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Review Article

PhET simulation in education: A bibliometric analysis of the Scopus database

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Abstract: The advancement of digital technology has significantly transformed approaches to science and mathematics education, notably through the use of interactive simulations. One of the most prominent innovations is PhET Simulations, widely employed to enhance conceptual learning and 21st-century skills. This study aims to analyze the trends and contributions of PhET Interactive Simulations in science and mathematics education through a bibliometric approach based on Scopus data (2006–2024). Using the PRISMA method, 82 selected articles were analyzed via VOSviewer and CSV to map publication dynamics, citations, international collaborations, and research focus. The results indicate a significant increase in publications since 2017, peaking in 2020–2021 due to technology adoption during the COVID 19 pandemic. Indonesia dominates in publication quantity (40 documents), while the United States leads in citation influence. Key topics include enhancing conceptual understanding, integrating problem-based learning (PBL) models, and utilizing interactive simulations for critical thinking skills. Early publications (2006–2008, remain the most influential references with 263 citations. However, the study identifies gaps, including limited research on long-term impacts, cultural context variations, and educators' roles in simulation-based learning. This analysis recommends exploring PhET integration in STEM models, developing adaptive pedagogical strategies, and conducting comparative studies on simulation vs. conventional methods. The findings underscore PhET's critical role as a transformative tool in digital education, particularly in facilitating exploratory and collaborative learning.
Keywords: bibliometric analysis; education; PhET simulation

1. Introduction

Technological developments in the world of education have made a significant contribution to the effectiveness of the learning process. One of the innovations that has received widespread attention in field of science education is PhET Interactive Simulations (PhET), a computer-based simulation platform developed by the University of Colorado Boulder. PhET is designed to provide an interactive learning environment that allows students to explore a variety of scientific concepts visually and dynamically (Ndagijimana et al., 2024; Moore & Perkins, 2018). In the context of science and mathematics learning, this simulation provides an alternative to laboratory experiments that are difficult or cannot be carried out directly, thereby allowing a deeper understanding of concepts through an exploration-based approach (Rayan et al., 2023a; Banda & Nzabahimana, 2023).

The use of technology in learning has a crucial role in improving students' learning experiences. (McKagan et al., 2008; Perkins et al., 2008). The use of interactive simulations such as PhET allows the application of more flexible inquiry-based learning strategies, where students can explore independently in a structured digital

environment. Several studies show that the integration of PhET in science learning can improve conceptual understanding, facilitate higher cognitive engagement, and encourage active and collaborative learning (Wieman et al., 2010; Hensberry et al., 2013). In addition, this simulation technology is able to provide visual representations of abstract concepts, making it easier for students to build a deeper understanding of the material being taught (Perkins, 2020; Perkins et al., 2012). In bibliometric analysis, we can see trends and developments in PhET Simulation research, as well as its impact in society (Lancaster et al., 2013).

PhET has a number of advantages that make it one of the most widely used technology-based learning tools in science education. The main advantage of this simulation lies in its ability to provide interactive visualizations that allow students to interact directly with relevant variables in a scientific phenomenon. In addition, its open-source nature makes it more accessible to educators and students at various levels of education. A study conducted by Moore (2016) shows that the integration of PhET in learning can increase learning motivation, strengthen understanding of concepts, and develop critical thinking and problem solving skills. The flexibility of its use in various learning models, both in face-to-face and online learning environments, further emphasizes the relevance of PhET in the current digital education ecosystem (Aminah & Astuti, 2020; Ramadan & Astuti, 2020).

Several previous studies have conducted systematic literature reviews (SLR) and bibliometric analyses to map the utilization of PhET simulations in education, primarily focusing on limited periods, specific disciplines, or regional contexts. For instance, some works emphasized physics education or were restricted to a few years of publication data, without integrating broader cross-disciplinary or longitudinal perspectives. However, none have comprehensively combined publication trends, citation impacts, thematic mapping, and global collaboration patterns over an extended timeline. This study fills that gap by offering a more holistic and updated bibliometric mapping of PhET-related research indexed in Scopus from 2006 to 2024, aiming to highlight both historical developments and current frontiers of research (Mardian et al., 2023)

