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EXPLORING TRENDS IN GAME-BASED PHYSICS EDUCATION: A BIBLIOMETRIC STUDY FROM 1973 TO 2023

Abstract. Games are widely used to increase students' interest and participation in physics lessons. We need an in-depth analysis of the consistency of this study. This study aims to analyze research trends in the use of games in physics education using a bibliometric approach. Data were retrieved from the Scopus database using the keywords "play" and "physical education". Among the 125 articles obtained based on the search criteria, a trend analysis of the study was conducted using RStudio and VosViewer software. The analysis shows that publications on this topic have increased significantly since the early 2000s, from 1973 to 2023. Researchers from the USA and Europe dominated the publication. Nevertheless, the countries of Asia and Australia also started to contribute significantly. Intercontinental cooperation is important to provide a broader perspective. The main magazine that publishes articles on this topic is "Computer and Education". The most cited articles focus mainly on the effects of games on students' learning of physics. They identified five main keyword clusters that represent different ways of using games in physics education. Overall, this study provides an in-depth understanding of research trends and key findings related to the use of games in physics education. Further research is recommended on game design, technology integration, and implementation strategies to maximize the benefits of play to improve the quality of instruction and student physical education achievement.

Keywords: bibliometric, game, physics education, Scopus, biblioshiny, VosViewer, Rstudio.

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Ойынға негізделген физика біліміндегі тенденцияларды зерттеу: 1973-2023 жылғы библиометриялық зерттеу

Аңдатпа. Студенттердің физика сабағына деген қызығушылығы мен сабаққа қатысуын арттыру үшін ойындар кеңінен қолданылады. Бізге бұл зерттеудің жүйелілігіне терең талдау қажет. Бұл зерттеу библиометриялық тәсілді пайдалана отырып, физиканы оқытуда ойындарды пайдалануды зерттеу тенденцияларын талдауға бағытталған. Деректер Scopus дерекқорынан «ойын» және «физикалық білім» кілт сөздерін пайдаланып алынды. Іздеу критерийлері негізінде алынған 125 мақаланың ішінде RStudio және VosViewer бағдарламалық құралдарының көмегімен зерттеудің трендтік талдауы жүргізілді. Талдау көрсеткендей, бұл тақырыптағы жарияланымдар 2000-шы жылдардың басынан бастап 1973 жылдан 2023 жылға дейін жарияланған жылы айтарлықтай өсті. Басылымда АҚШ пен Еуропаның зерттеушілері басым болды. Соған қарамастан, Азия мен Австралия елдері де айтарлықтай үлес қоса бастады. Кеңірек перспективаны қамтамасыз ету үшін континентаралық ынтымақтастық маңызды. Осы тақырып бойынша мақалалар жариялайтын негізгі журнал – «Компьютер және білім». Ең көп келтірілген мақалалар негізінен ойынның студенттердің физиканы үйренуіне әсеріне бағытталған. Олар физиканы оқытуда ойындарды қолданудың әртүрлі тәсілдерін көрсететін бес негізгі кілт сөз кластерін анықтады. Тұтастай алғанда, бұл зерттеу физиканы оқытуда ойындарды қолдануға байланысты зерттеулердің тенденциялары мен негізгі қорытындыларын терең түсінуге мүмкіндік береді. Оқыту сапасы мен оқушылардың дене тәрбиесі жетістіктерін жақсарту үшін ойынның артықшылықтарын барынша арттыру үшін ойын дизайны, технологияларды біріктіру және іске асыру стратегияларына қатысты қосымша зерттеулер ұсынылады.

Кілт сөздер: библиометрия, ойын, физикалық білім, Scopus, кітапхана, VosViewer, Rstudio.

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Изучение тенденций в игровом обучении физике: библиометрическое исследование с 1973 по 2023

Аннотация. Игры широко используются для повышения интереса и участия учащихся в уроках физики. Нам необходим углубленный анализ последовательности этого исследования. Целью данного исследования является анализ тенденций в использовании игр в образовании по физике с использованием библиометрического подхода. Данные были получены из базы данных Scopus с использованием ключевых слов «игра» и «физическое воспитание». Среди 125 статей, полученных по критериям поиска, был проведен анализ тенденций исследования с помощью программного обеспечения RStudio и VosViewer. Анализ показывает, что публикации на эту тему значительно возросли с начала 2000-х годов, с 1973 по 2023 год. В публикации преобладали исследователи из США и Европы. Тем не

менее, страны Азии и Австралия также начали вносить значительный вклад. Межконтинентальное сотрудничество важно для обеспечения более широкой перспективы. Основным журналом, публикующим статьи на эту тему, является «Компьютер и образование». Наиболее цитируемые статьи посвящены в основном влиянию игр на изучение физики учащимися. Они определили пять основных групп ключевых слов, которые представляют различные способы использования игр в обучении физике. В целом, это исследование обеспечивает глубокое понимание тенденций исследований и ключевых выводов, связанных с использованием игр в образовании по физике. Рекомендуется провести дальнейшие исследования в области игрового дизайна, интеграции технологий и стратегий внедрения, чтобы максимизировать преимущества игры и улучшить качество обучения и достижения учащихся в области физического воспитания.

