The Impact of Game-Based Learning on Student Competencies in Science: A Systematic Review

Dampak Pembelajaran Berbasis Permainan terhadap Kompetensi Siswa dalam Sains: Tinjauan Sistematis

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Abstract: *Game-Based Learning (GBL) is an application that encourages active engagement and enhances knowledge and skills. Its effectiveness in fostering student competencies has been proven and applies in various fields. This systematic review analyzes the science topics, student competencies, and learning outcomes associated with Game-Based Learning implementation in primary and secondary education. The method used refers to the procedures outlined by Kitchenham and Charters. The reporting adheres to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The research sample consisted of 22 articles extracted from 478 articles based on predetermined inclusion and exclusion criteria. The review results show that GBL is applicable across all core science domains-namely physics, biology, and chemistry. The competencies that can be improved using Game-Based Learning consist of three aspects, namely affective, cognitive, and psychomotor. Science learning using Game-Based Learning can significantly improve the three students' competencies in almost all studies. To conclude, Game-Based Learning can serve as an effective and recommended learning strategy to support the digital transformation of science education.*

Keywords: *game-based learning, science education, systematic review, student engagement*

Abstrak: *Game-Based Learning (GBL) merupakan aplikasi yang mendorong keterlibatan aktif dan meningkatkan pengetahuan serta keterampilan siswa. Efektivitasnya dalam mengembangkan kompetensi telah terbukti dan digunakan di berbagai bidang. Penelitian ini bertujuan untuk menganalisis secara sistematis topik sains, kompetensi siswa, dan capaian pembelajaran yang terkait dengan penerapan Game-Based Learning pada pendidikan dasar dan menengah. Metode yang digunakan mengacu pada langkah-langkah yang dijelaskan oleh Kitchenham dan Charters yang disajikan dengan berpedoman pada Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). Sampel penelitian terdiri atas 22 artikel yang diekstraksi dari 478 artikel berdasarkan kriteria inklusi dan eksklusi yang telah ditentukan sebelumnya. Hasil tinjauan menunjukkan bahwa topik sains dapat diakomodasi menggunakan Game-Based Learning di semua*

cabang sains, yaitu fisika, biologi, dan kimia. Kompetensi/keterampilan yang dapat ditingkatkan menggunakan Game-Based Learning terdiri atas tiga aspek, yaitu afektif, kognitif, dan psikomotorik. Pembelajaran sains menggunakan Game-Based Learning dapat meningkatkan ketiga aspek kompetensi siswa secara signifikan di hampir semua pembelajaran. Dengan demikian, Game-Based Learning dapat diposisikan sebagai pendekatan strategis dalam mendukung transformasi digital pembelajaran sains.

Kata kunci: *game-based learning, pendidikan sains, tinjauan sistematis, keterlibatan siswa*

INTRODUCTION

Considering current learning trends, classroom learning has developed rapidly by using beyond chalk and blackboards to deliver lesson materials (Lau et al., 2014). Siagian et al. (2007) stated that interactive learning media in teaching and learning activities has changed classroom dynamics. Material previously taught through a monotonous lecture method can now be provided with more variety by integrating text, sound, moving images, and video. In line with that, Lau et al. (2014) argued that among the various media types, Game-Based Learning (GBL) is one of the media considered adequate for learning. Research related to GBL is increasingly popular because of the paradigm that this medium can significantly increase student motivation in learning.

Hainey et al. (2016) defined GBL as the application development specifically implemented for learning purposes, where a particular subject is taught to encourage active involvement. Furthermore, Qian & Clark (2016) stated that GBL creates a context in which knowledge and skill enhancement occur through game content and play. When problem-solving and challenges are presented in gaming activities, it provides a sense of accomplishment to the player or learner. In addition, students' internal motivation and acceptance of learning technology can influence learning success and the quality of the playing experience in the context of learning using GBL (Ninaus et al., 2017). GBL has the potential to meet the needs for autonomy, competence, and relatedness through the design of appropriate game mechanics so that it can generate autonomous motivation and a more meaningful learning experience (Eyupoglu & Nietfeld, 2019; Proulx et al., 2017).

