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# Game-based Biology Learning: A Systematic Review of the Literature during 2010-2019

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**Abstract**

Educational games have been proved to enhance students learning of science. Many researchers have investigated the implementation of game-based learning in the classroom and reviewed the trends or current development of game science learning in many review articles. However, the analysis of the development biology game is still limited. Currently, the analysis review focuses on science game learning. The research aims to portray the current evidence of the biology game from 2010 to 2019 based on the Scopus database. There are 47 final papers examined in this review. The study focuses on the author's nationality, journal, education level, research types, learning strategies, biology topics, and research issues. We found that most of the author's nationality and journal published from the USA. The majority of participants are high school students. The findings also revealed that the majority of learning strategy is active learning. The dominant research type is quantitative. Further, there are various biology themes: Cells and control; Genetics; Natural Selection and Genetic Modification; Health, Disease and the development of medicine; Plant structure and functions; Animal Coordination, control, and homeostasis; and Ecosystem material cycles. The highest proportion is the Genetics theme. The study also indicates that the research issues mainly in the cognitive domain, for instance, students understanding biology concepts. The implications and suggestions for further research resulting from these findings are discussed.

**Keywords:** Game-based learning, Digital game, Gamification, Biology education, Meta-analysis

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## Introduction

Games in the educational environment to support students learning had been implemented by many researchers. In recent years, using the game as a media or learning tool (Anderson & Barnett, 2011) supports learning and transforms learning (Srisawasdi & Panjaburee, 2019). The idea of game-based learning is based on the theoretical background, which is a game has the primary foundation to support students in motivation, cognitive, motivation, affective, and sociocultural engagement with the subject matter (Plass, Homer, & Kinzer 2015; Cózar-Gutiérrez & Sáez-López, 2016; Pesare et al., 2016)

Implementation of digital game gives many benefits, for instance, to enhance the motivation (Johnson et al., 2012; Chen & Hwang, 2014) to understand the concept (Khenissi, Essalmi, & Jemni, 2015) to stimulate the cognitive enhancement and the formation of mental structure became long-lasting (Corredor, Gaydos, & Squire, 2014; Khoiriah et al., 2016). Besides, games affect attitudes (Divjak & Tomic, 2011), learning quality both in formal and informal education (Muehrer et al., 2012), and improve the generic skills in science (Mulyani et al., 2016). Research by Hung, Huang, & Hwang (2014) revealed that the game-based e-book learning model effectively promoted the students' learning achievement, self-efficacy, and mathematics motivation. Further research in the cognitive domain uses educational games to encourage brain health with the neurocognitive approach (Fissler, Kolassa, and Schrader (2015). In addition, Qian & Clark (2016) stated that using game-based Learning (GBL) can promote the development of 21$^{st}$ century skills.

Based on the importance of the digital game, several studies were conducted to review empirical evidence of game-based learning. According to Clark, Tanner-Smith, & Killingsworth (2016) meta-analysis method has been used to analyze the evidence of the game. Li & Tsai (2013) stated a surging interest in games in science education from 2002 to 2013. Meta-analysis was conducted by Cheng et al. (2015) stated that game research in science education during 2007-2013 has significant trends. As a result, the educators started to examine the effectiveness of the educational game. Cheng et al. (2015) stated that research in game-based science learning has three dimensions: the research method dimension, the game dimension, and the pedagogical dimension.

The previous study (Adita, Nugraheni & Srisawasdi, 2020) conducted systematic reviews focusing on the game dimension, which are trends digital game, non-digital game, and Gamification in biology. Based on the research, most implementation is the digital game that stands at 60 %; meanwhile, only 36% non-digital game and 4 % gamification. The vast majority of the digital game is a simulation, while a non-digital game is a board game. The review has been conducted regarding biology games, and the focus was limited to the game types. The study needs to explore more aspects such as research types and learning strategies, as Chang & Hwang (2019) mentioned in their analysis review. They divided the study into three parts which are game-used, pedagogical used, and research method. Besides, the research issues also essential to explore more to further research in developing biology game. Therefore, this paper focuses on exploring the other empirical evidence in implementing a biology game divided into six dimensions to


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cover up the data analysis in the previous study.

In this research, the questions were:

1) What were the author's nationality and journal published in the biology game article published from 2010 to 2019?

2) What were participants' education levels in implementing the biology game article published from 2010 to 2019?

3) What were the research types in the biology game article published from 2010 to 2019?

4) What were the learning strategy types in the biology game article published from 2010 to 2019?

5) What were the biology themes in the biology game article published from 2010 to 2019?

