plant structure and development. This idea will give students a more comprehensive understanding of various aspects of biology and their relevance to everyday life. In preparing DGBL, it is also essential to consider the learning strategies and models used as an integrative part of digital games. Learning models such as problem-based, experiential, inquiry, and project-based learning can be the right choice for developing DGBL. The selection of instructional models should align with students' learning goals and requirements. In this regard, DGBL can be a powerful medium for

fostering immersive and personalized learning experiences.

Computer-based and mobile games are the primary technologies used in this context, where social interaction and intellectual problem-solving form the foundation of the integrated gaming experience. This strategy allows players to enhance their collaborative skills, cooperation, and problem-solving abilities while engaging in an interactive and captivating gaming environment. These developments offer exciting potential for future research in DGBL. An untapped potential needs to be harnessed, especially considering that researchers have preferred integrating mobile games and the Internet in recent years, as learning can be more effective when the process is more flexible. With the continuous advancement in technology, games that utilize mobile gaming while considering game elements can provide an immersive and interactive learning environment, enabling players to learn concepts more practically and enjoyably.

This study implies that future studies should consider cooperation, particularly in the realm of applied biology. This advice stems from the observation that researchers have exhibited a specific interest in applied biology, notably in biomedical science, throughout the past decade. This finding suggests that interdisciplinary research that brings professionals from diverse domains within applied biology can provide useful insights and breakthroughs. DGBL has shown potential in promoting health. In the context of biomedical research and healthcare, DGBL can be utilized as an effective teaching tool to enhance 21st century skills. Future research should explore how DGBL can foster 21st century skills, such as self-regulated learning and other social skills.

Author contributions: RPS & HaS: conceptualization & writing, **RPS, HaS, M & HeS:** methodology & analysis, **RPS, HaS, M, HeS, C-YC & S-YL:** writing, proofreading, & editing. All authors have agreed with the results and conclusions.

Funding: This study was supported by Universitas Negeri Malang-Indonesia through International Research Collaboration Scheme (Decree Number: 5.4.1/UN32/KP/2023).

Ethical statement: The authors stated that this study does not require an ethical committee approval as it is a subject of comparison of theories & review of literature. Searching for data on the Scopus database is done via an official subscription account, namely Universitas Negeri Malang-Indonesia.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Abidin, Z., Sulthoni, & Susilaningsih. (2020). Development of game based learning biology course. In *Proceedings of the 1st International Conference on Information Technology and Education* (pp. 705-707). Atlantis Press. https://doi.org/10.2991/assehr.k.201214.323

Addy, T. M., Dube, D., Croft, C., Nardolilli, J. O., Paynter, O. C., Hutchings, M. L., Honsberger, M. J., & Reeves, P. M. (2018). Integrating a serious game into case-based learning. *Simulation and Gaming, 49*(4), 378-400. https://doi.org/10.1177/1046878118779416

Adita, A. (2020). Trends of instructional research using biology game: A systematic review of the evidence during 2010-2019. In *Proceedings of the 28th International Conference on Computers in Education* (pp. 418-424).

Adita, A., Ratnaningtyas, A., Nugraheni, E., & Srisawasdi, N. (2021). Game-based biology learning: A systematic review of the literature during 2010-2019. *Journal of Education Khon Kaen University, 44*(2).

Aguilera, E., & de Roock R. (2022). Digital game-based learning: Foundations, applications, and origins of digital game-based learning and related terms. *Oxford Research Encyclopedias*. https://doi.org/10.1093/acrefore/9780190264093.013.1438

Aivelo, T., & Uitto, A. (2016). Digital gaming for evolutionary biology learning: The case study of parasite race, an augmented reality location-based game. *Lumat, 4*(1), 1-26. https://doi.org/10.31129/LUMAT.4.1.3

Alexiou, A. (2018). Digital game elements, user experience and learning: A conceptual framework. *Education and Information Technologies, 23*(6), 2545-2567. https://doi.org/10.1007/s10639-018-9730-6

All, A., Castellar, E. P. N., & Looy, J. Van. (2013). A systematic literature review of methodology used to measure effectiveness in digital game-based learning. In *Proceedings of the 7th European Conference on Games Based Learning* (pp. 607-616).

Alrehaili, E. A., & Al Osman, H. (2022). A virtual reality role-playing serious game for experiential learning. *Interactive Learning Environments, 30*(5), 922-935. https://doi.org/10.1080/10494820.2019.1703008

Antón-Solanas, I, Rodríguez-Roca, B., Urcola-Pardo, F., Anguas-Gracia, A., Satústegui-Dordá, P. J., Echániz-Serrano, E., & Subirón-Valera, A. B. (2022). An evaluation of undergraduate student nurses' gameful experience whilst playing a digital escape room as part of a FIRST year module: A cross-sectional study. *Nurse Education Today, 118*, 105527. https://doi.org/10.1016/j.nedt.2022.105527

Arztmann, M., Hornstra, L., Jeuring, J., & Kester, L. (2022). Effects of games in STEM education: A meta-analysis on the moderating role of student background characteristics. *Studies in Science Education, 59*(1), 109-145. https://doi.org/10.1080/03057267.2022.2057732