Many successes have been recorded when GBL media was used in learning. Recent research by Alotaibi (2024) showed that GBL has moderate to large effects on cognitive (g=0.46, p<0.001), social (g=0.38, p<0.001), emotional (g=0.35, p<0.001), motivational (g=0.40, p<0.001), and engagement (g=0.44, p<0.001) outcomes in early childhood and highlights its potential to promote learning and development. In line with that, research by Safitri & Jumadi (2024) proved that the use of GBL media based on Problem-Based Learning is significantly and strongly able to improve students' critical thinking skills in science learning, with an effect size of 0.972, which includes the large category. Other studies have shown that

GBL plays an essential role in improving 21st-century skills (Bodnar & Clark, 2017; Huang et al., 2020; Lestari et al., 2019; Ryu et al., 2021), problem-solving skills (Rosydiana et al., 2023), scientific thinking (Aida et al., 2022), motivation (Sung & Hwang, 2013; Ubaidullah et al., 2019; Zou et al., 2021), self-regulated learning (Rajan, 2022; Sabourin et al., 2012), self-efficacy (Meluso et al., 2012; Sung & Hwang, 2013; Zou et al., 2021), speaking skills (L. Li et al., 2023), socio-physical expertise and skills (Pramono et al., 2021), and student involvement in learning (Lai et al., 2012). GBL media has also been developed in various scientific disciplines, including science (Aida et al., 2022; Asniza et al., 2021; Meluso et al., 2012; Ristanto et al., 2022; Rosydiana et al., 2023; Sung & Hwang, 2013; M. Wang & Zheng, 2021), mathematics (Ahmad et al., 2010; Hung et al., 2014; Sun et al., 2021), computer science (Kaldarova et al., 2023; Schmitz et al., 2011), and language (Huang et al., 2020; Pitarch, 2018).

Many systematic reviews discuss the use of GBL media in various subjects (Alper et al., 2021; Hainey et al., 2016; Jabbar & Felicia, 2015; Noroozi et al., 2020), but there are still a few systematic reviews that discuss the use of GBL media in science learning (M.-C. Li & Tsai, 2013). Meanwhile, studies related to contextual needs, such as the demand for scientific literacy, low student interest in science, and post-pandemic digital learning, are urgently needed to improve the quality of learning. It shows that studies related to the effectiveness of GBL media in the context of science learning are still limited and require further attention. This systematic review focuses on the science learning context and investigates the following research questions.

- RQ1. What science topics are applied in learning using GBL?
- RQ2. What competencies/skills can be achieved when implementing GBL in science learning?
- RQ3. What are the results obtained from implementing GBL in science learning?

Considering the growing research evidence, this study aims to systematically analyze the science topics, student competencies, and learning outcomes associated with GBL implementation in primary and secondary education.

METHOD

This systematic review analyses secondary studies obtained based on reviews of previous research. This study aims to summarize GBL research trends in science subjects and their relevance in education. A systematic review of an issue is very important because it can identify and report research results that can be used as a basis for further research.

The literature review method in this article adapts the systematic review procedure guidelines proposed by (Kitchenham & Charters, 2007). The method used consists of the following steps.

- Planning the review is a step in determining research questions.
- Conducting the review, including literature search, determining criteria, data

extraction, data synthesis, and data coding.

- Reporting the review is a step in reporting the analysis results and discussing findings, trends, and conclusions according to PRISMA 2020 guidelines (Page et al., 2021).

The following is a flowchart of the research method presented in Figure 1.

Figure 1 Research Method Flowchart
Source: Author, 2024

A literature search was carried out to collect empirical studies resulting from research in the form of articles using Publish or Perish (PoP) software in the Google Scholar search category. This selection is intended to obtain a greater number of articles, thus providing a more accurate representation. The literature search was conducted in October 2023. The keywords used are "game-based learning in science, game-based learning in physics, game-based learning in chemistry, game-based learning in biology," with a year range chosen between 2014-2023 and a maximum number of searches of 500 studies. The initial search found 478 studies and ignored 22 studies that needed to include information on the year of publication of the study. Based on the initial search, the following categories can be identified.

- Types of study include journal articles, proceedings, books, book sections, thesis reports, and dissertation reports.
- The study is in English, and a small part is in Chinese.
- The study is research in various economic, social, educational, medical, and technological fields.
- Education studies include science, mathematics, technology, English, and computer science.
- The initial search discusses learning in games and studies using other learning media.

A total of 478 studies were then sorted based on general criteria established to answer the research questions asked. All studies from the initial search were examined and assessed. The general criteria used are presented below based on the research questions.

- The year of publication is in the range 2014 – 2023.
- Studies are identified as "articles", not books, book sections, thesis reports, or dissertation reports.