6) What were the research issues in the biology game article published from 2010 to 2019?

## ■ Literature Review

*Game-based Learning (GBL)*

There are several definitions related to GBL. According to Siang, Avni & Zaphiris (2008), GBL refers to learning through the game. Perrotta et al. (2013) also mentioned that GBL broadly relates to video games to support teaching and learning. Meanwhile, Salen & Zimmerman (2010) stated that games define by rules and conflict that engage with enjoyment through educational materials. Simões, Redondo, & Vilas (2013) noted that the games are used in leisure and profound ways to support learning. The games used to attempt the learning objectives are called serious games (Vorderer & Ritterfeld, 2009).

GBL has several foundations: cognitive, motivation, affective, and sociocultural engagement (Plass, Homer, & Kinzer, 2015). One of the critical foundations is the mental foundation related to the effect of game elements in cognitive processing. According to Mayer (2016), processing information depends on how learners maximize their working memory potential. As Alexiou & Schippers (2018) mentioned, engagement starts with attention, scaffolding, and interaction design. Meanwhile, researchers need to explore using specific elements to enhance the reason (Plass, Homer, & Kinzer, 2015) to motivate.

There are several categories to be considered to differentiate the game from the non-game. Prensky (2001b) explained which a game must have six elements: challenge, rules, goals, story or representation, feedback, and interaction. Meanwhile, Li & Tsai (2013) stated that the games consist of rewards, feedback, fun characteristics, and challenges. Plass, Homer, & Kinzer (2015) explained several game elements: learning objectives, game mechanics, visual aesthetics, narrative, incentives, player engagement, and musical score. At the same time, Alexiou & Schippers (2018) explained three main layers: game system, narrative, and aesthetics.

Perrotta et al. (2013) the principles of the game consist of intrinsic motivation, learning through intense enjoyment and fun, authenticity, self-reliance and autonomy, and experiential learning. In authenticity, contextual skills prioritize abstract ideas and facts that are appreciated in traditional teaching. Meanwhile for self-reliance and autonomy refers to gaming encourages independent inquiry and

exploration. Besides, there are eight mechanisms mentioned by Perrotta et al. (2013), which are 1) rules, 2) challenging goals, 3) fictional setting or "fantasy" that provides a compelling background, 4) progressive difficulty levels, 5) interaction and a high degree of student control, 6) degree of uncertainty and unpredictability, 7) Immediate and constructive feedback and 8) a social element that allows people to share experiences and build bonds.

*Digital Game-based Learning (DGBL) and Gamification*

DGBL refers to the use of digital devices in game-based learning. Prensky (2001a) stated that DGBL combines fun, engagement, interactive entertainment, and serious learning. Meanwhile, Loh, Sheng, & Ifenthaler (2015); Sanchez (2020) explained that DGBL uses computer games to achieve learning outcomes. The development of computers and multimedia through DGBL provides opportunities to experience and cope with problems in daily life (Tapingkae, Panjaburee, Hwang, & Srisawasdi, 2020).

The foundation in DGBL is similar to GBL. To support learning and enhance motivation, the designer must consider the foundations and game elements of the games. Engagement in cognitive and emotional foundations can be improved by using narrative elements and challenges (Alexiou & Schippers, 2018). Besides, using the constructivist theory to develop games can achieve the expected learning outcomes (Alexiou & Schippers, 2018). While, another research suggested that challenges should be able to maintain the student's abilities in the GBL environment (Hamari et al., 2016).

GBL, DGBL, and gamification terms are always seen in many articles. However, the concept of gamification is different from GBL or DGBL. Gamification is not game, meaning gamification borrows game mechanics (Loh, Sheng, & Ifenthaler 2015). Teachers create the objective and challenge to be applied in a learning activity (Simões, Redondo, & Vilas 2013). Kim, Song, Lockee, & Burton (2018) stated that gamification is related to the actions to solve the problems in learning and education. According to Perrrota et al. (2013), gamification refers to using 'elements' from video-game design, elements' derived from video-game design, then applied in various contexts, rather than using individual video games. Gamification is designed to improve student learning performance, student engagement, and motivation and also provide feedback.