Barwood, D., Smith, S., Miller, M., Boston, J., Masek, M., & Devine, A. (2020). Transformational game trial in nutrition education. *Australian Journal of Teacher Education, 45*(4), 18-29. https://doi.org/10.14221/ajte.2020v45n4.2

Behnamnia, N. (2022). A review of using digital game-based learning for preschoolers. *Journal of Computers in Education, 10*, 603-636. https://doi.org/10.1007/s40692-022-00240-0

Bouris, A., Mancino, J., Jagoda, P., Hill, B. J., & Gilliam, M. (2016). Reinvigorating adolescent sexuality education through alternate reality games: The case of the source. *Sex Education, 16*(4), 353-367. https://doi.org/10.1080/14681811.2015.1101373

Bouzid, T., Kaddari, F., Darhmaoui, H., & Bouzid, E. G. (2021). Enhancing math-class experience throughout digital game-based learning, the case of Moroccan elementary public schools. *International Journal of Modern Education and Computer Science, 13*(5), 1-13. https://doi.org/10.5815/ijmecs.2021.05.01

Brown, C. L., Comunale, M. A., Wigdahl, B., & Urdaneta-Hartmann, S. (2018). Current climate for digital game-based learning of science in further and higher education. *FEMS Microbiology Letters, 365*(21), fny237. https://doi.org/10.1093/femsle/fny237

Buyukozturk, B., & Shay, H. (2022). Social play? The critical role of social interaction in geeky games. *Leisure Sciences*. https://doi.org/10.1080/01490400.2022.2036274

Carrera-Rivera, A., Ochoa, W., Larrinaga, F., & Lasa, G. (2022). How-to conduct a systematic literature review: A quick guide for computer science research. *MethodsX, 9*, 101895. https://doi.org/10.1016/j.mex.2022.101895

Casanoves, M., Salvadó, Z., González, Á., Valls, C., & Novo, M. T. (2017). Learning genetics through a scientific inquiry game. *Journal of Biological Education, 51*(2), 99-106. https://doi.org/10.1080/00219266.2016.1177569

Casanoves, M., Solé-llussà, A., Haro, J., Gericke, N., Casanoves, M., Valls, C., Solé-llussà, A., & Haro, J. (2022). Assessment of the ability of game-based science learning to enhance genetic understanding enhance genetic understanding. *Research in Science & Technological Education, 41*(4), 1496-1518. https://doi.org/10.1080/02635143.2022.2044301

Chang, C. Y., Kao, C. H., Hwang, G. J., & Lin, F. H. (2020). From experiencing to critical thinking: A contextual game-based learning approach to improving nursing students' performance in Electrocardiogram training. *Educational Technology Research and Development, 68*(3), 1225-1245. https://doi.org/10.1007/s11423-019-09723-x

Chang, S. C., & Hwang, G. J. (2017). Development of an effective educational computer game based on a mission synchronization-based peer-assistance approach. *Interactive Learning Environments, 25*(5), 667-681. https://doi.org/10.1080/10494820.2016.1172241

Chau, D., Yong, W., & Huang, M. (2023). Exploring the influence of competition and collaboration on learning performance in digital game-based learning. *Educational Technology Research and Development, 71*, 1547-1565. https://doi.org/10.1007/s11423-023-10247-8

Chen, C. C. (2021). The effect of digital game-based learning on learning motivation and performance under social cognitive theory and entrepreneurial thinking. *Frontiers in Psychology, 12*. https://doi.org/10.3389/fpsyg.2021.750711

Chen, C.-H., Shih, C.-C., & Law, V. (2020). The effects of competition in digital game-based learning (DGBL): A meta-analysis. *Educational Technology Research and Development, 68*(4), 1855-1873. https://doi.org/10.1007/s11423-020-09794-1

Chen, M.-B., Wang, S.-G., Chen, Y.-N., Chen, X.-F., & Lin, Y.-Z. (2020). A preliminary study of the influence of game types on the learning interests of primary school students in digital games. *Education Sciences, 10*(4), 96. https://doi.org/10.3390/educsci10040096

Chen, S. W., Yang, C. H., Huang, K. S., & Fu, S. L. (2019). Digital games for learning energy conservation: A study of impacts on motivation, attention, and learning outcomes. *Innovations in Education and Teaching International, 56*(1), 66-76. https://doi.org/10.1080/14703297.2017.1348960

Chen, Y.-C. (2017). Empirical study on the effect of digital game-based instruction on students' learning motivation and achievement. *EURASIA Journal of Mathematics, Science and Technology Education, 13*(7), 3177-3187. https://doi.org/10.12973/eurasia.2017.00711a

Cheng, M. T., Chou, W. C., Hsu, M. E., & Cheng, F. C. (2022). Blending educational gaming with physical experiments to engage high school students in inquiry-based learning. *Journal of Biological Education*. https://doi.org/10.1080/00219266.2022.2157861

Chin, J.-C., & Tsuei, M. (2014). A multi-modal digital game-based learning environment for hospitalized children with chronic illnesses. *Educational Technology and Society, 17*(4), 366-378.