- The study is not a meta-analysis/Systematic Literature Review study of previous studies.

A total of 91 studies were obtained through sorting based on general criteria. These results were obtained by analysing each research title and collecting references from the primary source to determine the form of study presented. Studies in the form of books, book sections, thesis reports, dissertation reports, or other systematic review research are not included in further studies. These articles are then downloaded to be studied in more depth regarding the relevance of the research content.

Apart from the general criteria used to select studies, inclusion criteria are also needed to limit the selected studies further so that they are relevant to the research questions being asked. The inclusion criteria used in this research are as follows.

- The study is research in the field of science education.
- The research participants were elementary to high school students.
- Research is a research article from a journal, not a proceeding.
- The research comes from research articles from reputable journals Q1 and Q2 (checking was done via the Scimagojr website).
- Competencies/skills achieved by students are used as results.

The exclusion criteria in this study are as follows.

- Studies not identified as research results in articles from a journal (for example, proceedings, books, book sections, thesis reports, and dissertation reports).
- The study is a meta-analysis of previous studies.
- Articles published before 2014 or after the fourth quarter of 2023.
- Articles involve kindergarten students, university students, teachers, and the general public as research subjects.
- Articles that do not use English in their presentation.
- Articles originate from reputable journals below Q2 or non-reputable journals.

Some articles cannot be accessed at this stage, so they were removed from the list of studies to be analysed. The study was sorted into 22 studies based on exclusion criteria, which will be carried out in the next stage. Figure 2 shows the resulting PRISMA flowchart.

Analyses were specified for each research question. This step aims to help group all relevant studies based on predetermined criteria. Data collection and analysis require information regarding the author, journal, data source, journal reputation, year of publication, research location, scientific topic, competencies/ skills achieved, and research results on applying GBL. Information related to the author, journal, data source, journal reputation, year of publication, and research location is placed in the research identity information. However, a more detailed process of reading and understanding the data is required to collect data related to other parameters.