*Previous Studies of Game-Based Learning*

Several studies conducted systematic reviews in the implementation of game-based learning. Hainey et al. (2016) showed that GBL had been used to teach various subjects to children and young people in primary education, with mathematics, science, language, and social studies being the most popular. Research by Giannakas et al. (2017) reviews 13 years of mobile game-based learning. One of the analyses is that future mobile game-based learning examines the potentials of creating new context-based learning activity strategies to assist developers in enriching context awareness. Another issue is finding the balance between gameplay and learning outcomes which inline the learning theories. Meredith (2016) presented that researchers' understanding of the GBL effect in


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teacher professional development. For instance, several distinct lines of future research, for example, analyses of instructional design to develop GBL professional development in classroom practices, could be pursued. Another review is the development of digital game cards in education by Kordaki & Gousiou (2017). One of the results is mainly adopted social and constructivist views of learning during their design and use. However, the views were explicitly reported in only a few of these. Another result is appeared to support students to acquire essential thinking skills through digital-card gameplay.

The development of the game has an impact on science education which several researchers prove. Srisawasdi & Panjaburee (2019) found that the implementation of the game with inquiry-based learning in chemistry can promote the understanding and motivation to learn chemistry. Chen, Huang, & Liu (2019) also proved that using inquiry scaffolding in science games helps students understand the concept, game performance, and behavioral patterns. As stated by (Cheng et al., 2015) that using serious games with instructional strategies is still few. Another analysis result is high interest in using serious science games from 2002-2013 (Cheng et al., 2015). A meta-analysis by Tsai & Tsai (2020) explained that students from cross educational levels have benefited from game-based learning. Besides, gaming mechanics play an essential role in improving students' knowledge.

Another review studied by Qian & Clark (2016) found that using GBL can promote twenty-first-century skills in the future. Also, the digital game has a pivotal role in enhancing the students' learning compared to the non-game treatment. The study involves a range of game genres, game design, and learning theories. Li & Tsai (2013) found that game-based learning articles from 2000-2011 primarily promoted concept learning while implementing games to encourage problem-solving skills only one-third. Besides, few studies examined the learning outcomes from the point of view of the scientific process, social-contextual learning, and engagement.

## ■ Research Method

*Data Collection*

The study was conducted by searched paper in the SCOPUS database with game-based biology learning criteria from 2010 to 2019. The keywords are (game) or (gamification) or (gamifying) and (learning) and (biology) (Fig.1). The search resulted in 257 journal articles from the database. The articles include only English journal articles. The unrelated topic papers were excluded from the analysis remained 127 papers. After eliminating 80 papers irrelevance with the study, the final result obtained 47 papers.

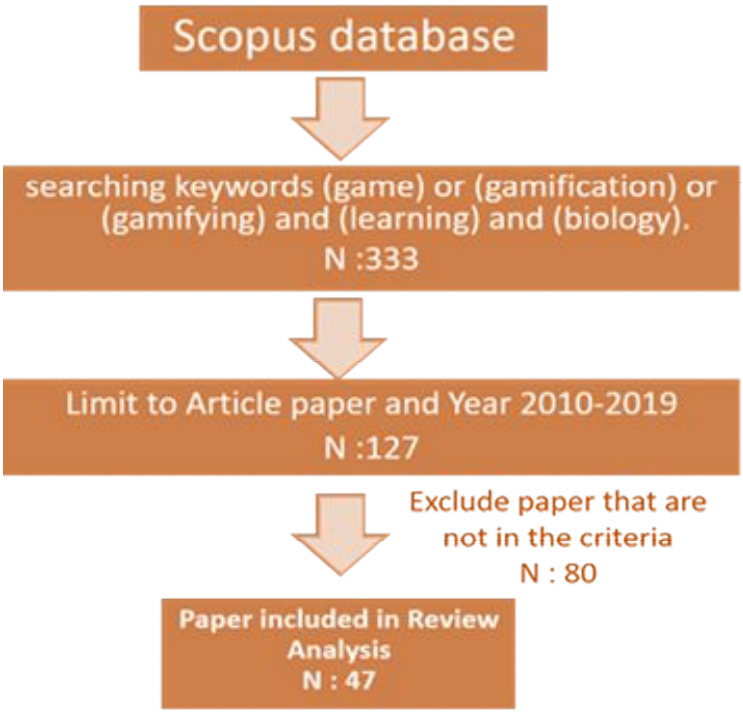


*Figure 1*. Steps of selecting articles.

*Coding Schemes*

For the coding of the study, three significant foci are using the game in science education: game-used, pedagogical used, and research method (Chang & Hwang, 2019). The previous study has revealed the game-used or the type of the games (Adita, Nugraheni & Srisawasdi, 2020). However, in this study, we only focused on six dimensions: the countries, foremost journal publishing, education level, learning strategies, research methods, the topics in biology game, and research issues. Each dimension is described in the following item:

1) *Nationalities of authors and journals:* The nationality and journals are standard information of those published papers are discussed. The countries dimension is the first author country, and in this research, we found 13 countries. The foremost journal publishing in this research was categorized into three mains collections based on Web of Science, which are Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), and Emerging Sources Citation Index (ESCI).