Christopoulos, A., Mystakidis, S., Cachafeiro, E., & Laakso, M. J. (2022). Escaping the cell: Virtual reality escape rooms in biology education. *Behavior & Information Technology, 42*(9), 1434-1451. https://doi.org/10.1080/0144929X.2022.2079560

Ciloglu, T., & Ustun, A. B. (2023). The effects of mobile AR-based biology learning experience on students' motivation, self-efficacy, and attitudes in online learning. *Journal of Science Education and Technology, 32*, 309-337. https://doi.org/10.1007/s10956-023-10030-7

Cole, M., & Stewart, K. (2017). 'A new life in the countryside awaits'*: Interactive lessons in the rural utopia in 'farming' simulation games. *Discourse, 38*(3), 402-415. https://doi.org/10.1080/01596306.2017.1306985

Culp, K. M. M., Martin, W., Clements, M., & Lewis Presser, A. (2015). Testing the impact of a pre-instructional digital game on middle-grade students' understanding of photosynthesis. *Technology, Knowledge and Learning, 20*(1), 5-26. https://doi.org/10.1007/s10758-014-9233-5

Dabbous, M., Kawtharani, A., Fahs, I., Hallal, Z., Shouman, D., Akel, M., Rahal, M., & Sakr, F. (2022). The role of game-based learning in experiential education: Tool validation, motivation assessment, and outcomes evaluation among a sample of pharmacy students. *Education Sciences, 12*(7), 434. https://doi.org/10.3390/educsci12070434

de Almeida, L. G., Pasternak Taschner, N., & Lellis-Santos, C. (2021). Outbreak! An online board game that fosters collaborative learning of viral diseases. *Journal of Microbiology & Biology Education, 22*(1), 10-13. https://doi.org/10.1128/jmbe.v22i1.2539

de la Vega, G. J., Falconaro, A. C., Soria, L., & Corley, J. C. (2022). Integrated pest management education: A video-game to improve management of drosophila Suzuki, soft-skin fruit pest. *Neotropical Entomology, 51*(5), 801-807. https://doi.org/10.1007/s13744-022-00977-4

Elsherbiny, M. M. K., & Raya, R. H. (2021). Game-based learning through mobile phone apps: Effectively enhancing learning for social work students. *Social Work Education, 40*(3), 315-332. https://doi.org/10.1080/02615479.2020.1737665

Erhel, S., & Jamet, E. (2013). Digital game-based learning: Impact of instructions and feedback on motivation and learning effectiveness. *Computers & Education, 67*, 156-167. https://doi.org/10.1016/j.compedu.2013.02.019

Ewell, P. J., Quist, M. C., Øverup, C. S., Watkins, H., & Guadagno, R. E. (2020). Catching more than pocket monsters: Pokémon Go's social and psychological effects on players. *Journal of Social Psychology, 160*(2), 131-136. https://doi.org/10.1080/00224545.2019.1629867

Falloon, G. (2020). From digital literacy to digital competence: The teacher digital competency (TDC) framework. *Educational Technology Research and Development, 68*(5), 2449-2472. https://doi.org/10.1007/s11423-020-09767-4

Felszeghy, S., Pasonen-seppänen, S., Koskela, A., Nieminen, P., Härkönen, K., Paldanius, K. M. A., Gabbouj, S., Ketola, K., Hiltunen, M., Lundin, M., Haapaniemi, T., Sointu, E., Bauman, E. B., Gilbert, G. E., Morton, D., & Mahonen, A. (2019). Using online game-based platforms to improve student performance and engagement in histology teaching. *BMC Medical Education, 19*, 273. https://doi.org/10.1186/s12909-019-1701-0

Fernández-Batanero, J. M., Montenegro-Rueda, M., Fernández-Cerero, J., & García-Martínez, I. (2022). Digital competences for teacher professional development: Systematic review. *European Journal of Teacher Education, 45*(4), 513-531. https://doi.org/10.1080/02619768.2020.1827389

Foss, B., Løkken, A., Leland, A., Stordalen, J., Mordt, P., & Oftedal, B. F. (2014). Digital game-based learning: A supplement for medication calculation drills in nurse education. *E-Learning and Digital Media, 11*(4), 342-349. https://doi.org/10.2304/elea.2014.11.4.342

Fu, Q. K., Zou, D., Xie, H., Cheng, G., & Hwang, G. J. (2022). Effects of a collaborative design approach on pre-service teachers' ability of designing for learning with a digital game. *Education and Information Technologies, 27*(4), 5641-5664. https://doi.org/10.1007/s10639-021-10818-3

Gauthier, A., Corrin, M., & Jenkinson, J. (2015). Exploring the influence of game design on learning and voluntary use in an online vascular anatomy study aid. *Computers & Education, 87*, 24-34. https://doi.org/10.1016/j.compedu.2015.03.017

Go, M., Golbin, R. A., Velos, S., Dayupay, J., Dionaldo, W., Cababat, F., Bongo, M., Troussas, C., & Ocampo, L. (2022). Evaluating digital mathematical games in improving the basic mathematical skills of university students. *International Journal of Mathematical Education in Science and Technology, 55*(4), 899-921. https://doi.org/10.1080/0020739X.2022.2089604