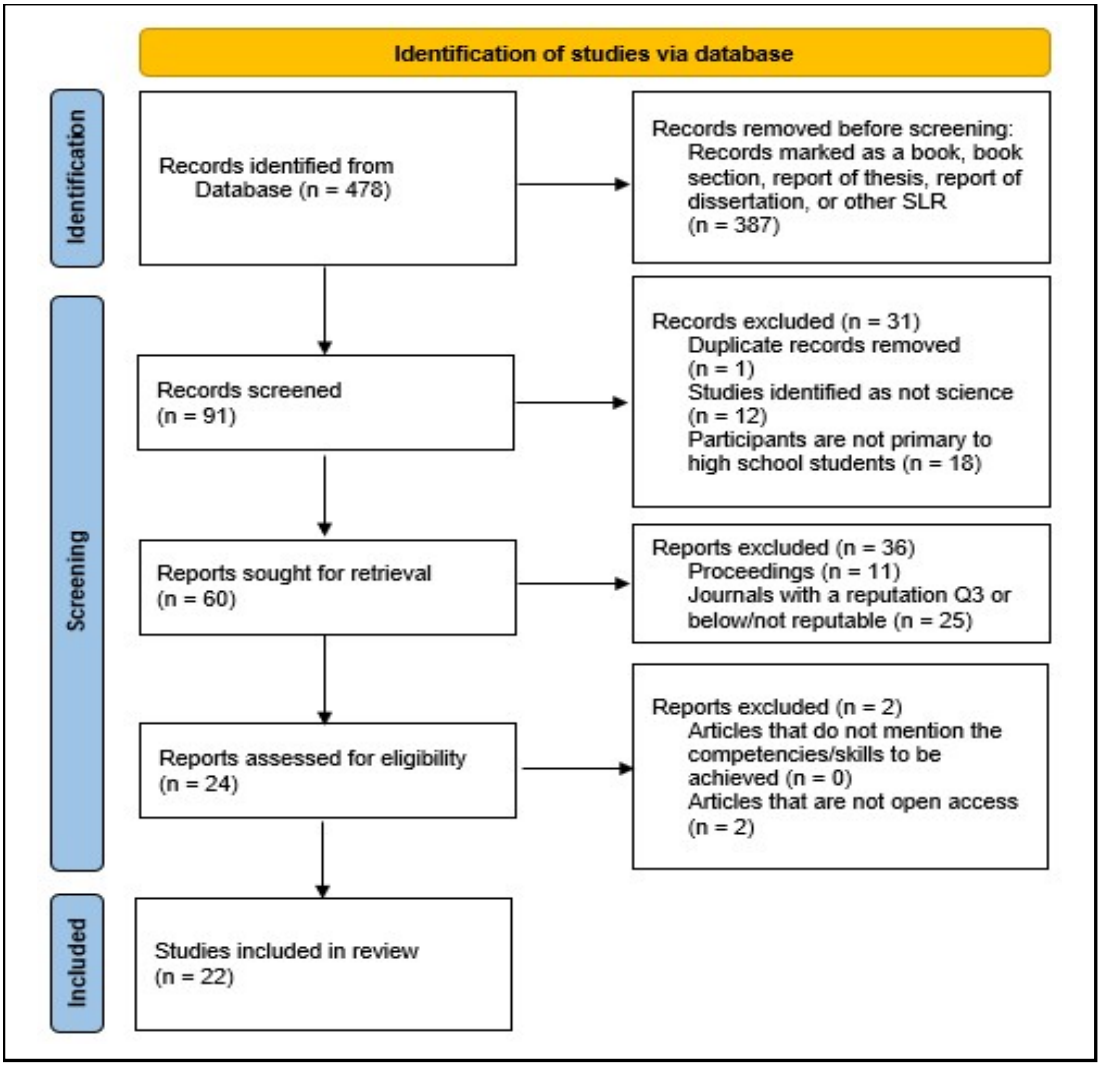

Figure 2 PRISMA Flowchart for Selecting Studies Related to GBL Publications
Source: Author, 2024

RESULT AND DISCUSSION

This section describes and discusses the results of the review. As explained at the beginning, study selection was based on inclusion and exclusion criteria, resulting in 22 studies. The data coding process is carried out according to predetermined categories. The results are presented according to the research questions. Table 1 presents data related to article descriptions from 22 studies collected based on journal name, data source, journal reputation, year of publication, and author's country of origin.

Based on Table 1, the studies derive from various data sources. The most significant data source is springer with 23%, followed by ERIC (18%), Taylor & Francis Online (18%), MDPI (9%), Inderscience (5%), Iopscience (5%), IEEExplore (5%), Sage (5%), Science Direct (5%), Wiley (5%), and Jedutechsoci (5%). Among the selected studies, 59% were published in Q1-ranked journals (n = 13), and 41% in Q2-ranked journals (n = 9). These studies were selected based on the

Table 1 Description of Analysed Article

Authors	Journal	Data Source	Index Scopus	Publication Year	Country
Ristanto et al.	Journal of Turkish Science Education	ERIC	Q2	2022	Indonesia
Kotzebue et al.	Multimodal Technologies and Interaction	MDPI	Q2	2022	Austria
Janković & Lambić	Journal of Baltic Science Education	ERIC	Q2	2022	Republic of Serbia
Y. Wang	International Journal of Science Education	Tandfonline	Q1	2022	Republic of China
Arboleya-García & Miralles	Education Sciences	MDPI	Q2	2022	Spain
Komalawardhana & Panjaburee	International Journal of Mobile Learning and Organisation	Inderscienceonline	Q2	2021	Thailand
Radulović	Journal of Baltic Science Education	ERIC	Q2	2021	Republic of Serbia
Y.-C. Chen et al.	Interactive Learning Environments	Tandfonline	Q1	2021	Taiwan
Pfirman et al.	Journal of Geoscience Education	Tandfonline	Q2	2021	Arizona
Bağ & Çalik	Physics Education	Iopscience	Q2	2021	Turkey
C.-Y. Chen et al.	IEEE Access	IEEExplore	Q1	2020	Taiwan
Videnovik et al.	Multimedia Tools and Applications	Springer	Q1	2020	Macedonia
Yıldırım & Baran	Education and Information Technologies	ERIC	Q1	2020	Turkey
S. Chen et al.	International Journal of Science Education	Tandfonline	Q1	2020	Republic of China
Jones et al.	Simulation and Gaming	Sage	Q2	2019	USA
Kao et al.	Computers and Education	Sciencedirect	Q1	2017	Republic of China
Price et al.	Journal of Science Education and Technology	Springer	Q1	2016	USA
Sadler et al.	Science Education	Wiley	Q1	2015	USA
Dorji et al.	Journal of Computers in Education	Springer	Q1	2015	Bhutan
Dorji et al.	Educational Technology and Society	Jeductechsoci	Q1	2015	Bhutan
M. P. Chen et al.	Educational Technology Research and Development	Springer	Q1	2014	Taiwan
Corredor et al.	Journal of Science Education and Technology	Springer	Q1	2014	Colombia

Source: Author, 2024

quality of the journal in which they were published, according to Scimago's assessment.