2) *Education Level:* The education level is categorized into several levels, which are primary education, high school education, undergraduate, pre-service teacher, postgraduate, and mixed.

3) *Learning Strategies:* The classification of learning strategies mentioned in the article consist of 6 strategies, namely outdoor education, interactive learning, direct guided learning, collaborative learning, active learning, and contextual learning. The classification of the learning strategies based on the


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researchers mentioned in the article. Outdoor education refers to experimental learning in the outdoor environment. Interactive learning in this research relates to the student's involvement in the activities in online situations. Direct guided learning means that learning through direct instruction through the teacher or program. Collaborative learning means that learning through small-group to complete the task. Active learning means that students actively engage in the learning activities such as problem-solving and case studies. Finally, contextual learning refers to the implementation of knowledge in real-life conditions.

4) *Research Method:* In research methods, we divided into four categories which are quantitative research, qualitative research, mixed-method, and R & D.

5) *Biology Themes:* According to Biological Science Curriculum Study (2006), there are six unifying themes in the biology subject which are 1 ) Evolution (patterns and product of the change in the living system); 2) Homeostasis (maintaining dynamic equilibrium in living systems); 3) Energy, matter, and organization (relationships in living systems); 4) Continuity (reproduction and inheritance in living systems); 5) Development (growth and differentiation in living systems) and 6) Ecology (interaction and interdependence in living systems). However, in this research, we divided the themes into eight categories which are: (a) cells and control, (b) genetics, (c) natural selection and genetic modification, (d) health, disease, and the development of medicine (e) plant structure and their functions (f) animal coordination, control, and homeostasis (g) exchange and transport in animals (h) ecosystem and material cycles (Barker et al., 2020)

6) *Research issues:* In this review, there are four aspects of research issues such as cognition, affective, psychomotor, and social. According to the search result, it is divided into five categories. The categories are cognitive, affective, psychomotor, social, cognitive-affective, and non-specific.

## ■ Results and Discussion

*Nationalities of authors and journals*

In this study, we analyzed the first author's nationality. As a result, it can be seen in Fig.2. that from 47 papers, the vast majority of biology games-based learning documents are from the USA (25 articles) then followed by Taiwan (5 articles), Brazil (4 articles), and Spain (3 articles), respectively. Based on the graph, the Asian country that actively published journals in Taiwan. The other countries, namely Canada, Colorado, Columbia, France, Helsinki, Poland, Turkey, and Serbia, only stood at one paper. However, compared to Western the Asian Country still has minor contributions.

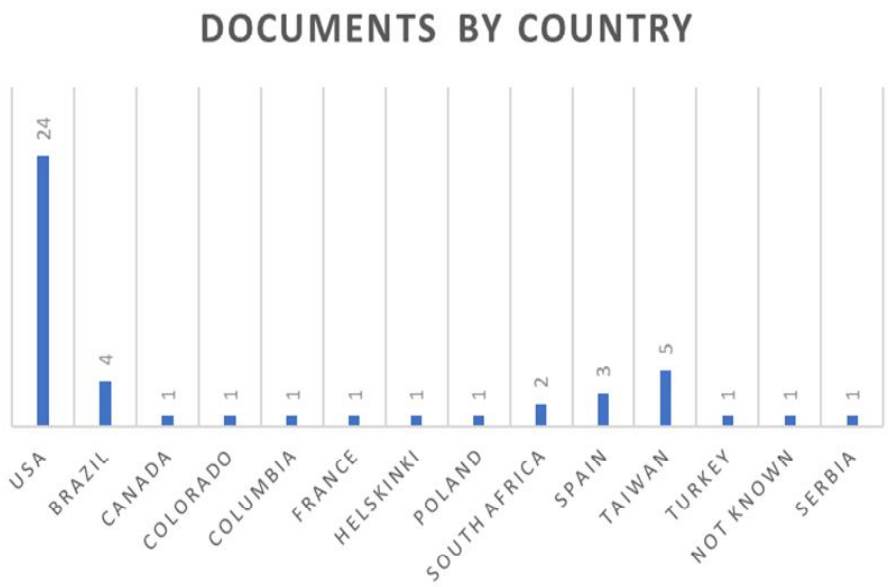


*Figure 2.* Article published by country from 2010 to 2019.