Guan, X., Sun, C., Hwang, G. J, Xue, K., & Wang, Z. (2022). Applying game-based learning in primary education: A systematic review of journal publications from 2010 to 2020. *Interactive Learning Environments, 32*(2), 534-556. https://doi.org/10.1080/10494820.2022.2091611

Hacioglu, Y., & Donmez Usta, N. (2020). Digital game design-based STEM activity: Biodiversity example. *Science Activities, 57*(1), 1-15. https://doi.org/10.1080/00368121.2020.1764468

Haddaway, N. R., Page, M. J., Pritchard, C. C., & McGuinness, L. A. (2022). PRISMA2020: An R package and Shiny app for producing PRISMA

2020-compliant flow diagrams, with interactivity for optimized digital transparency and open synthesis. *Campbell Systematic Reviews, 18*(2), e1230. https://doi.org/10.1002/cl2.1230

Hartt, M., Hosseini, H., & Mostafapour, M. (2020). Game on: Exploring the effectiveness of game-based learning. *Planning Practice and Research, 35*(5), 589-604. https://doi.org/10.1080/02697459.2020.1778859

Hawkins, W. D., Grush, E. R., & Klionsky, D. J. (2023). The world's first (and probably last) autophagy video game. *Autophagy, 19*(1), 352-357. https://doi.org/10.1080/15548627.2022.2143212

Hou, X., Nguyen, H. A., Richey, J. E., Harpstead, E., Hammer, J., & McLaren, B. M. (2022). Assessing the effects of open models of learning and enjoyment in a digital learning game. *International Journal of Artificial Intelligence in Education, 32*(1), 120-150. https://doi.org/10.1007/s40593-021-00250-6

Howard, S., Buttke, D. E., Lovejoy, T. E., Clark, K. A., Ashby, E. J., & Alonso Aguirre, A. (2021). The loop trail "quest": Use of a choice-based digital simulation, an interactive video, and a booklet to communicate and analyze decision-making of park visitors. *Environmental Communication, 15*(8), 1025-1044. https://doi.org/10.1080/17524032.2021.1927129

Huang, Y. M., Huang, S. H., & Wu, T. T. (2014). Embedding diagnostic mechanisms in a digital game for learning mathematics. *Educational Technology Research and Development, 62*(2), 187-207. https://doi.org/10.1007/s11423-013-9315-4

Hwang, G J. (2020). Facilitating decision-making performances in nursing treatments: A contextual digital game-based flipped learning approach. *Interactive Learning Environments, 31*(1), 156-171. https://doi.org/10.1080/10494820.2020.1765391

Hwang, G. J., & Chen, C. H. (2016). Influences of an inquiry-based ubiquitous gaming design on students' learning achievements, motivation, behavioral patterns, and tendency towards critical thinking and problem solving. *British Journal of Educational Technology, 48*(4), 950-971. https://doi.org/10.1111/bjet.12464

Ibharim, L. F. M. (2019). Development of rubric to measure children's 21st century skills in digital game-based learning. *Universal Journal of Educational Research, 7*(10), 7-12. https://doi.org/10.13189/ujer.2019.071702

Ishak, S. A., Hasran, U. A., & Din, R. (2023). Media education through digital games: A review on design and factors influencing learning performance. *Education Sciences, 13*(2), 102. https://doi.org/10.3390/educsci13020102

Janakiraman, S., Watson, S. L., & Watson, W. R. (2018). Using game-based learning to facilitate attitude change for environmental sustainability. *Journal of Education for Sustainable Development, 12*(2), 176-185. https://doi.org/10.1177/0973408218783286

Kahila, J., Valtonen, T., Tedre, M., Mäkitalo, K., & Saarikoski, O. (2020). Children's experiences on learning the 21st century skills with digital games. *Games and Culture, 15*(6), 685-706. https://doi.org/10.1177/1555412019845592

Kalogiannakis, M., Papadakis, S., & Zourmpakis, A. I. (2021). Gamification in science education. A systematic review of the literature. *Education Sciences, 11*(1), 22. https://doi.org/10.3390/educsci11010022

Kanyapasit, P., & Srisawasdi, N. (2014). Development of Digital game-based biology learning experience on cell cycle through DSLM instructional approach. In *Proceedings of the 22nd International Conference on Computers in Education* (pp. 857-866).

