The Use of Serious Games in Physics: A Review of Selected Empirical Studies from 2012 to 2021

Mohamed Achour*, Jalal Khouna, and Ahmed Tahiri

***Abstract*—Serious games have been proven to be effective in enhancing students learning of physics. Many educators have investigated the integration of serious games in the classroom for formal educational settings. In addition, they have reviewed the trends development of game-assisted learning in many review papers. However, in the subject of physics, the analysis of the development of Serious games is still limited and overlooked problem. As a consequence, this research paper aims to conduct a systematic review of the empirical studies related to the use of serious games in physics teaching between 2012 and 2021. A total of 80 articles were included from Scopus and Web of Science databases. Based on an in-depth analysis of the quantitative data, several significant insights were generated in this study including the following : (1) the number of published articles has witnessed a dramatic growth in 2021; (2) computers and education are the main contributing journals in the empirical studies; (3) the highest proportion of the physics topics is the mechanics theme; (4) junior high school students were the most involved as sampling groups; (5) quantitative methodology design was adopted in the majority of selected papers; (6) American authors have contributed the most via a high number of publications; (7) cognitive outcomes were the major investigated research foci in Serious games-related studies. Along with the systematic review, this study has implicitly indicated some implications and suggestions that are in need of further research and discussion.**

***Index Terms*—Serious games, physics, educational settings, systematic review**

I. Introduction

With the prevalence of serious games among students in different grade levels, the potential of using educational physics games to facilitate learning has received an increasing attention among educators and researchers alike [1–3]. Although both motivation and student's engagement are significantly increased when they start playing serious games [4, 5]. The learning experience through games is contributed to the approaches embedded in serious games designs to help student's concept understanding [6, 7]. In the same context, Prensky *et al*. [8] stated that serious games must verify six main characteristics: rules, challenge, goals, representation or story, interaction, and feedback. Furthermore, Plass *et al*. [9] interpreted several serious games elements including game mechanics, learning objectives, visual aesthetics, incentives, narrative, musical score, and engagement. In addition to these characteristics, serious games could provide an attractive new way of effective learning, and efficient problem-solving skills [3, 10, 11]. To improve their effectiveness, some principal methodologies in the design of serious games were selected by Sandí *et al*. [12] and cited in abbreviations, such as, EMERGO, EDoS, LEGADEE, SAVIE, DODDEL, VGSCL, MECONESIS, MPIu+a, MPDSG.

The capability of serious games to better understand the concepts/phenomena of learners and to raise their motivation has drawn the importance by researchers. Moreover, some scientists found that the learners' interest to study science is more likely to be increased when their learning is contextualized [13, 14]. As a result, learners might be effectively developing their abilities and cognitive outcomes (problem-solving skills and critical thinking skills) to promote the 21st century skills.

For the sake of achieving these objectives, learning by playing serious games has been raised as a promising alternative in teaching science education [14–16]. Some serious games have been already created for physics subject such as Physics Playground, Supercharged, Kirchhoff's Revenge, Surge and Angry Birds, and evaluated in the classroom with different methods, such as behavioral observations, a feedback survey responded by students and teachers, and a comparative study into the control and experimental group using pre and post-test for measuring the learning gain [17, 18].

These games provide a virtual world where learners can apply their skills and learn scientific knowledge by accomplishing assigned activities. Hence, several empirical studies were conducted to evaluate the effectiveness of game-assisted learning. For example, Stege *et al*. [17], Vogel *et al*. [19], Wouters *et al*. [20], and Saprudin *et al*. [21] concluded that students who used educational physics games showed better results, specifically in cognitive gains toward learning compared to those using traditional teaching methods.

There have been a various articles reviewing the use of serious games in science education. Li and Tsai [22] identified 31 articles related to serious games in science education and they concluded that constructivism and cognitivism were the most theoretical foundations implemented by digital game-based learning researchers. Kara *et al*. [23] reviewed 37 papers published between 2016 and 2021 and as a result, experimental science was the most discussed discipline in the majority of the studies, while the subject area related to physics included only three articles. In addition, Cheng *et al*. [24] reviewed 53 empirical studies and

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five review studies related to the use of serious games in science education published between 2002 and 2013. They have confirmed that the majority of the reviewed studies were placing more emphasis on investigating serious games in terms of cognitive outcomes effectiveness, besides, they have revealed that the number of empirical studies related to serious games in education science has increased over the years, while the research topics related to physics covered only 11 studies. Connolly *et al.* [25] also analyzed 129 research papers published between 2004 and 2009 so as to understand the effects of serious games on learning, skill improvement, and engagement in different topics.