There are 25 journals founded in this review (Fig. 3). Based on the core of collection Web of Science, there are four core collections which are Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (AHCI), and Emerging Sources Citation Index (ESCI). However, this review only found three significant core collections: SCIE, SSCI, and ESCI.

There are five journals indexed in SCIE, five journals indexed in SSCI, and eight journals indexed in ESCI. Besides, two journals indexed by both SCIE and SSCI, namely Journal of Biological Education and Journal of Science Education and Technology. However, four journals are not indexed in the Web of Science (i.e., Bioscience, LUMAT, Acta Academica, and Eurasia Journal of Mathematics, Science and Technology Education). In addition, one journal has additional Web of Science indexes in Zoological Record (Evolution: Education and Outreach).


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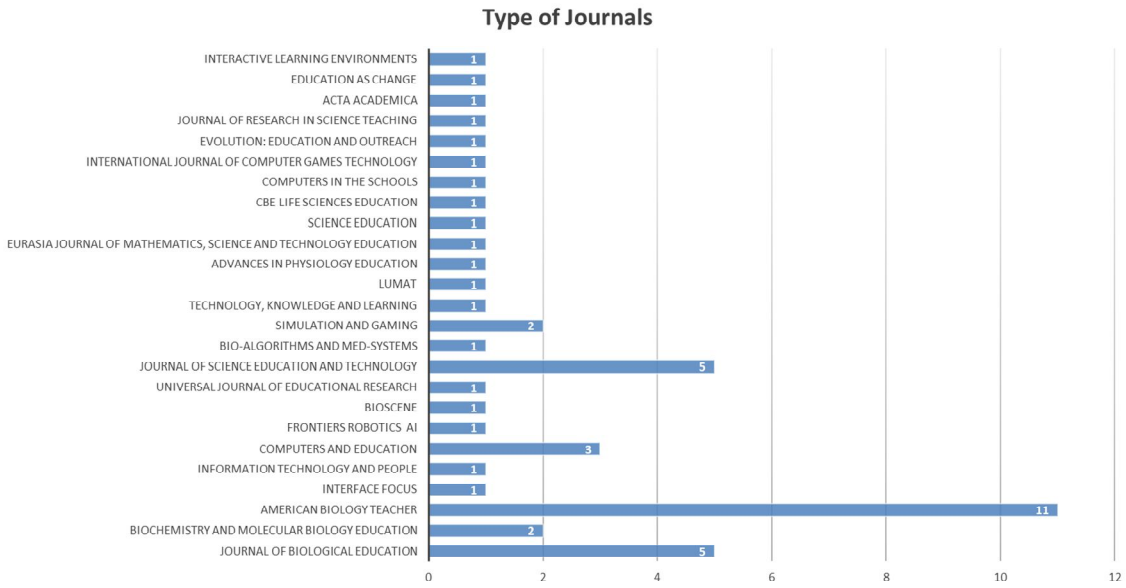


*Figure 3.* Number of articles on biology game published in international journals from 2010 to 2019.

The dominant journal is American Biology Teacher (categorized in ESCI), which publishes 11 papers then followed by the journal of science education and technology (categorized in SCIE and SSCI) and journal of biological education (categorized in SCIE and SSCI), which stood at five papers. Journal computers and education (categorized in ESCI) published four papers while Journal Simulation and Gaming (categorized in ESCI) and Journal Biochemistry and Molecular Biology Education (categorized in SCIE) have two papers over ten years. The other journals only show 1 article during the period that most of them categorized into ESCI.

*Education Level*

The important thing about education level the biology game implementation, including digital, non-digital, and gamification, is knowing the current status or trend. In this research, digital game use exceeded non-digital game and gamification, a digital game around 60% while non-digital game around 36 %. The rising numbers of the digital game caused by technology and students' characteristics as digital natives living in the digital era.