Most of the research, or as much as 55%, was carried out on the Asian continent, where the dominance of research was in the Republic of China (n=3). Then, countries on the European continent (23%), North America (18%), and a small part of South America (5%) followed.

Articles implementing GBL in the science learning experience fluctuate every year. Figure 3 shows the distribution of articles based on the year of publication.

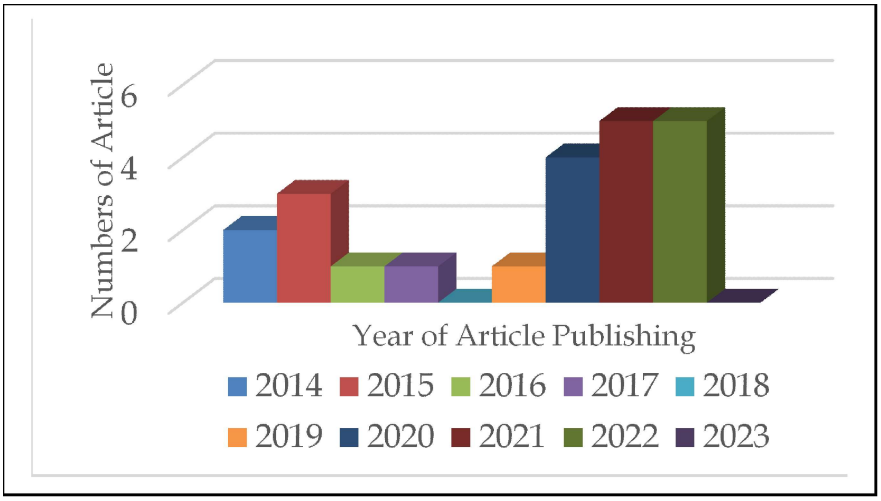

Figure 3 Distribution of Articles Based on Publication Year
Source: Author, 2024

Based on Figure 3, the trend of research on learning using GBL was high in 2015 (n=3) but then decreased in 2018. It indicates that there was no research related to learning using GBL in science subjects. The GBL research trend is rising again and reaching its peak in 2021 and 2022, namely five studies for each of these years.

Several criteria have been determined regarding the study's content. Table 2 shows several criteria that will be used to answer the research questions about science topics applied in learning using GBL.

The students involved in this systematic review were students from elementary to high school, with the smallest number of students in a study, 12 students, and the most significant number, 42,195 students. This study, which involved the most significant number of students, was carried out with the help of teachers in many schools. The total number of students involved in all studies was 46,423 students.

Apart from finding out the science topics that are usually taught, this research also aims to find out the competencies/skills that can be accommodated by GBL media and the results of implementing GBL in learning. Table 3 shows the competencies/skills to be achieved and the main results of learning using GBL.

Based on these results, the answers to the questions in this study literature is described as follows.

Table 2 Review Based on Participant Aspects and Topics of Science Material Taught

Authors	Educational Level	Total participants	Topic
Ristanto et al.	Secondary school	46	Genetic
Kotzebue et al.	Secondary school	84	Sex education
Janković & Lambić	Primary school	113	Natural science (related to the biology content)
Y. Wang	Secondary school	155	Magnetic field
Arboleya-García & Miralles	Primary school	111	Marine environment
Komalawardhana & Panjaburee	Primary school	282	Force and motion
Radulović	Secondary school	172	Electric current
Y.-C. Chen et al.	Primary school	168	Light
Pfirman et al.	Secondary school and High school	42195	Polar and Earth system
Bağ & Çalik	Primary school	12	Force
C.-Y. Chen et al.	Primary school	115	Light
Videnovik et al.	Secondary school	40	Living habits of animals in the zoo
Yıldırım & Baran	Secondary school	83	Force, newton's motion law, and friction force
S. Chen et al.	Secondary school	114	Chemical elements and compounds
Jones et al.	Secondary school and High school	18	Transcription and translation
Kao et al.	Secondary school	126	Basic machinery
Price et al.	Primary school	242	Human biological systems
Sadler et al.	High school	1888	Biotechnology
Dorji et al.	High school	129	Energy consumption and conservation
Dorji et al.	High school	129	Electric energy conservation
M. P. Chen et al.	Secondary school	115	Chemical formula
Corredor et al.	Primary school	86	Viral reproduction
Total Participants		46423	

Source: Author, 2024

Research Question 1

RQ1. What science topics are applied in learning using GBL?