Generally, it is accepted that serious games can offer a live experience in which players can engaged and involved in embedded learning activities [24, 25]. Therefore, this study aims to systematically reviewing the empirical studies of serious games related to physics learning between 2012 and 2021 and to investigate the following thorough research questions:

1) How was evolved the number of articles on the use of physics games?
2) What were the top journals publishing physics games studies?
3) What were the physics' themes in the physics games papers?
4) What sampling groups were frequently preferred in physics games studies?
5) What were the research methods adopted mostly in physics games studies?
6) What were the top countries integrating physics games studies?
7) What were the research foci in the physics games studies?

II. Method

A. Data Collection

This research study aims at providing an in-depth analysis of empirically conducted studies on the involvement of serious games in teaching physics between 2012 and 2021. As Scopus and Web of Science are highly recognized and well-regarded databases, the Science Citation Index (SCI) and Social Science Citation Index (SSCI) were used as the main sources in this systematic literature review. For the objective of appropriately selecting relevant studies for the review, two phases have been adopted. First, searching the SCI database and the SSCI database using articles titles, abstracts and keywords. Second, using the advanced research method where Boolean logical terms have been used in conjunction with keywords related to digital games (digital game-based learning, serious game, educational game, computer game, video game, online game, on-line game, DGBL, gaming), and keywords related to physics (learning physics, physics learning, teaching physics, physics teaching, physics instruction, instruction physics, physics). The two keywords' sets were combined together by applying the logical operator ''AND'' where the Boolean operator "OR'' was used to combine the synonyms between them.

For the data collection method, data is collected manually and processed by using Excel software to get required results.

B. Data Analysis

The selection of publications was adopted by thoroughly analyzing the content of articles and research papers via their titles and abstracts. Articles that are directly meeting and obeying the following criteria:

1) Serious game articles should be related to physics teaching.
2) literature review papers are to be discarded from the selected publications.
3) Only empirical articles across a variety of research designs may be included.
4) Articles published from 2012 to 2021 in journals are selected, unpublished dissertations, Conferences proceeding, books and book chapters are excluded from the study.

Papers not verifying the four aforementioned criteria are to be excluded. As a results, a total of 80 empirical studies were selected in the present study as relevant sample for an extensive literature review.

III. Results and Discussion

A. The Number of Articles Published and Major Contributing Journals

As shown in Fig. 1, there has been a steady increase in the number of articles from 2012 to 2021 reaching two peaks (in 2016 and 2021). Moreover, Fig. 2 clearly shows that out of the 80 empirical studies, only 12 articles were published from 2012 to 2014. Whereas, in the last period of 2018–2021 the number of published studies displayed a meaningful increase (38 papers). These results imply that the potential of serious games in learning physics has evoked and enlightened so many researchers and educators, especially over the last four years (see Fig. 2). This leads to a dramatic growth in the number of studies that has been carried out recently to shed light on the effectiveness of serious games in physical discipline.

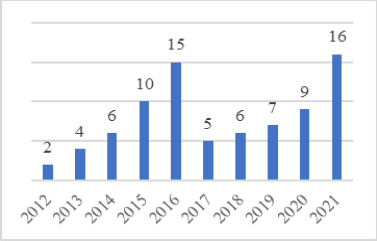

Fig. 1. Number of serious games articles published from 2012 to 2021.

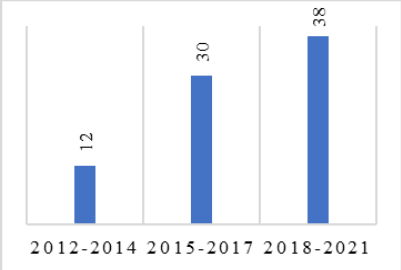

Fig. 2. Number of publications by selected periods from 2012 to 2021.