Kao, C. W. (2020). The effect of a digital game-based learning task on the acquisition of the English article system. *System, 95*, 102373. https://doi.org/10.1016/j.system.2020.102373

Khan, A., Ahmad, F. H., & Malik, M. M. (2017). Use of digital game based learning and gamification in secondary school science: The effect on student engagement, learning and gender difference. *Education and Information Technologies, 22*(6), 2767-2804. https://doi.org/10.1007/s10639-017-9622-1

Kim, S. (2022). Two-phase wireless bandwidth allocation scheme based on cooperative game solutions. *Wireless Personal Communications, 127*(4), 3061-3077. https://doi.org/10.1007/s11277-022-09910-9

Klaassen, R. G. (2018). Interdisciplinary education: A case study. *European Journal of Engineering Education, 43*(6), 842-859. https://doi.org/10.1080/03043797.2018.1442417

Klit, K. J. M., Nielsen, C. K., & Stege, H. (2020). Iterative development of a digital game-based learning concept: Introduction of veterinary herd health management in a virtual pig herd. *Journal of Veterinary Medical Education, 47*(4), 523-531. https://doi.org/10.3138/JVME.0618-073R2

Kostenius, C., Hallberg, J., & Lindqvist, A. K. (2018). Gamification of health education: Schoolchildren's participation in the development of a serious game to promote health and learning. *Health Education, 118*(4), 354-368. https://doi.org/10.1108/HE-10-2017-0055

Kurniati, E., Suwono, H., Ibrohim, I., Suryadi, A., & Saefi, M. (2022). International scientific collaboration and research topics on STEM education: A systematic review. *EURASIA Journal of Mathematics, Science and Technology Education,*

18(4), em2095. https://doi.org/10.29333/ejmste/11903

Lam, J. T., Gutierrez, M. A., Goad, J. A., Odessky, L., & Bock, J. (2019). Use of virtual games for interactive learning in a pharmacy curriculum. *Currents in Pharmacy Teaching and Learning, 11*(1), 51-57. https://doi.org/10.1016/j.cptl.2018.09.012

Lawson, D. F., Stevenson, K. T., Peterson, M. N., Carrier, S. J., Seekamp, E., & Strnad, R. (2019). Evaluating climate change behaviors and concern in the family context. *Environmental Education Research, 25*(5), 678-690. https://doi.org/10.1080/13504622.2018.1564248

Lee, Y. N., & Zhu, M. (2022). Digital game-based learning can develop students' literacy skills and meet learning standards in the US. *Computers in the Schools, 39*(3), 274-296. https://doi.org/10.1080/07380569.2022.2075163

Leith, A. P., Ratan, R. A., & Wohn, D. Y. (2016). The (de-)evolution of evolution games: A content analysis of the representation of evolution through natural selection in digital games. *Journal of Science Education and Technology, 25*(4), 655-664. https://doi.org/10.1007/s10956-016-9620-x

Li, F.-Y., Hwang, G.-J., Chen, P.-Y., & Lin, Y.-J. (2021). Effects of a concept mapping-based two-tier test strategy on students' digital game-based learning performances and behavioral patterns. *Computers & Education, 173*, 104293. https://doi.org/10.1016/j.compedu.2021.104293

Li, K., Peterson, M., & Wang, Q. (2022). Out-of-school language learning through digital gaming: A case study from an activity theory perspective. *Computer Assisted Language Learning*. https://doi.org/10.1080/09588221.2022.2067181

Li, Y., Xu, Z., Hao, Y., Xiao, P., & Liu, J. (2022). Psychosocial impacts of mobile game on K12 students and trend exploration for future educational mobile games. *Frontiers in Education, 7*. https://doi.org/10.3389/feduc.2022.843090

Lin, C.-S., & Yang, C.-C. (2023). Evaluation of a digital game for teaching behavioral aspects of clinical communication in dentistry. *BMC Medical Education, 23*, 78. https://doi.org/10.1186/s12909-023-04040-7

Lookadoo, K. L., Bostwick, E. N., Ralston, R., Elizondo, F. J., Wilson, S., Shaw, T. J., & Jensen, M. L. (2017). "I forgot I wasn't saving the world": The use of formative and summative assessment in instructional video games for undergraduate biology. *Journal of Science Education and Technology, 26*(6), 597-612. https://doi.org/10.1007/s10956-017-9701-5

Luo, Z. (2022). Gamification for educational purposes: What are the factors contributing to varied effectiveness? *Education and Information Technologies, 27*(1), 891-915. https://doi.org/10.1007/s10639-021-10642-9

Maddison, J. A., Kržić, M., Simard, S., Adderly, C., & Khan, S. (2018). Shroomroot: An action-based digital game to enhance postsecondary teaching and learning about mycorrhizae. *American Biology Teacher, 80*(1), 11-20. https://doi.org/10.1525/abt.2018.80.1.11

Mengist, W., Soromessa, T., & Legese, G. (2020). Method for conducting systematic literature review and meta-analysis for environmental science research. *MethodsX, 7*, 100777. https://doi.org/10.1016/j.mex.2019.100777

Molero, A., Calabrò, M., Vignes, M., Gouget, B., & Gruson, D. (2021). Sustainability in healthcare: Perspectives and reflections regarding laboratory medicine. *Annals of Laboratory Medicine, 41*(2), 139-144. https://doi.org/10.3343/alm.2021.41.2.139

Noroozi, O. (2018). Considering students' epistemic beliefs to facilitate their argumentative discourse and attitudinal change with a digital dialogue game. *Innovations in Education and Teaching International, 55*(3), 357-365. https://doi.org/10.1080/14703297.2016.1208112