Several science topics taught using GBL media can be seen in Table 2. These science topics are divided into three groups based on the branch of science, namely physics, biology, and chemistry. Physics topics taught using GBL include magnetic fields (Y. Wang, 2022), force and motion (Baç & Çalik, 2021; Komalawardhana & Panjaburee, 2021; Yýdýrým & Baran, 2020), electric current (Raduloviæ, 2021), light (C.-Y. Chen et al., 2020; Y.-C. Chen et al., 2021), polar and Earth systems

Table 3 Review Based on Aspects of Scientific Competencies/Skills to be Achieved and The Main Results of the Research

Authors	Competencies/skills achieved	Results
Ristanto et al.	conceptual understanding	Students who take part in Flipped Classroom-Digital Game-Based Learning (FC-DGBL) show a better understanding of the concept of Genetics compared to students who take part in traditional learning models.
Kotzebue et al.	motivation and knowledge acquisition	Digital Education Escape Room (DEER) is a significant and empirically proven approach to support learning in the context of sex education. This method also makes a positive contribution to increasing student motivation.
Janković & Lambić	academic achievement	The experimental group that used Kahoot to study Natural Science material achieved significantly higher post-test scores than the control group. There was no significant difference in academic performance between the group that used Quizizz and the other two groups.
Y. Wang	engagement, learning performance, and satisfaction	Augmented Reality Game-based Science Learning (ARGSL) improves student interaction, performance, and learning satisfaction better than game and book-based learning methods.
Arboleya-García & Miralles	knowledge	Understanding of the marine environment increased in both age groups, children and adults, although the increase was slightly higher in the children's group.
Komalawardhana & Panjaburee	perceptions of learning activities, improvement, and achievement	The students in the game group using a web-based mastery learning approach showed more satisfaction and positive attitudes towards learning activities than students in the conventional game group. Both students with high and low achievements who were involved in games using a web-based mastery learning approach and students with medium and low achievements who were involved in conventional games could gain significant knowledge. Students in the game group with a web-based mastery learning approach significantly outperformed the conventional game group's achievement.
Radulović	educational efficiency and students' involvement	Educational efficiency and student engagement levels are higher in the Game-Based Student Response Systems (GSRS) approach when compared to conventional approaches.
Y.-C. Chen et al.	scientific knowledge and argumentation skills	Three types of learning that use technology, namely game-based instruction (high LTE), video-based instruction (medium LTE), and traditional instruction (low LTE), significantly improve students' scientific knowledge and argumentation skills.
Pfirman et al.	conceptual understanding	Of the 13 states, students in Rhode Island, Oregon, Arizona, and Washington achieved the highest overall scores when using Kahoot!, while the response from students in Ohio and Illinois seemed less favourable, as if they were just guessing.