The present study is similar to other related research

[24–26], inasmuch as the review study results demonstrated a surge of interest to take serious games in teaching. These results are promoting because they show a deeper understanding of what serious games offer to physics, as well as the various positive effects that learners can gain.

Several journals were contributed to publishing productivity related to the efficiency of serious games for teaching/learning the physics science. The below part spotlighted the major journals of this research domain.

TABLE I: TOP SEVEN CONTRIBUTING JOURNALS IN TERMS OF THE NUMBER OF EMPIRICAL STUDIES PUBLISHED ON USING SERIOUS GAMES IN PHYSICS TEACHING FROM 2012 TO 2021

Rank	Journal title	N
1	Computers and Education	11
2	Computers in Human Behavior	6
3	Physics Education	4
4	European Journal of Physics	3
4	Journal of Computer Assisted Learning	3
4	Journal of Baltic Science Education	3
4	Educational Technology & Society	3

Based on Table I, the dominant journal is Computers and Education with 11 published articles, which relatively explains that relevant studies focused mainly on digital learning. In this regard, Ching-Yi *et al*. [27] found that the journal of Computer and Education published most of the studies related to learning by mobile era. As identified in this study, Arici *et al*. [28] and Cheng *et al*. [24] supported these findings and confirmed that the journal of Computers and Education published mostly serious game-related studies. As it is ranked in second place in journal of Computers in Human Behavior (6 articles), it can be noted that serious games provide not only cognitive outcomes but also influence the students' emotional states. Then, the frequency of journals related to physics subject is justified by its ranking on the third position in the journal physics education (4 articles).

B. Physics Themes

Table II shows the number of physics topics in the empirical studies. There are nine main categories of physics topics detected in this study, the highest number in the educational physics games is mechanics (49 articles), then it is followed by electricity by 10 published articles, and electromagnetism and electrostatic which stood at 6 papers. The other themes, such as optics, quantum mechanics, astronomy, waves, and thermodynamics were conducted in only 19 papers.

The dominant mechanic's theme in the implementation of serious games in the classroom suggested that discipline is mostly characterized by problem-solving situations. In this respect, serious games can be considered as a form of problem solving, and capable to create an experiential learning [3, 29], where students deeply understand the mechanics concepts, for instance, Laws of Newton, and to develop their scientific thinking effectively [3, 30]. It can also be concluded from these findings that the evolution number of serious games research related to mechanics themes in the last ten years, revealed the current evidence development in designing mechanics games.

TABLE II: THE PHYSICAL DISCIPLINES SELECTED FOR SERIOUS GAME STUDIES FROM 2012 TO 2021

Physics domains	2012–1014	2015–2017	2018–2021	Total
Mechanics	6	18	25	49
Electricity	2	1	7	10
Electromagnetism and electrostatic	2	1	3	6
Optics	1	3	1	5
Quantum mechanics	1	2	2	5
Astronomy	0	4	1	5
Waves	0	1	2	3
Thermodynamics	0	1	0	1
Global warming	1	0	0	1
Renewable energy	0	1	0	1
Energy education	0	1	0	1

Note: *Studies that reached multiple physics domains were counted repeatedly.

C. Research Sample Groups Selected

Table III shows the distribution of the research sample groups targeted in those serious game studies. It is found that from 2012 to 2021, research samples of junior high school students are selected the most (35 studies), followed by university students (22 studies) and senior high school students (20 studies). On the other side, only a few studies selected primary school students (10 studies) and pre-school students (2 studies) as the research sample. However, the highest frequency of junior high school students in the reviewed articles can be explained by two reasons: first, students in that grade level are applying mostly acquired knowledge to solve problems in new situations (competence approach). Second, the teaching process during their activities focuses primarily on the qualitative approach which is appropriate for the most of serious game designs.

TABLE III: TARGETED AUDIENCE OF THE REVIEWED STUDIES PUBLISHED FROM 2012 TO 2021

Target students	2012–1014	2015–2017	2018–2021	Total
Kindergartners	0	2	0	2
Primary school	2	4	4	10
Junior high school	7	12	16	35
Senior high school	2	5	13	20
College	1	10	11	22
Teachers	0	2	5	7
Other	0	1	1	2
Non-specified	1	0	0	1

* Studies that reached multiple sample groups were counted repeatedly.