Novoseltseva, D., Lelardeux, C. P., & Jessel, N. (2022). Examining students' behavior in a digital simulation game for nurse training. *International Journal of Serious Games, 9*(4), 3-24. https://doi.org/10.17083/ijsg.v9i4.543

Oliver, J. S., Hodges, G. W., Moore, J. N., Cohen, A., Jang, Y., Brown, S. A., Kwon, K. A., Jeong, S., Raven, S. P., Jurkiewicz, M., & Robertson, T. P. (2019). Supporting high school student accomplishment of biology content using interactive computer-based curricular case studies. *Research in Science Education, 49*(6), 1783-1808. https://doi.org/10.1007/s11165-017-9675-6

Page, M. J., Moher, D., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., …, & McKenzie, J. E. (2021). PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews. *BMJ, 372*, n160. https://doi.org/10.1136/bmj.n160

Perry, J., & Klopfer, E. (2014). UbiqBio: Adoptions and outcomes of mobile biology games in the ecology of school. *Computers in the Schools, 31*(1-2), 43-64. https://doi.org/10.1080/07380569.2014.879771

Polit, D. F., & Beck, C. T. (2010). Generalization in quantitative and qualitative research: Myths and strategies. *International Journal of Nursing Studies,*

47(11), 1451-1458. https://doi.org/10.1016/j.ijnurstu.2010.06.004

Pombo, L., & Marques, M. M. (2019). Improving students' learning with a mobile augmented reality approach–The EduPARK game. *Interactive Technology and Smart Education, 16*(4), 392-406. https://doi.org/10.1108/ITSE-06-2019-0032

Price, C. A., Gean, K., Christensen, C. G., Beheshti, E., Pernot, B., Segovia, G., Person, H., Beasley, S., & Ward, P. (2016). Casual games and casual learning about human biological systems. *Journal of Science Education and Technology, 25*(1), 111-126. https://doi.org/10.1007/s10956-015-9580-6

Puttick, G. (2018). Building systems from Scratch: An exploratory study of students learning about climate change. *Journal of Science Education and Technology, 27*, 306-321. https://doi.org/10.1007/s10956-017-9725-x

Radhakrishnan, K., Toprac, P., O'Hair, M., Bias, R., Kim, M. T., Bradley, P., & MacKert, M. (2016). Interactive digital e-health game for heart failure self-management: A feasibility study. *Games for Health Journal, 5*(6), 366-374. https://doi.org/10.1089/g4h.2016.0038

Razali, N. E. M., Ramli, R. Z., Mohamed, H., Mat Zin, N. A., Rosdi, F., & Mat Diah, N. (2022). Identifying and validating game design elements in serious game guideline for climate change. *Heliyon, 8*(1), e08773. https://doi.org/10.1016/j.heliyon.2022.e08773

Ristanto, R. H. (2022). Flipped classroom–Digital game-based learning (FC-DGBL): Enhancing genetics conceptual understanding of students in bilingual program. *Journal of Turkish Science Education, 19*(1), 328-348. https://doi.org/10.36681/tused.2022.1124

Robinson, G. M., Hardman, M., & Matley, R. J. (2021). Using games in geographical and planning-related teaching: Serious games, edutainment, board games and role-play. *Social Sciences & Humanities Open, 4*(1), 100208. https://doi.org/10.1016/j.ssaho.2021.100208

Rosenheck, L., Cheng, M. T., Lin, C. Y., & Klopfer, E. (2021). Approaches to illuminate content-specific gameplay decisions using open-ended game data. *Educational Technology Research and Development, 69*(2), 1135-1154. https://doi.org/10.1007/s11423-021-09989-0

Roukouni, A., Lukosch, H., Verbraeck, A., & Zuidwijk, R. (2020). Let the game begin: Enhancing sustainable collaboration among actors in innovation ecosystems in a playful way. *Sustainability, 12*(20), 8494. https://doi.org/10.3390/su12208494

Sadler, T. (2013). Game-based curricula in biology classes: Differential effects among varying academic levels. *Journal of Research in Science Teaching, 50*(4), 479-499. https://doi.org/10.1002/tea.21085

Sadler, T. D. (2015). Learning biology through innovative curricula: A comparison of game- and nongame-based approaches. *Science Education, 99*(4), 696-720. https://doi.org/10.1002/sce.21171

Sandbrook, C. (2015). Digital games and biodiversity conservation. *Conservation Letters, 8*(2), 118-124. https://doi.org/10.1111/conl.12113

Sardone, N. B., & Devlin-Scherer, R. (2010). Teacher candidate responses to digital games: 21st century skills development. *Journal of Research on Technology in Education, 42*(4), 409-425. https://doi.org/10.1080/15391523.2010.10782558

Schneider, J., & Schaal, S. (2018). Location-based smartphone games in the context of environmental education and education for sustainable development: Fostering connectedness to nature with geo-games. *Environmental Education Research, 24*(11), 1597-1610. https://doi.org/10.1080/13504622.2017.1383360

Silva, M. F. M., Martins, P. M., Mariano, D. C. B., Santos, L. H., Pastorini, I., Pantuza, N., Nobre, C. N., & de Melo-Minardi, R. C. (2019). Proteingo: Motivation, user experience, and learning of molecular interactions in biological complexes. *Entertainment Computing, 29*, 31-42. https://doi.org/10.1016/j.entcom.2018.11.001