Bağ & Çalik	students' argumentation	Results from the third pilot study showed that at the beginning of the intervention, elementary school students faced difficulties in referring to evidence and claims in their arguments. Nevertheless, the quality of their arguments gradually improved and involved all argumentative components as time passed.
C.-Y. Chen et al.	conceptual understanding and argumentation skills	The use of Multi-genre digital Game-based Instruction (MGI) resulted in significant improvements in conceptual understanding and argumentation skills compared to those who received only traditional instruction.
Videnovik et al.	learning experience	Factors such as ease of use, utility, student attitude, motivation, and suitability of the educational components in the game will increase the quality of the student's learning experience.
Yıldırım & Baran	academic achievements	The use of instruction involving digital games and physical activity games has a positive impact on student academic achievement.
S. Chen et al.	students' emotions and academic achievement	The experimental group (using cards, board games, and riddles) showed higher levels of positive emotions and lower levels of negative emotions during the intervention period.
Jones et al.	student engagement and the learning experience	The whole activity positively influenced students and teachers because students could understand the Transcription and Translation material in a fun and interesting way through 'KAHOOT!'
Kao et al.	learning outcomes: knowledge acquisition and design creativity.	The marking critical features scaffolding group significantly outperformed the demonstration scaffolding group in gaining conceptual knowledge and in the sensitivity dimension of design creativity. Meanwhile, the group that used demonstration scaffolding scored higher in the flexibility dimension of design creativity.
Price et al.	scientific attitudes and conceptual understanding	There was a slight increase in scientific attitudes, the ability to recognize human biological systems, and students' skills in describing the collaboration of these systems in the context of real-world situations.
Sadler et al.	knowledge, science interest	Participants who engaged in both approaches (using computer-based games and narrative cases) experienced statistically and practically significantly improved biological knowledge assessments at proximal and distal levels. Neither group showed an increase in science interest.
Dorji et al.	learning achievement and energy-saving awareness	RES-battle can decrease the difference between female and male learning achievements reasonably, and energy-saving awareness.
Dorji et al.	learning achievement, awareness, and satisfaction	Designed educational computer games can increase student learning achievement, awareness and satisfaction to a higher level.
M. P. Chen et al.	performance and motivation	Worked examples significantly impact knowledge understanding and marginally impact knowledge application. Students show a mild level of positive motivation to learn chemistry through 3D RPG games.
Corredor et al.	conceptual understanding	Video games stimulate the development of mental models of scientific phenomena that differ from the models formed by conventional educational methods, such as text and graphics.

(Pfirman et al., 2021), basic machinery (Kao et al., 2017), and energy consumption and conservation (Dorji et al., 2015b, 2015a). Biology topics taught using GBL include genetics (Ristanto et al., 2022), sex education (Kotzebue et al., 2022), natural science (Jankoviæ & Lambiæ, 2022), marine environment (Arboleya-García & Miralles, 2022), living habits of animals in the zoo (Videnovik et al., 2020), transcription and translation (Jones et al., 2019), human biological systems (Price et al., 2016), biotechnology (Sadler et al., 2015), and viral reproduction (Corredor et al., 2014). Chemistry topics taught using GBL include chemical elements and compounds (S. Chen et al., 2020) and chemical formulas (M.-P. Chen et al., 2014).

These findings are in line with research conducted by Tsai et al. (2020) which stated that the GAME (Gamification, Assessment, Modeling, Inquiry) pedagogical model is in accordance with the PISA science literacy framework, which assesses students' ability to apply knowledge in the context of everyday life. These results are reinforced by research conducted by Ho et al. (2022) which revealed that games can simulate real global issues, including the climate crisis, social inequality, and cooperation between countries, through the involvement of abstraction processes, solution exploration, and policy experimentation as measured by PISA in the context of science and public policy.

Research Question 2

RQ2. What competencies/skills are achieved when implementing GBL in science learning?

Several competencies/skills that have been taught using GBL media in science learning is seen in Table 3. The competencies are divided into three aspects, namely affective, cognitive, and psychomotor.

Affective aspects that can be achieved when implementing GBL include motivation (M.-P. Chen et al., 2014; Kotzebue et al., 2022), engagement/involvement (Jones et al., 2019; Raduloviæ, 2021; Y. Wang, 2022), learning performance (M.-P. Chen et al., 2014; Y. Wang, 2022), satisfaction (Dorji et al., 2015a; Y. Wang, 2022), perception (Komalawardhana & Panjaburee, 2021), emotions (S. Chen et al., 2020), learning experience (Jones et al., 2019; Videnovik et al., 2020), scientific attitudes (Price et al., 2016), science interest (Sadler et al., 2015), and awareness (Dorji et al., 2015b, 2015a).

Cognitive aspects that can be achieved when implementing GBL include conceptual understanding (C.-Y. Chen et al., 2020; Corredor et al., 2014; Pfirman et al., 2021; Price et al., 2016; Ristanto et al., 2022), knowledge acquisition (Kao et al., 2017; Kotzebue et al., 2022), academic/learning achievement (S. Chen et al., 2020; Dorji et al., 2015a, 2015b; Jankoviæ & Lambiæ, 2022; Komalawardhana & Panjaburee, 2021; Yýldýrým & Baran, 2020), improvement (Komalawardhana & Panjaburee, 2021), educational efficiency (Raduloviæ, 2021), and learning outcomes (Kao et al., 2017).

The psychomotor aspects that can be achieved when implementing GBL are argumentation skills (Baç & Çalik, 2021; C.-Y. Chen et al., 2020; Y.-C. Chen et al., 2021) and design creativity (Kao et al., 2017).