Ключевые слова: библиометрия, игра, образование по физике, Scopus, библиотека, VosViewer, Rstudio.

Introduction

Physics has become a challenging subject in contemporary education. Students often find it difficult to understand physics [1]. One of the reasons is the abundance of mathematical formulae and concepts that are considered to be false [2]. The study of physics should give room to the creativity of students [3]. Minimal interest in physics affects the difficulty of students developing understanding because they don't take lessons well. So from that, educators should be able to cultivate students' interest in physics. Students will understand the material more easily if they are interested in studying it. Educators need to master the material, understand the core concepts, and the best way to teach them [4]. Conventional methods centered on teachers boring students. For that, a pleasant learning medium is needed [5]. The best way to attract a student's interest in learning is to take advantage of what's most in-demand, like games. Although many are still skeptical of this, technology depends on its users [6]. If used wisely, games can boost the enthusiasm and interest of students in learning physics. Thus, the knowledge that is to be passed on can be well received.

Educational games have the primary purpose of helping students receive material well, not just entertainment [7]. Learning and teaching are interrelated; learning depends on the recipient, and teaching on the teacher [8]. If the teacher uses the game wisely, the students will be easier to absorb the material delivered. Games make the learning process more interesting and interactive so students don't get bored quickly. Games can also trigger curiosity and challenge students to solve problems, not just listen to boring lectures. The game raises the hypothesis and the best action in the interests of the player [9]. It supports a better learning process. According to [10], games provide direct feedback that allows learning to be more effective by increasing fidelity and in-depth experience. Integrating games into physics learning that is considered boring can have a huge impact. Students tend to love games and addiction to them. The combination of both makes physics more attractive so that matter is more acceptable. The more senses are involved in learning, the better absorption and material retention [11]. Students will be motivated to try the challenge of teachers to develop an understanding of physics.

The use of games in physics learning potentially increases students' interest, involvement, and understanding of the material, thereby creating a more attractive and effective learning environment. Therefore, a deep understanding of the use of games in physics learning is required by analyzing the consistency of previous research. One way that can be used is bibliometric analysis. Bibliometric analysis applies mathematical and statistical methods to evaluate scientific publications, so it can identify research trends [12]. Benefits of bibliometric analytics include being able to visualize trends in research, international collaboration and authorship, research keywords, as well as future research recommendations [13]. Therefore, bibliometric analysis research methods

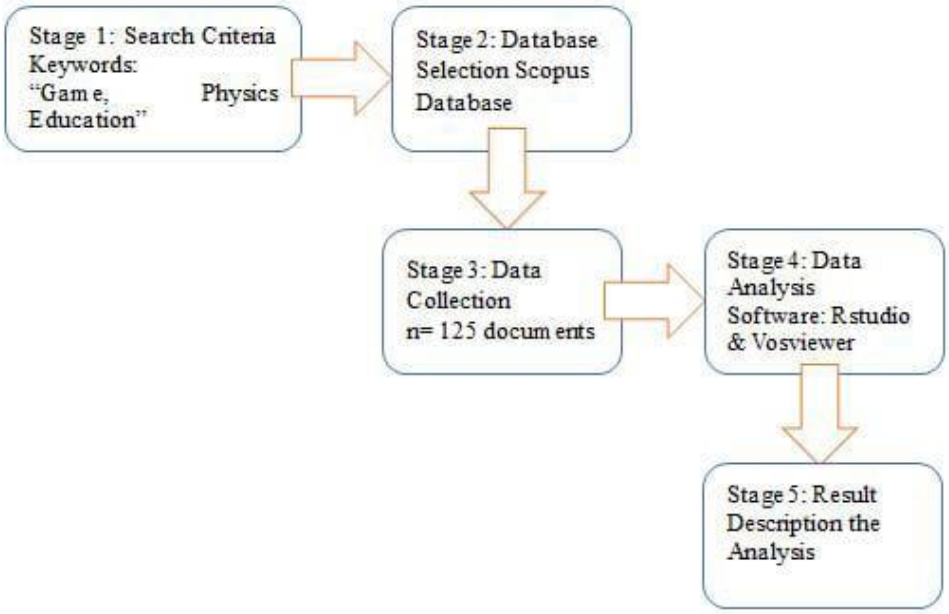
are essential to evaluate previous research results and provide consistent validation of findings. The use of bibliometric analysis can provide in-depth insight into the use of games in physics learning.

Bibliometric analysis has been done on a wide range of topics such as Virtual Reality (VR), Augmented Reality, and Physical Activity (PA) [14]; patents and scholarly publications from cross-disciplinary projects [15]; augmented reality in physics education [16]; power analysis [17]; Academic coaching [18]; Situational interest [19]; Islamic counselling [20]; Digital transformation [21]; mobile learning adaptation [22]; mathematical creativity [23] Community engagement [24]; Accreditations [25]; Preschool literacy [26]; Virtual reality in nursing [27]; Journal of special education technology [28], and emerging adulthood [29]. Some bibliometric researches use software such as R Studio, Vosviewer, and SainsMath to analyze data [12, 13]. RStudio with biblioshiny package is often used due to ease of operation and analytical features such as collaboration writer, country, trends, mapping, and keyword. In addition to RStudio, VosViewer is also useful in deepening analysis. The combination of these two software will give rise to a comprehensive trend analysis. Although there is a lot of bibliometric research on physics, special analysis related to the use of games in physical education has not been done much. Therefore, the study aims to carry out bibliometric analysis using the RStudio features to provide a deep understanding of the publication characteristics, research productivity, collaboration, keywords, and recommendations for further research related to this topic.