Skantz-Åberg, E., Lantz-Andersson, A., Lundin, M., & Williams, P. (2022). Teachers' professional digital competence: An overview of conceptualizations in the literature. *Cogent Education, 9*(1), 2063224. https://doi.org/10.1080/2331186X.2022.2063224

Smiderle, R., Rigo, S. J., Marques, L. B., Peçanha de Miranda Coelho, J. A., & Jaques, P. A. (2020). The impact of gamification on students' learning, engagement and behavior based on their personality traits. *Smart Learning Environments, 7*, 3. https://doi.org/10.1186/s40561-019-0098-x

Solé-Llussà, A. (2019). Annapurna expedition game: applying molecular biology tools to learn genetics. *Journal of Biological Education, 53*(5), 516-523. https://doi.org/10.1080/00219266.2018.1501409

Solé-Llussà, Anna, Aguilar, D., & Ibáñez, M. (2021). Video worked examples to promote elementary students' science process skills: A fruit decomposition inquiry activity. *Journal of Biological Education, 55*(4), 368-379. https://doi.org/10.1080/00219266.2019.1699149

Subhash, S. (2018). Gamified learning in higher education: A systematic review of the literature. *Computers in Human Behavior, 87*, 192-206. https://doi.org/10.1016/j.chb.2018.05.028

Supriana, I., Agustin, R. D., Bakar, M. A., & Zin, N. A. M. (2018). Serious games for effective learning. In *Proceedings of the 2017 6th International Conference on Electrical Engineering and Informatics: Sustainable Society Through Digital Innovation* (pp. 1-6). https://doi.org/10.1109/ICEEI.2017.8312466

Suwono, H, Pratiwi, H. E., Susanto, H., & Susilo, H. (2017). Enhancement of students' biological literacy and critical thinking of biology through socio-biological case-based learning. *Jurnal Pendidikan IPA Indonesia, 6*(2), 213-222. https://doi.org/10.15294/jpii.v6i2.9622

Suwono, H., Maulidia, L., Saefi, M., Kusairi, S., & Yuenyong, C. (2022). The development and validation of an instrument of prospective science teachers' perceptions of scientific literacy. *Eurasia Journal of Mathematics, Science and Technology Education, 18*(1), em2068. https://doi.org/10.29333/ejmste/11505

Suwono, H., Permana, T., Saefi, M., & Fachrunnisa, R. (2021a). The problem-based learning (PBL) of biology for promoting health literacy in secondary school students. *Journal of Biological Education, 00*(00), 1-15. https://doi.org/10.1080/00219266.2021.1884586

Suwono, H., Rofi'Ah, N. L., Saefi, M., & Fachrunnisa, R. (2021b). Interactive socio-scientific inquiry for promoting scientific literacy, enhancing biological knowledge, and developing critical thinking. *Journal of Biological Education, 00*(00), 1-16. https://doi.org/10.1080/00219266.2021.2006270

Tan, C. K. W., & Nurul-Asna, H. (2023). Serious games for environmental education. *Integrative Conservation, 2*(1), 19-42. https://doi.org/10.1002/inc3.18

Thornhill-Miller, B., Camarda, A., Mercier, M., Burkhardt, J.-M., Morisseau, T., Bourgeois-Bougrine, S., Vinchon, F., El Hayek, S., Augereau-Landais, M., Mourey, F., Feybesse, C., Sundquist, D., & Lubart, T. (2023). Creativity, critical thinking, communication, and collaboration: Assessment, certification, and promotion of 21st century skills for the future of work and education. *Journal of Intelligence, 11*(3), 54. https://doi.org/10.3390/jintelligence11030054

Timmis, S., & Williams, J. (2017). Playing the interdisciplinary game across education–Medical education boundaries: Sites of knowledge, collaborative identities and methodological innovations. *International Journal of Research and Method in Education, 40*(3), 257-269. https://doi.org/10.1080/1743727X.2017.1299125

Tsopra, R., Courtine, M., Sedki, K., Eap, D., Cabal, M., Cohen, S., Bouchaud, O., Mechaï, F., & Lamy, J. B. (2020). AntibioGame®: A serious game for teaching medical students about antibiotic use. *International Journal of Medical Informatics, 136*, 104074. https://doi.org/10.1016/j.ijmedinf.2020.104074

Tucker-raymond, E., Puttick, G., Cassidy, M., Harteveld, C., & Troiano, G. M. (2019). "I broke your game!": Critique among middle schoolers designing computer games about climate change. *International Journal of STEM Education, 6*, 41. https://doi.org/10.1186/s40594-019-0194-z

Vlachopoulos, D. (2017). The effect of games and simulations on higher education: A systematic literature review. *International Journal of Educational Technology in Higher Education, 14*, 22. https://doi.org/10.1186/s41239-017-0062-1

von Kotzebue, L. (2022). Digital escape rooms as game-based learning environments: A study in sex education. *Multimodal Technologies and Interaction, 6*(2), 8. https://doi.org/10.3390/mti6020008

von Kotzebue, L., Förtsch, C., Förtsch, S., & Neuhaus, B. J. (2022). Dealing with student errors in whole-class discussions of biology lessons at German secondary schools. *International Journal of Science and Mathematics Education, 20*(3), 459-480. https://doi.org/10.1007/s10763-021-10171-4