Research conducted by Tsai et al. (2020) stated that the GAME model trains critical thinking, scientific literacy, collaboration, and problem-solving through a technology-based and exploratory approach, and these competencies support Sustainable Development Goal 4 (SDG-4) with an innovative approach based on real challenges and strengthening global competence. The GAME model encourages independent exploration, process-based assessment, and active participation. These competencies are in line with the Merdeka Belajar philosophy. Al-Khayat et al. (2023) through their research strengthen these findings by revealing that GBL encourages active, collaborative, and exploratory learning, which develops critical thinking skills, problem-solving, and creativity. Furthermore, Ho et al. (2022) through their research found that digital and non-digital games significantly improve students' perceptions, knowledge, and attitudes toward SDGs. In digital games, the largest effect reached d=-3.671 for attitudes, especially in high school students.

Research Question 3

RQ3. What are the results obtained from implementing GBL in science learning?

Science learning using GBL generally shows positive results from all reviewed studies. The results of the analysis of these studies can be seen in Table 3. The GBL developed from these studies, mainly utilizes digital technology. The review results of these studies state that science learning using GBL can significantly improve students' affective, cognitive, and psychomotor aspects (Arboleya-García & Miralles, 2022; Baç & Çalik, 2021; C.-Y. Chen et al., 2020; M.-P. Chen et al., 2014; S. Chen et al., 2020; Y.-C. Chen et al., 2021; Corredor et al., 2014; Dorji et al., 2015a, 2015b; Jankoviæ & Lambiæ, 2022; Jones et al., 2019; Kao et al., 2017; Komalawardhana & Panjaburee, 2021; Kotzebue et al., 2022; Pfirman et al., 2021; Raduloviæ, 2021; Ristanto et al., 2022; Sadler et al., 2015; Videnovik et al., 2020; Y. Wang, 2022; Yýldýrým & Baran, 2020). Only one study states a slight increase in students' scientific attitudes after using GBL in learning (Price et al., 2016).

In their research, Ho et al. (2022) stated that the role-based experiential learning model, simulation, and discussion in games can encourage critical reflection and decision-making and provide space for student autonomy and creativity. This idea is in accordance with the concept of Merdeka Belajar which emphasizes active, contextual, collaborative, and fun learning. In another study, H. Li & Zhang (2025) emphasized that the museum GBL design accommodates contextual learning, active participant roles, social cooperation, and personal meaning-making, all of which reflect a pure constructivist approach.

The six dimensions in the constructivist GBL framework that are accommodated are self-determination, contextualization, social interaction, knowledge construction, meaning-making, and immediate feedback. Research by

Hosseinpour & Keshmiri (2025) revealed that GBL reduces irrelevant cognitive load and increases working memory allocation for understanding formation and increases self-efficacy through active, social, and contextual learning experiences. Al-Khayat et al. (2023) also argued that GBL provides opportunities for students to construct meaning, experiment, and interact socially, rather than simply passively receiving information through direct experience and real contexts. GBL is said to be effective when the complexity of the game is under working memory capacity and is accompanied by scaffolding. Games also increase intrinsic motivation because they provide autonomy (options and control), competence (adaptive challenges), and relatedness (cooperation).

CONCLUSION AND RECOMMENDATION

Conclusion

The discussion of GBL in this systematic review aims to systematically analyse the science topics, student competencies, and learning outcomes associated with GBL implementation in primary and secondary education. The findings reveal facts about the development of GBL which continues to evolve to this day. GBL supports the development of conceptual understanding, engagement, and argumentation across physics, biology, and chemistry topics in primary and secondary education.

GBL-based science learning has generally been proven to be effective in improving students' affective, cognitive, and psychomotor aspects, although one study only showed a small increase in scientific attitudes. The implication of this research is that GBL can be positioned as a recommended approach in the digital transformation of science education.

Recommendation

Based Learning in science learning is worthy of consideration as an effective approach to fostering enjoyable and meaningful learning experiences for students. Therefore, more focused future studies are needed, such as meta-analyses comparing its effectiveness with other digital strategies or investigations into its impact across diverse demographic groups. Within the field of policy, it is strongly recommended to integrate the GBL framework into national curriculum design and teacher professional development. In terms of applicability, GBL modules should be developed for science topics that have been proven effective, such as genetics, forces, and chemical reactions, to enable broader and more systematic implementation."

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