Method

The purpose of this research is to look at research trends using bibliometric analysis. Bibliometric is an analysis approach that aims to explore opportunities and identify trends in research development through quantitative analysis of scientific literature and publications [30]. This research focuses on developing trends in research on the use of games in physical education.

Figure 1. *Bibliometric Research Stream*



The research began with a search using the keywords "Game" and "Physics Education" in the Scopus database, which produced as many as 125 articles that were then prepared for further analysis using tools such as RStudio and VosViewer. Through the analysis process, researchers can interpret emerging research trends and conduct keyword groupings to present a comprehensive picture of the relationship between games and physical education. The results of this analysis are expected to provide valuable insights into developments and focus of research about the integration

of games in physics education.

Results

General Characteristics of Literature

Game research in physical education showed the general characteristics listed in Table 1. In the Scopus database, as many as 125 articles were identified after setting the appropriate search criteria. The number of researchers discussing this topic was 312; the average citation per article was 12.23; the percentage growth rate of publication was 4.71%; the median citations per article were 12.23; and the average age of an article was 8.92.

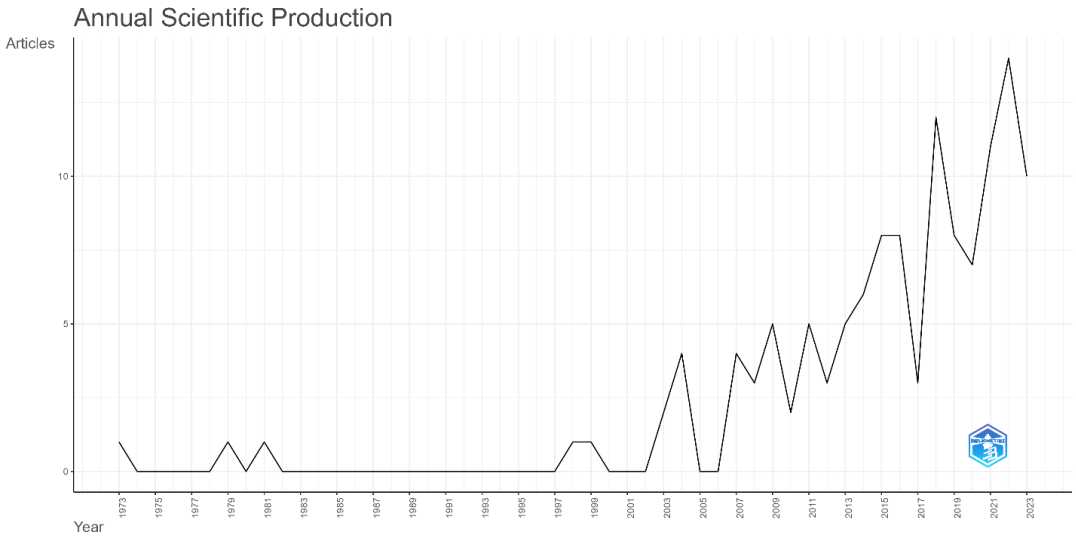
Table 1. *Main Information*

Description	**Results**
Main information about data	
Timespan	1973:2023
Sources (Journals, Books, etc)	63
Documents	125
Annual Growth Rate %	4,71
Document Average Age	8,92
Average citations per doc	12,23
References	3754
Document contents	
Keywords Plus (ID)	390
Author’s Keywords (DE)	272
Authors	
Authors	312
Authors of single-authored docs	28
Authors collaboration	
Single-authored docs	29
Co-Authors per Doc	2,86
International co-authorships %	8,8
Document types	
article	83
book chapter	6
conference paper	33
letter	1
note	2

Annual Scientific Production

The results of the research show that the first article on games in physics education has been published a long time ago, in 1973. However, research on this topic did not experience significant improvement until 2000. The annual scientific production of Game research in physical education began to increase significantly in 2002. Figure 2 shows the annual publication on this topic.

Figure 2. *Annual Scientific Production of Game Research in Physics Education*



The Influential Aspects of The Game in Literature Physics Education

The Most Influential Country

Table 2 shows the ten most influential countries seen from the number of quotations and the average quotation of their articles. It was found that the United States was the most influential country in game research in physical education.

Table 2. *Ten Countries Most Influential in Game Research in Physics Education*

Country	TC	Average Article Citations
USA	462	17,80
China	183	22,90
United Kingdom	40	8,00
Chile	35	35,00
Netherlands	33	16,50
Australia	25	25,00
Philippines	23	5,80
Norway	21	10,50
Canada	20	20,00
Greece	20	20,00

The Most Influential Journal

Table 3 lists the top ten Game research journals in physics education based on index-h of articles published in related journals. The h index is more effective in predicting future scientific achievement than other metrics such as the total number of citations, average citations per paper, and total papers [31]. In addition to index-h, index-g, and index-m, the number of quotations (TC), the number of publications (NP), and the first year of publication (PY-Start) are also shown in Table 3.