Although many studies have been conducted regarding the effectiveness of PhET in learning, there are still several research gaps that need further attention (Ruwiyah et al., 2021). Most previous research focuses on the short-term impact of using PhET on students' conceptual understanding, while studies examining its long-term impact are still very limited (Susila et al., 2021; Chotimah, 2020; Rustana et al., 2021). In addition, the effectiveness of PhET in various cultural contexts and educational systems has not been explored in depth (Alsalhi et al., 2024). Pedagogical aspects related to the role of educators in facilitating simulation-based learning are also still an open area of research, especially in identifying the most effective strategies for optimizing the use of PhET in increasing students' learning outcomes (Ndihokubwayo et al., 2020; Mahtari et al., 2020; Aminoto et al., 2021). Research trends regarding PhET Simulation have shown a significant increase in recent years (Habibi et al., 2020). This increase is in line with the increasingly widespread adoption of technology in education systems in various countries (Assawaphum et al., 2023). Bibliometric studies of scientific literature indexed in the Scopus database indicate that the number of publications focusing on the use of PhET in education has increased substantially in the last decade (Hasyim et al., 2020; Medeiros et al., 2024; Chinaka, 2021). Recent studies also show that PhET is starting to be applied not only in formal education settings, but also in various community-based training and learning programs (Nuraida et al., 2021) (Saputra & Wilujeng, 2020). Along with technological developments, the PhET platform has also experienced various improvements, including compatibility with a wider variety of digital devices,

thereby increasing its accessibility in various learning contexts (Wilujeng & Hardiyanti, 2020).

This research uses a bibliometric analysis approach, namely quantitative and qualitative methods to see research trends on certain topics. This bibliometric analysis has been widely carried out both in the field of education and in other fields (Susetyarini & Fauzi, 2020). Bibliometric analysis provides more systematic insight into the development of a research topic based on metadata from published scientific articles (Clark & Chamberlain, 2014; Husamah et al., 2022). By using data from the Scopus index base, this analysis can reveal the dynamics of research related to PhET Simulation, including citation patterns, thematic evolution, as well as identifying research areas that are still open for further exploration (Putranta & Wilujeng, 2019; Diab et al., 2024). Several previous studies have examined the effectiveness of PhET in improving student learning outcomes and developing higher order thinking skills. However, studies that specifically map publication trends and research patterns in PhET globally are still limited, so a more comprehensive analysis is needed to understand the development of studies in this field. Thus, this article will present a comprehensive understanding of PhET simulation, explore its advantages, discuss recent developments and highlight the key role of PhET simulation in educational transformation. In addition, bibliometric analysis and the latest research will enrich our understanding of PhET Simulation in the context of the world of education.

The primary objective of this study is to systematically explore and map the scientific landscape related to PhET Simulation in the field of education through a bibliometric approach using data from Scopus. This study is specifically designed to uncover publication growth trends over time, patterns of international research collaboration, and key thematic areas that dominate PhET Simulation research. By analyzing various scholarly sources such as journal articles, conference proceedings, and other relevant publications, the study aims to provide a deeper understanding of the direction, scope, and dynamics of research in this domain. The main contribution of this study lies in providing accurate and structured data-driven insights into the development of PhET Simulation research, an area that has not been extensively examined in a comprehensive manner. The findings are expected to serve as a valuable reference for researchers to identify research gaps, formulate more relevant research questions, and determine strategic directions for future investigations. Furthermore, the results can also offer a foundational basis for educators and policymakers in integrating interactive simulation technologies like PhET more effectively into educational practices

Researchers try to collect research data related to PhET Simulation using a bibliometric approach based on data obtained from Scopus. In this context, this article aims to present a comprehensive bibliometric analysis of PhET Simulation research in Education which includes trends in the number of publications, Trends in Research Collaboration Between Countries, Research Focus. By analyzing journals, conferences and other related scientific publications. We will try to identify the key trends and research topics that are most dominant in this scientific literature. Thus, it is hoped that the results of this research can provide a more systematic picture of research trends related to PhET and provide recommendations for future research agendas.