Wallin, J. (2022). Game preserves: Digital animals at the brink of the post-Anthropocene. *Green Letters, 26*(1), 102-115. https://doi.org/10.1080/14688417.2021.2023607

Wang, A., Thompson, M., Roy, D., Pan, K., Perry, J., Tan, P., Eberhart, R., & Klopfer, E. (2019). Iterative user and expert feedback in the design of an educational virtual reality biology game. *Interactive Learning Environments, 30*(4), 677-694. https://doi.org/10.1080/10494820.2019.1678489

Wang, L. H. (2022). Effects of digital game-based STEM education on students' learning achievement: A meta-analysis. *International Journal of STEM Education, 9*, 26. https://doi.org/10.1186/s40594-022-00344-0

Wang, X.-M., Wang, S.-M., Wang, J.-N., Hwang, G.-J., & Xu, S. (2022). Effects of a two-tier test strategy on students' digital game-based learning performances and flow experience in environmental education. *Journal of Educational Computing Research, 60*(8), 1942-1968. https://doi.org/10.1177/07356331221095162

Webb, A. (2015). Agriscience teachers' implementation of digital game-based learning in an introductory animal science course. *Journal of Science Education and Technology, 24*(6), 888-897. https://doi.org/10.1007/s10956-015-9571-7

Wildan, A., Yau, C. D., Ng, E. M. W., Xiao, K., Liew, O. W., & Ng, T. W. (2020). Algae photosynthesis and respiration experimentation with physical and augmented reality modes. *Journal of Biological*

Education, 56(2), 163-173. https://doi.org/10.1080/00219266.2020.1757487

Wilson, C. D. (2018). Teacher implementation and the impact of game-based science curriculum materials. *Journal of Science Education and Technology, 27*(4), 285-305. https://doi.org/10.1007/s10956-017-9724-y

Wilson, E. (2018). 'Diagrams of motion': Stop-motion animation as a form of kinetic sculpture in the short films of Jan Švankmajer and the Brothers Quay. *Animation, 13*(2), 148-161. https://doi.org/10.1177/1746847718782890

Wommer, F. G. B. (2021). Insects GO: A gaming activity for entomology teaching in middle school. *Research in Science and Technological Education, 41*(2), 581-595. https://doi.org/10.1080/02635143.2021.1921724

Wu, M. L., Richards, K., & Saw, G. K. (2014). Examining a massive multiplayer online role-playing game as a digital game-based learning platform. *Computers in the Schools, 31*(1-2), 65-83. https://doi.org/10.1080/07380569.2013.878975

Xiao, Y., & Watson, M. (2019). Guidance on conducting a systematic literature review. *Journal of Planning Education and Research, 39*(1), 93-112. https://doi.org/10.1177/0739456X17723971

Yang, J. C. (2020). An investigation of game behavior in the context of digital game-based learning: An individual difference perspective. *Computers in Human Behavior, 112*, 106432. https://doi.org/10.1016/j.chb.2020.106432

Yang, Y. C. (2013). Empowering students through digital game authorship: Enhancing concentration, critical thinking, and academic achievement. *Computers & Education, 68*, 334-344. https://doi.org/10.1016/j.compedu.2013.05.023

Yeo, C. L., Ho, S. K. Y., Tagamolila, V. C., Arunachalam, S., Bharadwaj, S. S., Poon, W. B., Tan, M. G., Edison, P. E., Yip, W. Y., Haium, A. A. A., Jayagobi, P. A., Vora, S. J., Khurana, S. K., Allen, J. C., & Lustestica, E. I. (2020). Use of web-based game in neonatal resuscitation–Is it effective? *BMC Medical Education, 20*, 170. https://doi.org/10.1186/s12909-020-02078-5

Yeo, J. H. (2022). Impact of gender and prior knowledge on learning performance and motivation in a digital game-based learning biology course. *Educational Technology Research and Development, 70*(3), 989-1008. https://doi.org/10.1007/s11423-022-10099-8

Yeo, J.-H., Cho, I.-H., Hwang, G.-H., & Yang, H.-H. (2022). Impact of gender and prior knowledge on learning performance and motivation in a digital game-based learning biology course. *Educational Technology Research and Development, 70*(3), 989-1008. https://doi.org/10.1007/s11423-022-10099-8

Yu, Y. T., & Tsuei, M. (2022). The effects of digital game-based learning on children's Chinese language learning, attention and self-efficacy. *Interactive Learning Environments, 31*(10), 6113-6132. https://doi.org/10.1080/10494820.2022.2028855

Zhang, F., & Kaufman, D. (2016). Physical and cognitive impacts of digital games on older adults: A meta-analytic review. *Journal of Applied Gerontology, 35*(11), 1189-1210. https://doi.org/10.1177/0733464814566678