Table 3. *Sources' Local Impact*

Journal	h-index	g-index	m-index	TC	NP	PY_start
Computers and Education	10	11	0,714	57	11	2011

Physics Education	7	12	0,152	4146	15	1979
Physics Teacher	4	5	0,148	45	15	1998
Education and Information Technologies	3	3	0,273	25	3	2014
Education Sciences	3	4	0,429	33	4	2018
Journal of Baltic Science Education	3	3	0,6	28	3	2020
Physical Review Physics Education Research	3	4	0,333	44	4	2016
Proceedings – Frontiers in Education Conference, Fie	3	4	0,188	29	4	2009
Educational Technology Research and Development	2	3	0,5	30	3	2021
Journal of Science Education and Technology	2	2	0,143	120	2	2011

The rankings of journals according to Bradford law are listed in Table 4. Bradford's law analyzes based on the distribution of a publication in the entire journal environment [32]. The frequency of publication of each source in game research in the field of physics education is ranked from the highest to the lowest. The journals in the first zone are described as the most influential sources in Bradford's law analysis. Table 4 lists the most influential journals according to this analysis.

Table 4. *Bradford's Law*

Journal	**Rank**	**Freq**	**cumFreq**	**Zone**
Physics Education	1	15	15	Zone 1
Physics Teacher	2	15	30	Zone 1
Computers And Education	3	11	41	Zone 1
Education Sciences	4	4	45	Zone 1
Physical Review Physics Education Research	5	4	49	Zone 2
Proceedings - Frontiers In Education Conference, Fie	6	4	53	Zone 2
Education And Information Technologies	7	3	56	Zone 2
Educational Technology Research And Development	8	3	59	Zone 2
IEEE Global Engineering Education Conference, Educon	9	3	62	Zone 2
Journal Of Baltic Science Education	10	3	65	Zone 2

The Most Influential Article

The most influential core articles in gaming research in the field of physics education are the most cited by other research, reviewed by the Global Citation Score (GCS) and Local Citations Score (LCS). Quotation is an important foundation for status and success in the scientific world [33]. The GCS shows the total number of quotations from around the world received by the article, while the LCS gives an overview of the extent to which the article is cited at the local level or within a particular research network. Table 5 presents the top ten articles based on GCS and LCS.

Table 5

Most Global Cited Documents and Their Local Cited

References	**DOI**	**Source**	**GCS**	**LCS**

References	DOI	Source	GCS	LCS
[34]	10.1103/PhysRevSTPER.3.020101	Physical Review Special Topics - Physics Education Research	182	0
[35]	10.1016/j.compedu.2011.05.007	Computers & Education	123	3
[36]	10.1016/j.compedu.2016.03.011	Computers & Education	93	0
[37]	10.1016/j.compedu.2015.07.009	Computers & Education	70	3
[38]	10.1016/j.compedu.2015.08.001	Computers & Education	69	2
[39]	10.1007/s10956-013-9438-8	Journal of Science Education and Technology	66	4
[40]	10.1016/j.compedu.2014.01.002	Computers & Education	64	3
[41]	10.1016/j.compedu.2017.05.022	Computers & Education	64	1
[42]	10.1007/s10956-010-9257-0	Journal of Science Education and Technology	54	2
[43]	10.1088/0031-9120/48/4/431	Physics Education	41	0

The Most Influential Authors

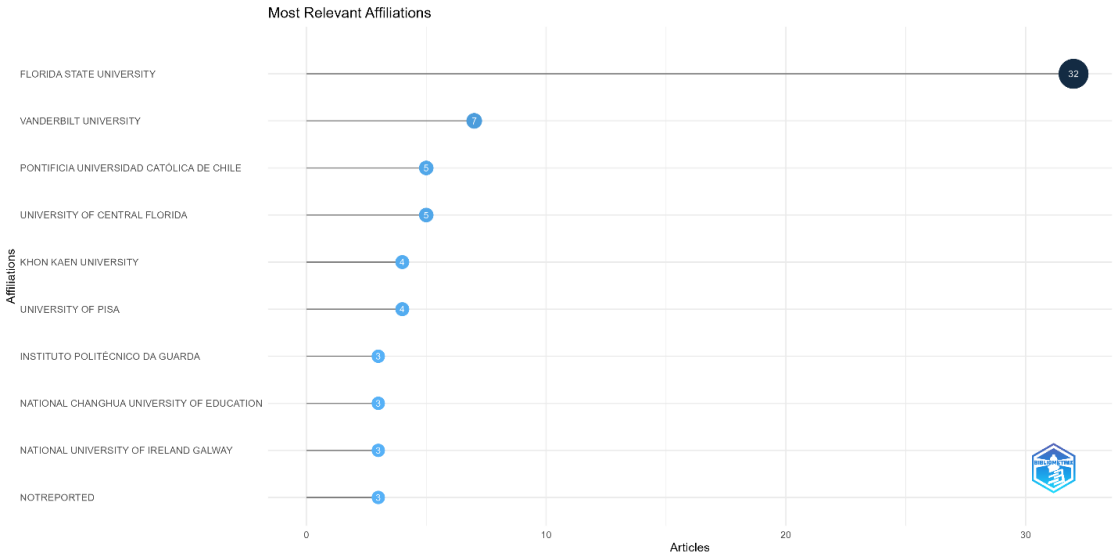
The most influential core writers or writers in game research in the field of physics education related to their index-h can be seen in Table 6. Based on the results of analysis, Rahimi S. and Smith G. are the most influent writers with the highest index-H and index-g.