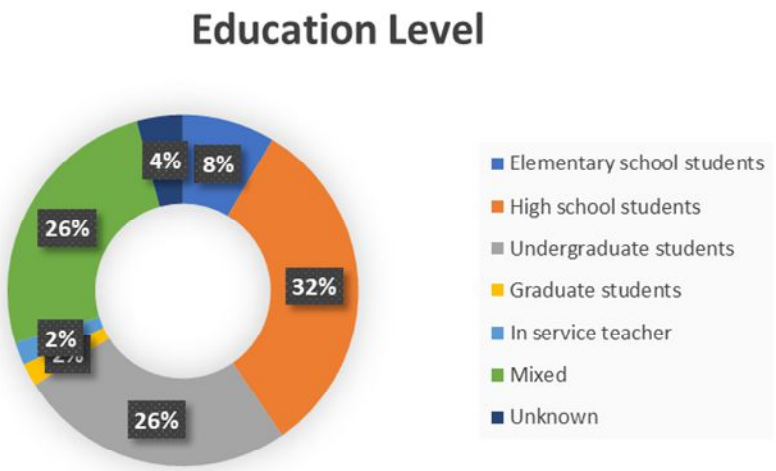


*Figure 4.* Numbers of type of education level from 2010 to 2019

Based on the type of education level (Fig.4), the majority game-used or implemented in high school students' level stood at 15 papers with a percentage of 32 %. Then it is followed by undergraduate students and mixed participants with a similar rate which is 26 %. The lowest percentage is an in-service teacher and graduate students. Meanwhile, elementary school students only have 8 %, which four times lower than high school students. According to Hainey et al. (2016), game-based learning has been used to teach primary students in various subjects such as mathematics, science, language, and social studies.

The game implemented at undergraduate students' level was ten papers which 2 of them are pre-service teachers. The mixed category shows 26 %, which was revealed in 12 articles. The mixed type divided into (i) high school students and elementary students, (ii) high school students and teachers, (iii) high school students and undergraduate students, and (iv) high school students and graduate students. The mixed category means that the category not only one education level but also a mix between the other education level.

The implementation of the game is mainly in the formal setting, around 96 %; meanwhile, for non-formal settings, only two papers. The papers explained that the researcher uses gamification in aquariums to promote marine animal conservations and museums to learn about the human biological system.

Tsai & Tsai (2020) presented that game-based learning has helped students across different levels of education. Besides, it also can be found that games are also used in pre-service teachers and in-service teachers, although the numbers only a few. It means that the development game in professional development still has room for improvement. According to Huizenga et al. (2017), teachers who use games in the classroom perceive student participation and cognitive achievement as using games informal teaching situations. After all, there is still a significant chance of developing games for high school students, given the current trend. Based on Bourgonjon et al. (2010), students' preferences to use the game in the classroom are affected by various factors such as personal experiences, learning opportunities, students'


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perceptions toward usefulness, and ease of use.

*Learning Strategies*

According to the graph, the vast majority of learning strategies used in the papers were active learning with 21 articles. Then, it is followed by collaborative learning with ten articles and interactive learning, which is nine papers. While contextual learning, direct guided learning, and outdoor learning only have two papers each. There are problem-based learning and inquiry-based learning in active learning, which have 7 and 2 articles. The classification of the learning strategies is based on the researchers mentioned in the article.

Encourage problem-posing and strategic thinking to become a new learning environment that can support the effectiveness of the 21st-century workforce and society (Qian & Clark, 2016). Most of the learning strategies mentioned can be applied to promote 21st-century skills, for instance, inquiry-based learning. However, in this research, the application of game biology in the schools only two papers.

Therefore, the implementation of inquiry learning in biology has a promising future. There are many shreds of evidence that can integrate inquiry with the science subject. Based on Srisawasdi & Panjaburee (2019), the inquiry can be integrated with game-based learning to transform learning into a science subject. In this study, the target of learning outcomes is student's conceptual understanding and motivation in the chemistry subject.

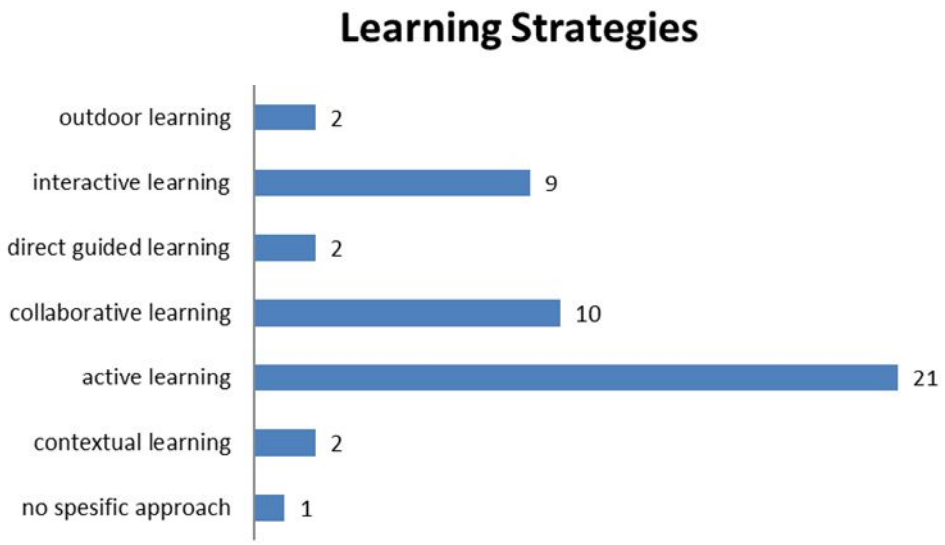


*Figure 5.* Numbers of learning strategies from 2010 to 2019

As a suggestion by Cheng et al. (2014), the instructional strategies must be integrated with the gameplay to fulfill the students learning outcomes or grasp the looked-for educational targets. In addition,