These results are quite similar to those published in a study conducted by Li and Tsai [22], Nuri Kara *et al*. [23] and Cheng *et al*. [24], which also confirms that participants selected in empirical studies were mainly high school students. As of 2015, many researchers have begun to reveal the vital role of involving serious games to facilitate secondary students learning (junior and senior high school) and college students. Research aiming to make adults and teachers participate were also found in the reviewed studies from 2015

to 2021. These data reflect that educational games are used as learning tools and teaching for formal and informal settings, as well as for teacher professional development and adult education. Similarly to these findings, Cheng *et al*. [24], Nuri Kara *et al*. [23] and Adita *et al*. [31] reported that serious games are applied in formal and informal education. Generally, serious games are not only student-teaching oriented, but they become also widely used in society.

D. Research Methods

Three research methodologies have been detected in our review including quantitative, qualitative and mixed method. Some researchers who follow mixed research methods combined the qualitative approach including the data with a textural form/comments and the quantitative approach which is requiring only the numerical data. Fig. 3 shows that quantitative-method research has reached the percentage of 57.5%, while mixed research which is adopted with an exclusively restricted percentage of 35% in serious game -relevant studies. A relatively qualitative approach was only applied in 7.5%. These research findings support the domination of quantitative research in serious game related studies in teaching [23–25, 28, 32].

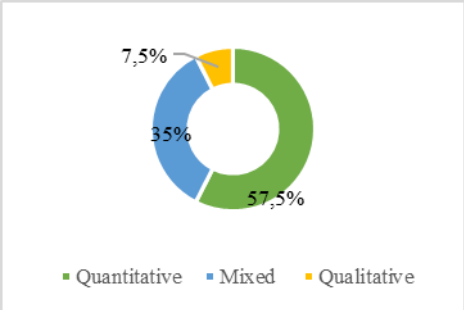

Fig. 3. The repartition of the research methods from 2012 to 2021.

The deep analysis derived from the Fig. 3 clearly confirms that researchers in serious games domain tended to mostly adopt the quantitative approach to further depict user motivations, engagements and perceptions, also to evaluate accurately the students' cognitive outcomes. In this regard, the research foci of the all-selected articles, were divided into three main categories: psychomotor domain, affective domain and cognitive domain.

E. Major Contributing Countries

Fig. 4 and Fig. 5 illustrates the major contributing countries of serious game articles in the last decade from 2012 to 2021. In the first five years (see Fig. 4), American authors were prominent when compared with authors from other countries as they produced the most publications (16 articles). Taiwanese authors were ranked in the top two contributors by almost 8 articles while Dutch authors contributed with four articles. In the second five years (see Fig. 5), American authors have contributed the most (18 articles) followed by Taiwanese authors with six published papers, while Indonesians authors and Chinese authors were contributed with four and three articles respectively. Whereas, Asian countries have recently published serious game research, especially in the last five years. While there is no contribution from African countries except for Morocco which has contributed with one research paper.

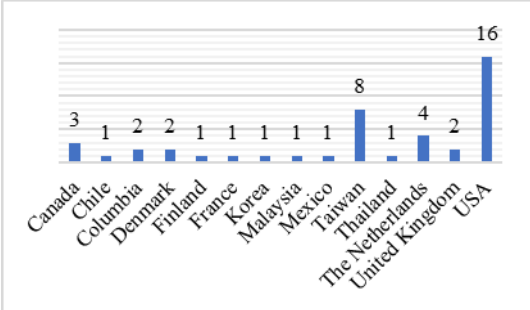

Fig. 4. Major contributing countries of serious game articles from 2012 to 2016.