Table 6. *Authors' Local Impact*

Element	h-index	g-index	m-index	TC	NP	PY-start
Rahimi S.	5	6	1,25	75	6	2021
Smith G.	5	6	1,25	75	6	2021
Kuba R.	5	5	1,25	73	5	2021
Shute V. J.	4	4	0,4	164	4	2015
Dai C-P	3	3	0,75	56	3	2021
Shute V.	3	4	0,75	50	4	2021
Yang X.	3	4	0,75	39	4	2021
Andres J. M. L.	2	2	0,2	4	2	2015
Barnett M.	2	2	0,143	120	2	2011
Clark D. B.	2	2	0,143	187	2	2011

We also analyzed the affiliation of the authors on this topic. Figure 3 shows the most active affiliates reviewed by the authors. Florida state university has become the most productive affiliate, far more than any other affiliate.

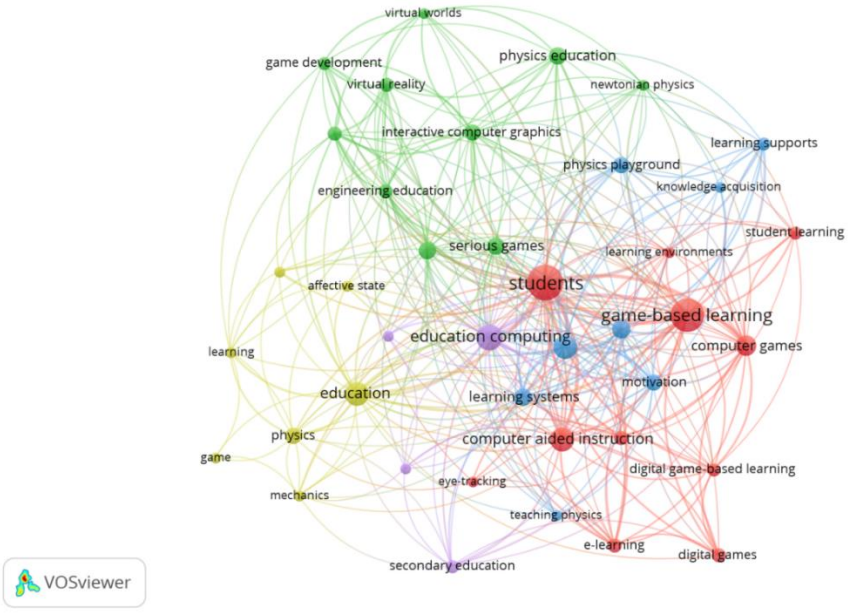
Figure 3. *The Ten Most Active Affiliates*



Research Groups Based on Keywords

Further, the researchers used VosViewer in mapping research groups and keyword innovations.

Figure 4. *Network Visualization (Keyword Occurance ≥ 3)*



From VosViewer's findings, there were five clusters that the researchers named after their grouping.

Table 7. *Keyword Grouping*

No	Cluster colour	Cluster name	Keywords
1	Red	Digital Game Based Physics Learning	Computer aided instruction, computer games, digital game-based learning, digital game, e-learning, eye-tracking, game based learning,

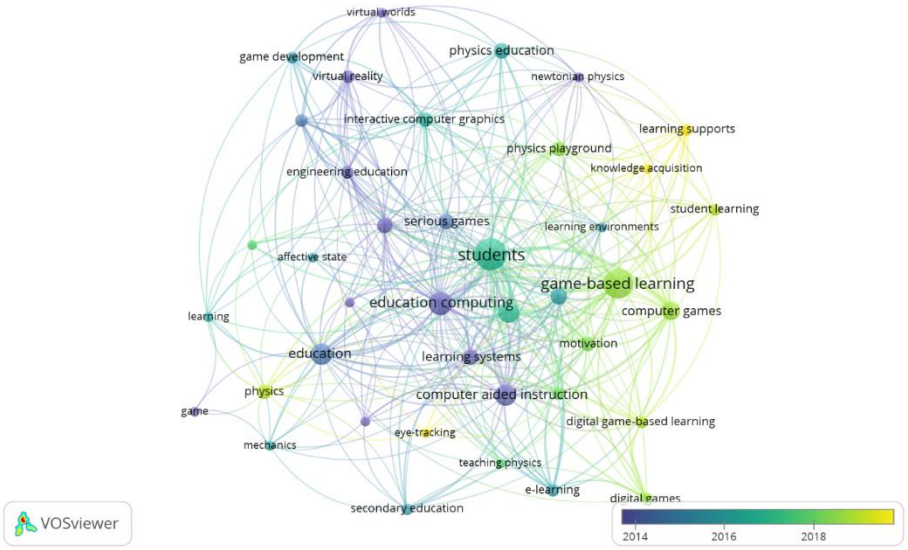
No	Cluster colour	Cluster name	Keywords
2	Green	Game-based physics learning and interactive technology	individual differences, learning environments, student learning, students engineering education, game development, interactive computer graphics, newtonian physics, physics education, serious games, software design, teaching, virtual reality, virtual worlds
3	Blue	Physics Learning Through Game Education: Physics Playground	educational game, educational games, knowledge acquisition, learning supports, learning systems, motivation, physics playground, teaching physics
4	Yellow	Physics Learning Through Games: Integrating Affective State and Engagement	affective state, education, engagement, game, learning, mechanics, physics
5	Purple	Interactive Simulation for Physics Education in Learning Environments	computer simulation, education computing, interactive learning environment, secondary education