Hung et al. (2013) also mentioned that a good learning strategy could provide an effective digital game-based learning environment.

*Research Types*

The chart shows that the dominant type of research is quantitative research with over 50 %, while mixed and qualitative methods share the same proportion that only 15 % and the R & D only 6 %. The highest number of quantitative research give the same trends with Chang & Hwang (2019), which the number of papers allocated in the experimental study from 2007 to 2016 was empirical research. The quantitative analysis in this review consists of a survey, action research, and experimental research. Compared to the experimental research and survey, the proportion of action research is the highest, which stood at 20 papers.

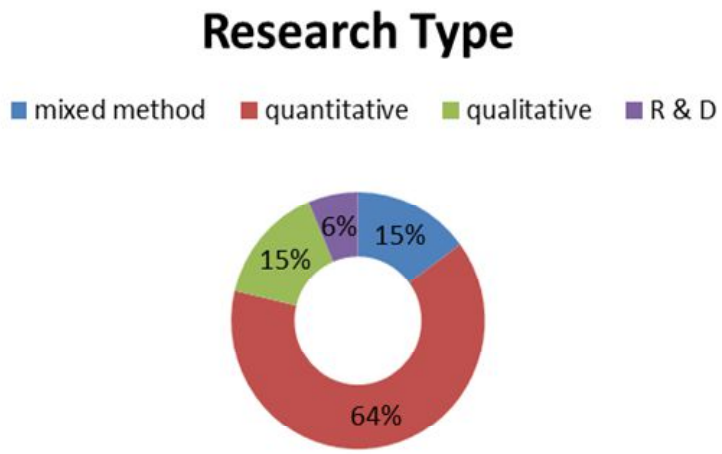


*Figure 6.* The percentage of research types from 2010 to 2019

*Biology Themes*

The seven themes found in this review are Cells and control Genetics; Natural Selection and Genetic Modification; Health, Disease and the development of medicine; Plant structure and functions; Animal Coordination, control, and homeostasis; and Ecosystem and material cycles.

Fig. 7 shows the distribution of topics in the papers. There are several categories of biology topics in the graphs based on the invention in the analysis steps. The highest proportion in the biology game is genetics which is 28 %. Then it is followed by Natural Selection and Genetic Modification which is 23 %, and Ecosystem and Material cycles which stood at 15 %. The percentage between Cells and control and Health, Diseases and the development of medicine have the same number which is 11 %. The lowest rate is in Plant structure and function, which is found in only two papers.


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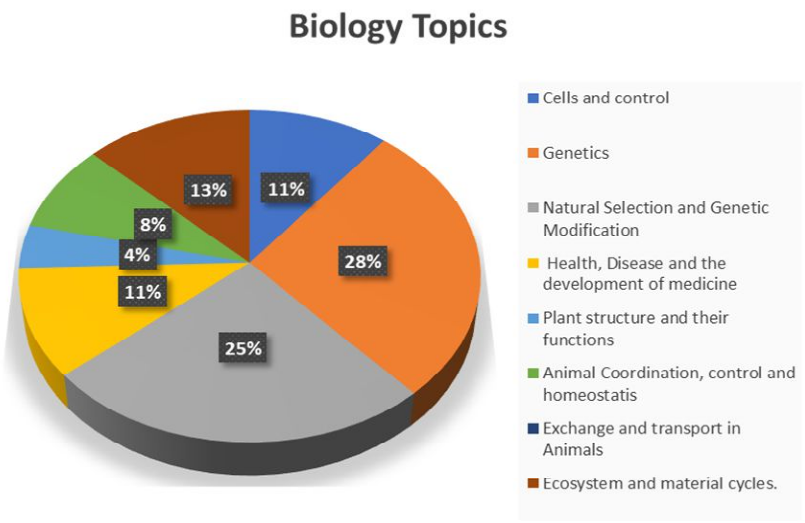


*Figure 7.* Numbers of biology topics from 2010 to 2019

In this research, Genetics comprises Meiosis, DNA, Protein synthesis, genetic variants, and Mendel. Meanwhile for Natural selection and genetic modification consist of evolution, classification, and biotechnology. Ecosystem and material cycles include ecosystem, energy transfer, and pollution. Health, Diseases, and the Development of medicine research are health and diseases, pathogens, viruses, and immune system. Meanwhile for plant structure and their function consist of photosynthesis. In the 47 journals, there are no topics related to the exchange and transport of animals.