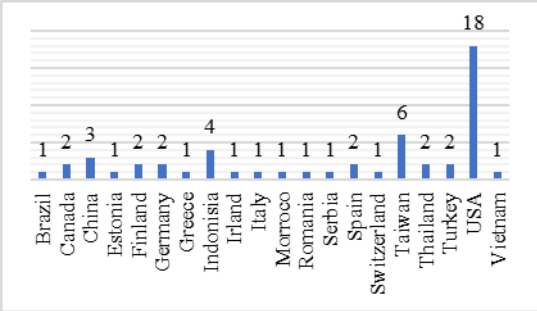

Fig. 5. Major contributing countries of serious game articles from 2017 to 2021. (*A Serious Game-related study might have more than one contributing country).

Moreover, it is revealed that in comparison with the first five years, the number of countries producing serious game studies has witnessed an important augmentation in the second five years (from 14 to 20), which might be explained by the fact that serious games are becoming a universal research topic due to increased awareness of the use of serious games in education. Related to these research findings, Hwang *et al*. [26] also mentioned that research in serious game-related studies, becoming widely investigated.

F. Research Foci

Fig. 6 shows the number of research foci (measured variables) in the selected papers. About 70% of the learning goals are in knowledge acquisition as a main level in the cognitive domain (Bloom's Taxonomy). Additionally, some measured variables in the cognitive outcomes, such as critical thinking skills (analyze, synthesize, evaluate, and create), argumentation skills, communication, and problem-solving skills, were recognized. Problem-solving skill was identified as a vital category of skills domain, and it has been highlighted in 14% of the selected articles. Moreover, there is a perception in learning style with 18 papers, which was widely reported in terms of designing games and the clarity of the proposed consigns established by designers. In the affective domain, it has been found generally three measured variables, motivation aspect, student enjoyment, and engagement. Each dimension was investigated in a quarter of all papers, in this respect, Fengfeng *et al*. [33] reviewed some studies, and reported that the engagement aspect was divided into three categories, such as affective, cognitive, and content engagement.

Besides, the other research issues in this study and psychomotor aspects only have 16 and 10 papers respectively. According to these reviewed studies, the majority of serious

game-related studies focused on cognitive outcomes. Several previous research [22–25, 31] confirmed the domination of cognitive outcomes in empirical research, which involved various domains of knowledge. Furthermore, all variables of research foci were evaluated and discussed in both formal and informal contexts related to the target audience of all ages. Accordingly, most of the learning goals in skills domain are focused on problem-solving strategies. Li and Tsai [22] supported these findings, by stating that most serious games were implemented to enhance students' scientific reasoning instead of problem-solving abilities. Taking into consideration, a variety of educational goals (for example, creativity, critical thinking, and soft skills) have also been assessed, and they should be incorporated consciously in designing games for the sake of promoting learners' development of 21st-century skills. Interestingly, the serious games are recognized by leisure activities, the educators who measure motivation, engagement and enjoyment as factors to improve the learning process. For this reason, affective aspects were investigated in more than 65% of selected papers. This reflects the potential of serious games to change students' emotions. Similarly, Cheng *et al*. [24] mentioned in a review study that 24 papers out of 53 selected articles were focused on affective outcomes. Consequently, future studies should obligatory focus not only on students' cognitive outcomes but also on the development of 21st-century skills and affective aspects.

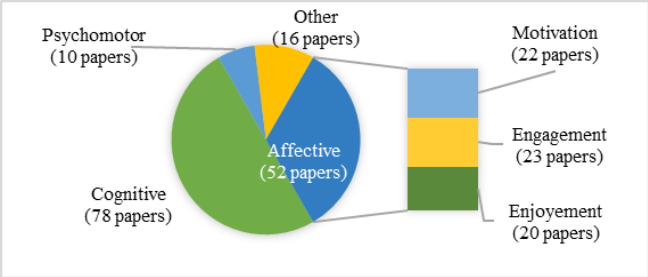

Fig. 6. Numbers of the research foci between 2012 and 2021. (*Multiple research foci might be revealed in a serious game-related study).