Source: VosViewer

Research Novelty

Overlay Visualization shows the novelty of keyword usage [44]. Figure 5 shows overlay visualization on this topic.

Figure 5. *The Overlay Visualization*



Discussion

Stable Development and Potential Sustainable Impact

The annual growth rate of publications in search datasets was found at 4.71% which indicates that the number of scientific publications on this field is increasing steadily every year, although not in large numbers. The average number of citations for the article was 12.23, which indicates that the publication in this dataset has been highly cited and influential. The average age

of article in the datasets is 8.92 years which indicates that most publications are contemporary and state-of-the-art literature that is relevant for review. Overall, this descriptive analysis indicates that this dataset is a good representation of cutting-edge research developments in game topics in physical education. This data set is dominated by influential new publications that are actively cited, thus providing a strong basis for future researchers to research this topic.

From the Emergence of Ideas In 1973 to A Significant Increase in The Early Millenium

The results showed that the first article on games in physics education had been published long ago, in 1973. This indicates that the idea of using games for learning physics has been around for decades. However, research on this subject did not experience significant improvement until the year 2000. The application of games in physics learning was relatively stagnant for several decades before entering this millennium. This sharp increase indicates that the use of games in physics learning has begun to gain significant attention from researchers and educators since the early millenniums. The findings describe the historical development of game research in the context of slow physical learning initially but accelerated in the last two decades. Forward projections suggest that research on this topic will continue to show a steady growth trend. The findings of several meta-analysis studies confirm that the use of games has a significant positive impact in the context of learning [45]. With these findings, it is foreseeable that interest and focus in exploring these concepts will continue to increase along with a deep understanding of the benefits of integrating games to improve the learning process.

Domination of Developed Countries, Challenges, and Opportunities for Cross-Continental Collaboration

The most influential countries in the publication of this topic are dominated by the countries on the continent of Europe, followed by the Americas, Asia, and Australia. Research and scientific publications related to this topic still dominate the developed countries in Europe and America. Nevertheless, the contributions of the countries in Asia and Australia also deserve to be taken into account. The findings are in line with the general pattern of global scientific productivity that is still dominated by Western countries. However, some countries in Asia have begun to experience increased scientific productiveness in recent decades. Contributions from Asian countries will likely increase in the future. On the other hand, increased collaboration with researchers in Africa is needed to provide new perspectives and insights into this topic. The African continent has so far not contributed much to global scientific publications. This is one of the causes of the limited resources devoted to research and development (R&D) activities [46]. With the involvement of researchers from Africa, new innovations and breakthroughs are expected to be born that will enrich the world's science. Inputs from a variety of geographical and cultural backgrounds are essential to enrich insights and innovations in the development of science. Cross-continental and cross-cultural scientific collaboration is essential to ensuring the progress of science that is inclusive and beneficial to all mankind. Scientific collaboration is an important mechanism that enables the integration of less developed countries into research activities [47]. The involvement of various tribes, backgrounds, and perspectives will further enrich and accelerate the development of science in the future.

Domination of Computers and Education, Challenges, and Discharges for the Physics Education Base Journal

Computers and Education have the highest index-h among the most influential sources in-game research in the field of physical education. This is mainly due to the focus and scope of this journal which is relevant to computer and technology topics in education, including games. The index-g shows the quotation performance of the most read articles, where Computers and Education also lead. The total quotation score (TC) of each journal marks the overall impact, where this journal is ranked first as well. Overall, based on a variety of such bibliometric indicators, Computers and Education is the most influential journal in the study of games in physics education research.

Computers and Education does have the highest rank in a variety of bibliometric indicators for game topics in physics education. In the future, journals that focus on the field of physical education need to play an active role and make significant contributions to this topic. The study of physical education requires publication in journals that target the community of physics educators and researchers specifically. Publications in applied journals in general education such as Computers and Education are not enough to build a foundation of knowledge in the field of physical education itself. For that, researchers on this subject need to actively publish their findings in the core journal of physical education. With increased publications in reputable journals of physics education, it is expected that there will be a transfer of knowledge and insight between researchers of physical education and physics teachers. This in turn can improve the quality of research and practice physics learning in the field through an empirical-based approach. Therefore, the active contribution of the core journal of physics education is essential to advance the game topic in physics learning forward.

Physics education journals like Physics Education and Physics Teacher rank second and third. This suggests that there is actually a great interest in publishing game research in physics learning in the core journals of physics education. The current trend that is still dominated by educational technology journals may be due to the greater focus of research on game development itself, not yet dominated in its impact on physics learning or students. Therefore, researchers in the field of physical education need to take a more active role in directing this research to focus more on the pedagogical aspects and their impact on physical learning outcomes. Thus, the contribution of physics education journals to the topic of games in physics learning is expected to increase in the future.