The topic mentioned in the games can develop more in the future, considering the characteristic of the issues that are abstract and complicated. Several themes can be applied. For instance, according to Cheng et al. (2014), the concepts of human immunology are complicated to understand. In addition, Huizenga et al. (2017) suggest that further studies using the suitable game for focusing on specific subjects and how students learn when using a game might be helpful.

*Research Issues*

The graph below (Fig.8) shows the proportions of the measured variable (research issue) in the papers. Over 70 % of the research issue is in the cognitive area, which has 39 articles. Meanwhile, the others aspect like affective and psychomotor only has three papers and one paper respectively. In addition, there are some mixed domains and other.

Some measured variables in the cognitive domain, such as conceptual understanding, critical thinking skills, argumentation skills, and communication skills, were recognized. Meanwhile, there is motivation with three papers and student's engagement and enjoyment with one article in the affective domain. In the psychomotor domain, it has been found that the measured variable is collaboration skills. The other research issue in this review is media literacy. Besides, the mixed part consists of two domain

which is cognitive and affective. The measured variable is students' understanding of biology concepts and students' attitudes or perceptions in the mixed.


*Figure 8.* Numbers of the research issue from 2010 to 2019

Most researchers allocated the conceptual understanding, which 29 articles discussed. The development of games should be meaningful, which means they contained high-order thinking skills (synthesize, analyze, create, and evaluate). The dominant articles to investigate understanding concepts also argue in Li & Tsai (2013), which stated that most digital games were utilized to enhance scientific knowledge instead of problem-solving skills. Cheng et al. (2015) also found that most research studies from review serious game are focused on investigating serious game from the perspective cognitive domain. Interestingly, although the game is known by fun activity, the researchers who measure the enjoyment and engagement still a few which is only found 1 article over ten years.

The findings of the domains have been supported by many researchers, such as Johnson et al. (2012), who revealed that the game has the benefit of enhancing the student's motivation in the affective domain. However, in this review, only two papers research the implementation of the biology game to measure the student's motivation. It has been known that the game can develop a student's conceptual understanding. There are many researchers exposed about that, for instance, Khenissi, Essalmi, & Jemni (2015). Even Corredor, Gaydos, & Squire (2014) stated the game could stimulate the cognitive enhancement and formation of mental structure. Besides, the findings align with Plass, Homer, & Kinzer 's (2015) idea about foundations in game-based learning that games must have motivation, cognitive motivation, affective, and sociocultural engagement with the subject matter.

In the research mentioned above issues, there are 21$^{st}$ century skills, such as critical thinking skills, collaborative skills, and media literacy. Thus, the research issue is in line with the Qian & Clark findings (2016) that using Game-Based Learning (GBL) can promote the development of 21$^{st}$-century skills.

## Conclusions

Based on the main aims, the research focuses on analyzing educational biology games from 2010 to 2019 can conclude that over the period, the numbers of publications show the current evidence development game-based learning in biology. The primary author nationality is from the USA, and the major journal publication is American Biology Teachers, which is categorized in Emerging Science Citation Index. The findings imply that publication in the game biology context still rare, especially from Asian countries. The level of education in this review shows that most participants are high school students, which the implementation is in the formal settings. The study also revealed that the dominant learning strategy is active learning. The findings imply that the other learning strategies, such as inquiry-based learning rarely implemented in the biology game. In addition, primarily, the publication is quantitative research. The others findings are Biology Topics which the highest percentage theme used is Genetics. It indicates that the complexity and abstract content have an enormous opportunity to be developed in the future. Lastly, the majority of research issues that are measured are in the cognitive domain. The other domains, such as affective, social, psychomotor, have the lowest percentage. The most considerable proportion in the cognitive part is the understanding of the concept domain.

Further suggestions, to develop a biology game, researchers must consider the learning strategies, topics, and research issues. There is a significant opportunity to develop the game using inquiry-based learning because of the trends. The learning strategies can develop more skills such as scientific process skills, not only understanding concepts. By doing so, learning will be meaningful.

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