IV. Conclusion

The purpose of this study was to conduct a systematic review related to the involvement of serious games in teaching physics from 2012 to 2021. Through a series of research, seven key questions are quantitatively answered. In precise, we have found that over the years, the number of serious game articles increased at an astonishing rate. Moreover, the mechanics' theme has been discussed in the majority of published articles. From the targeted audience perspective, junior high school students are primarily involved in the studies. In adition, it is clearly confirmed that quantitative research methodology for empirical studies is adopted in the most of publications. Regarding the research foci, it can also be concluded that empirical studies are mainly interested in cognitive outcomes. As it is exposed in this study, the majority of learning objectives were discussed in terms of knowledge construction, whereas the variety of other learning objectives (for example, problem-solving abilities, and communication skills) have been investigated as well in a few studies. In consequence, in future research, more emphasis should be placed on the exploration of the ability of serious games to enhance the physics concepts understanding of the secondary Moroccan students and foster their problem-solving. This study makes a significant contribution to research providing researchers with a holistic overview and preliminary launching groundwork to the serious game studies relating to physics concepts.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

MA selected the reviewed studies, collected the Data, discussed, and wrote the manuscript, JK analyzed the manuscript, discussed, and supervised our study; AT supervised the preparation of this manuscript. All authors had approved the final version.

References

[1] P. Marc, "The games generations: How learners have changed," *Digital-Game Based Learning*, 2001, vol. 1, no. 1, pp. 1–26.

[2] K. Squire, M. Barnett, J. M. Grant, and T. Higginbotham, *Electromagnetism Supercharged! Learning Physics with Digital Simulation Games*, p. 8, 2004.

[3] B. Y. White, "Designing computer games to help physics students understand Newton's laws of motion," *Cogn. Instr*., vol. 1, no 1, pp. 69–108, 1984. doi: 10.1207/s1532690xci0101_4

[4] J. Khouna, R. Ahmed, and E. M. Abdelilah, "Are educational games engaging and motivating moroccan students to learn physics?" *Int. J. Emerg. Technol. Learn*, vol. 14, no. 16, p. 66, 2019. doi: 10.3991/ijet.v14i16.10641

[5] W. M. Idrissi, G. Chemsi, K. Kababi, and M. Radid, "The impact of serious game on the nursing students' learning, behavioral engagement, and motivation," *Int. J. Emerg. Technol. Learn*, vol. 17, no. 01, pp. 18–35, 2022. doi: 10.3991/ijet.v17i01.26857

[6] G. David, A. Clark, and P. Marc, *Games and Simulations in Online Learning: Research and Development Frameworks: Research and Development Frameworks*, Idea Group Inc (IGI), 2006.

[7] K. Michele and C. Lankshear, *A New Literacies Sampler*, vol. 29, Peter Lang, 2007.

[8] P. Marc, "Fun, play and games: What makes games engaging," *Digital Game-Based Learning*, 2001, vol. 5, no 1, pp. 5–31.

[9] J. L. Plass, B. D. Homer, and C. K. Kinzer, "Foundations of game-based learning," *Educ. Psychol.*, vol. 50, no 4, pp. 258–283, 2015, doi: 10.1080/00461520.2015.1122533

[10] J. P. Gee, *What Video Games Have to Teach Us About Learning and Literacy*, vol. 1, no 1, p. 5, 2003.

[11] N. T. H. Giang and L. H. Cuong, "Evaluating feasibility and effectiveness of digital game-based instructional technology," *Int. J. Emerg. Technol. Learn*, vol. 16, no 16, p. 4, 2021. doi: 10.3991/ijet.v16i16.23829

[12] S. Delgado, J. Carlos, and B. P. Alejandra, "Designing serious games: Analysis of methodologies," *E-Ciencias de la Información*, 2021, vol. 11, no 2, pp. 80–106.

[13] Honey and Hilton, *Learning Science through Computer Games and Simulations*, Washington, D.C: National Academies Press, 2011.

[14] M. J. Mayo, "Games for science and engineering education," *Commun*., vol. 50, no 7, pp. 30–35, 2007. doi: 10.1145/1272516.1272536

[15] S. Barab and C. Dede, "Games and immersive participatory simulations for science education: An emerging type of curricula," *J. Sci. Educ. Technol.*, vol. 16, no 1, pp. 1–3, 2007. doi: 10.1007/s10956-007-9043-9

[16] A. Maxmen, "Video games and the second life of science class," *Cell*, vol. 141, no. 2, pp. 201–203, 2010. doi: 10.1016/j.cell.2010.03.045

[17] L. Stege, G. Lankveld, P. Spronck, and P. O. Box, "Teaching high school physics with a serious game," *Int. J. Comput. Sci. Sport*, vol. 10, p. 12, 2012.