Content Analysis of the Most Cited Articles: Game Technology Innovations in Influencing Understanding of Physical Concepts, Student Motivation, and Learning Outcomes

The most cited first-order paper was written by Tuminaro and Redish in 2007 [34]. This article talks about cognitive models in solving physical problems, especially focusing on the idea of epistemic games that affect the way students deal with physical problems. It was found that students often use an epistemic game framework that limits the resources they use in a particular task. The research also identifies differences in problem-solving approaches between experts and beginners, as well as how unexpected messages can be delivered to students through the teaching methods used.

The second most cited paper was written by Clark et al. in 2011 [35]. This article deals with the use of digital games with integrated concepts, combining popular game elements with formal physical representations and terms, to help learn Newton's mechanics. The study used the game "SURGE" in high school students in Taiwan and the United States. The results show an increased understanding of Newton's mechanics, measured with the Force Concept Inventory, and a high level of motivation. Despite this, there are some shortcomings such as the variation of completion time and the tendency of some students to ignore the help of physics. Research recommends further development on a more sensitive assessment of student understanding relationships, deeper learning support, more engaging interface design, and the development of reward systems in line with learning goals. Although there are still challenges in design aspects, these digital games demonstrate the potential to support students' understanding of core science concepts.

The third most cited paper was written by Tsai et al. in 2006 [36]. This article discusses the use of eye-tracking technology to explore the visual behavioural differences between high-performance and low-performing gamers in the context of game-based learning (GBL). This study found that low-performance gamers divert more visual attention to the components and conceptual representations in the game. These patterns of behavior indicate students having difficulty understanding concepts. While high performance players show better visual attention control in

multitasking and more efficient text reading strategies in GBL, as well as experiencing higher levels of flow in control and concentration aspects while playing games. This research recommends further research to develop more sensitive assessment elements to measure incremental learning in GBL, integrate scaffolding support and visual signals to help students associate intuitive and formal understanding, conduct sequential analysis of visual and manipulative behavior of players in games, and explore possible relationships between all aspects of flow measurement and eye-tracking in different GBL contexts.

The fourth most cited paper, was written by Kim and Shute in 2015 [37]. This article discusses how changes in the play sequence of a game, called gameplay sequence linearity, can affect the quality of judgment (such as validity, reliability, and fairness), learning, and pleasure in the context of game-based testing. This study compared two versions of the same Physics Playground except in its gameplay sequence. The results suggest that changes in game sequence can affect the way players interact with the game and the strength of evidence from the measurement in the game, which in turn affects the validity of the judgment. Although there were no significant differences in learning between the two conditions, only players on the nonlinear version showed improved understanding of physics qualitatively. There was no significant difference in pleasure between the two versions. These findings show the importance of testing various design principles in the development of future game-based judgment.

The fifth most cited paper, written by Shute et al. in 2015 [38]. This article discusses the relationship between incoming knowledge, persistence, affective states, in-game progress, and consequently learning outcomes for students using the game Physics Playground, an educational game. This study uses structural equation analysis to test the relationship between these variables. The results showed that pre-test scores and student performance in games significantly influenced learning outcomes. Performance in games can be predicted by data pretest, frustration, and engaged concentration. The findings also revealed the existence of two indirect paths from engaged focus and frustration to learning, via the in-game progress measure. The research emphasizes the importance of emotion and perseverance in shaping learning outcomes, as well as the need to design effective learning support in a game context.

The focus of the discussion on the five most cited articles involved cognitive models, game design, eye-tracking technology, gameplay sequence linearity, and student emotional factors. This research consistently explores how technological innovation in games can influence the understanding of physical concepts, student motivation, and overall learning outcomes in the context of physical education. Increases in the development of in-depth teaching methods, attractive interface designs, and reward systems in games that match the learning objectives became the crucial focus. To improve student understanding, it is necessary to carry out future research related to assessments that are responsive to variations in student understanding. Furthermore, further exploration of the optimum design principles for game-based tests will provide valuable insights for research contributions to this topic.

Influence And Potential of New Researchers

Although still new in the world of publication by 2021, Rahimi S. and Smith G. managed to significant influence in this topic by acquiring a high h-index. The H-index shows a combination of research productivity and the impact of the situation, giving an indication that their scientific contributions have been noticed and appreciated by the research community. These achievements show their potential to become leaders in this field over time, and their research results can be a substantial contribution to the development and understanding of such topics in scientific literature. Researchers can further explore new aspects or innovative approaches to understanding the role of games in physical education. Further researchers do not need to feel hindered by the time of their introduction to the world of publication, as the high h-index acquisition suggests that success can be achieved without relying on long publication experience starting in a given year.

Challenges and Potential for Inter-Affiliate Collaboration

Florida State University became the most productive affiliate, standing out from other affiliates. This may indicate that the institution has a speciality or a deep research focus on this topic. These findings may stimulate further researchers to be able to explore more intensive collaborations with the institution or other institutions. Expanding cooperation with various affiliates can bring many diverse perspectives, both geographically and culturally, which can complexly enrich research on the topic of games in physics learning.

Research Groups Based on Keywords

Research group analysis is seen from network visualization (See Figure 4 and Figure 7). In the context of the red cluster, physics learning uses a variety of technologies such as computer-aided instruction, digital game-based learning, and e-learning to create an interactive and enjoyable learning environment. The use of computer games and digital games in physics learning can enhance student engagement and facilitate understanding of complex physical concepts through practical experiences and virtual simulations [48]. Elements such as eye-tracking can also be used to monitor student attention and understanding during the learning process, providing valuable information to teachers to optimize instructional design. The importance of understanding individual differences in learning physics using game media creates opportunities for personalized approaches in instructional design [49]. Each student has a unique learning style and needs, and game-based learning can be customized to accommodate these variations [50]. Thus, the cluster summarizes various aspects that create an interactive and adaptive learning framework that utilizes technological excellence to enhance students' understanding and achievement in studying physics.

In the context of "Game-based Physics Learning and Interactive Technology", engineering education, game development, interactive computer graphics, and Newtonian physics unite to form a learning paradigm that combines technical expertise with in-depth physical concepts. Through the application of virtual reality, software design, and virtual worlds, learning physics becomes more dynamic and allows students to experience physical concepts in an enticing simulation environment [51]. By bringing these aspects together, physics learning not only becomes more interactive and enjoyable, but also provides an opportunity for students to develop technical skills, understanding of physical concepts, and software design expertise, creating a unique balance between science and technology expertise.

In the cluster "Learning Physics Through Game Education: Physics Playground", educational games became a major focus in supporting the acquisition of knowledge of physics. Physics Playground creates an interactive environment that blends educational elements with games to provide a learning system that supports physics learning [52]. Through a variety of educational games, students not only gain an in-depth understanding of the concepts of physics, but also feel a high motivation to learn because of the entertaining game atmosphere [53]. Thus, this cluster creates an exciting learning ecosystem and blends the excitement of play with educational purposes, providing a profound and meaningful physical learning experience for students.

In the concept of "Learning Physics Through Games: Integrating Affective State and Engagement", physics learning not only focuses on cognitive aspects, but also considers the influence of affective states or emotional states of students as well as their level of engagement in the learning process [54]. By integrating exciting game mechanics, physics learning becomes more interactive and in-depth, enabling students to engage actively in the exploration of physical concepts [55]. The combination of the game elements and the purpose of physics learning creates a learning environment that builds positive affective states, increases student engagement, and ultimately strengthens the learning process [56]. Thus, this cluster emphasizes the importance of understanding and leveraging the emotional aspects and student involvement as key elements in the effectiveness of games as a physical learning medium.

In the cluster "Interactive Simulation for Physics Education in Learning Environments", computer simulation becomes the main focus as an interactive physical learning tool. The application of computer simulation in physics learning at the secondary education level creates a

challenging and exciting learning environment for students [57]. Computing education plays a central role in utilizing technology to provide a more in-depth and practical learning experience, while ensuring that the interactive learning environment provides appropriate support for the development of students' understanding of physics. This approach is relevant in the context of secondary education, where computer simulation can present physical concepts more concretely and understandably [58]. Interactive simulations not only increase students' appeal to physics learning but also enable them to conduct virtual experiments and understand physical phenomena in a safe and controlled way. This cluster creates synergies between computer simulation, education computing, and interactive learning environments to improve the quality of physical learning at the secondary level through innovative approaches and supporting technologies.

Keyword-Based Search Innovations

Bright colours on keywords such as learning supports, knowledge acquisition, and eye-tracking reflect significant shifts in physics learning approaches through games. Learning supports emphasizes the importance of providing assistance and guidance to students in dealing with the challenges of learning physics. In the context of game-based learning, this leads to the development of mechanisms that support comprehension of complex physical concepts and provide guidance when students experience difficulties. Knowledge acquisition, as another bright keyword, describes an increased focus on the process of student knowledge acquisition through games. Through the use of interactive technology in games, students are not only asked to remember physical facts, but also to understand and apply such concepts in real-life situations. Meanwhile, eye-tracking highlights the use of technology to monitor students' eye movements during interaction with the game, providing valuable insights into their focus of attention. By leveraging discussions on learning supports, knowledge acquisition, and eye-tracking approaches, this approach creates an adaptive, inclusive learning environment, and provides a deep understanding of physical concepts through play.

Conclusion

Based on bibliometric analysis, research into the use of games in physics learning showed a relatively slow development at first, but a significant increase since the early 2000s. This indicates the potential positive impact of game integration that is increasingly recognized by researchers and physics education educators. Researchers from developed countries such as the United States and Europe dominate publications on this topic. However, countries in Asia and Australia are also beginning to make significant contributions. Cross-continental collaboration is important to provide a broader perspective. The main journal that publishes the most articles on this topic is Computers and Education. However, core journals in the field of physical education such as Physics Education have also been actively publishing related research. The most widely cited articles consistently explore the use of games and interactive technologies to enhance students' understanding of the concepts, motivations, and learning outcomes of physics. Five main keyword clusters reflect various approaches in applying games to physics learning, including digital game-based learning, virtual reality, educational games, affective state, and computer simulation.

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