[18] C. Adriana and F. Jessamyn, "Game-based learning to engage students with physics and astronomy using a board game," *Research Anthology*

on Developments in Gamification and Game-Based Learning. IGI Global, 2022. pp. 785–801.

[19] J. J. Vogel, D. S. Vogel, J. Cannon-Bowers, C. A. Bowers, K. Muse, and M. Wright, "Computer gaming and interactive simulations for learning: A meta-analysis," *J. Educ. Comput. Res*., vol. 34, no 3, pp. 229–243, 2006. doi: 10.2190/FLHV-K4WA-WPVQ-H0YM

[20] Wouters. (2013). A meta-analysis of the cognitive and motivational effects of serious games. PsycNET. [Online]. Available: https://doi.apa.org/doiLanding?doi=10.1037%2Fa0031311

[21] Saprudin *et al*., "The effectiveness of using digital game towards students' academic achievement in small and large classes: A comparative research," *International Journal of Learning, Teaching and Educational Research*, 2019, vol. 18, no 12, pp. 196–210.

[22] M.-C. Li and C.-C. Tsai, "Game-based learning in science education: A review of relevant research," *J. Sci. Educ. Technol*., vol. 22, no 6, pp. 877–898, 2013. doi: 10.1007/s10956-013-9436-x

[23] N. Kara, "A systematic review of the use of serious games in science education," *Contemp. Educ. Technol*., vol. 13, no 2, p. ep295, 2021. doi: 10.30935/cedtech/9608

[24] M.-T. Cheng, J.-H. Chen, S.-J. Chu, and S.-Y. Chen, "The use of serious games in science education: A review of selected empirical research from 2002 to 2013," *J. Comput. Educ*., vol. 2, no 3, pp. 353–375, 2015. doi: 10.1007/s40692-015-0039-9

[25] T. M. Connolly, E. A. Boyle, E. MacArthur, T. Hainey, and J. M. Boyle, "A systematic literature review of empirical evidence on computer games and serious games," *Comput. Educ.*, vol. 59, no 2, pp. 661–686, 2012. doi: 10.1016/j.compedu.2012.03.004

[26] G.-J. Hwang and P.-H. Wu, "Advancements and trends in digital game-based learning research: a review of publications in selected journals from 2001 to 2010: Colloquium," *Br. J. Educ. Technol*., vol. 43, no 1, pp. E6–E10, 2012. doi: 10.1111/j.1467-8535.2011.01242.x

[27] C.-Y. Chang and G.-J. Hwang, "Trends in digital game-based learning in the mobile era: A systematic review of journal publications from 2007 to 2016," *International Journal of Mobile Learning and Organisation*, 2019, vol. 13, no 1, pp. 68–90.

[28] F. Arici, P. Yildirim, Ş. Caliklar, and R. M. Yilmaz, "Research trends in the use of augmented reality in science education: Content and bibliometric mapping analysis," *Comput. Educ*., vol. 142, p. 103647, 2019. doi: 10.1016/j.compedu.2019.103647

[29] G. David, L. Duarte, and C. Carlo, "Serious gaming for experiential learning," in *Proc. 2011 Frontiers in Education Conference (FIE)*, IEEE, 2011, pp. T2G-1–T2G-6.

[30] Djamas *et al*., "Development of interactive multimedia learning materials for improving critical thinking skills," *Research Anthology on Developing Critical Thinking Skills in Students. IGI Global*, 2021, pp. 507–525.

[31] Adita. Arum *et al*., *Game-based Biology Learning: A Systematic Review of the Literature during 2010-2021*, 2021, vol. 44, no 2, pp. 1–18.

[32] E. A. Boyle *et al*., "An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games," *Comput. Educ*., vol. 94, pp. 178–192, 2016. doi: 10.1016/j.compedu.2015.11.003

[33] F. Ke *et al*., "Game-based learning engagement: A theory-and data-driven exploration," *British Journal of Educational Technology*, 2016, vol. 47, no. 6, pp. 1183–1201.

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