2. Materials and Methods

This research uses a descriptive bibliometric analysis method which consists of four important stages, namely identification, screening, eligibility and inclusion (Moher et al., 2010). At the level identification Researchers conducted a search using keywords that matched the research theme, namely "PhET Simulation" in the Scopus database. Through this step, 233 relevant articles were identified. The next stage is screening. At this stage, researchers filtered 233 articles that had been obtained in the

previous stage using the criteria that the keyword "PhET Simulation" must be included in the article title. Based on these criteria, 149 articles do not meet these criteria and will not be processed further. Meanwhile there are 84 articles that meet the criteria and will continue to the next stage, namely eligibility. At this stage the researcher evaluates whether the 84 articles that have passed the previous stage are suitable for inclusion in the final stage of the research. Researchers decided to only include publications published in English format, leaving 82 articles that met these criteria. A total of 82 articles that meet these criteria can proceed to the inclusion stage (see Figure 1).

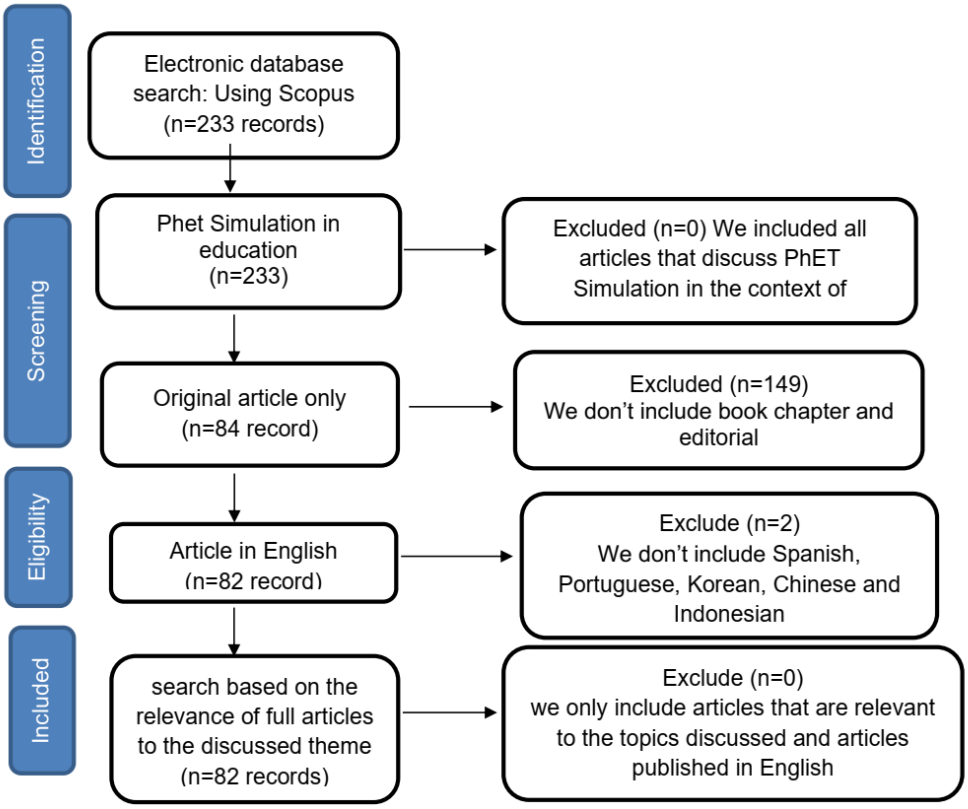

Figure 1. Flowchart of systematic review using the PRISMA paradigm

Researchers use various applications to help process research data. The Microsoft Excel application is used to display tables such as publication trends and quotation trends. The VOSviewer application is used to display images of relations between countries as well as research focus related to the field being studied. The PoP application is used to calculate quotation trends such as NCP, C/CP, H-index and others.

3. Results

In this section, we will discuss trends in the number of publications, trends in the number of citations, trends in research collaboration between countries, and research focus related to PhET Simulation in Education. The trend in the number of publications reflects the development of the number of scientific publications that have been published in this field during the time period 2006 to 2024. This trend provides an illustration of the growth of research carried out by scientists and academics in studying PhET Simulation in Education. Furthermore, the trend in the number of citations illustrates the extent to which the research has influenced subsequent research and has become a reference for other scientists. The increase in the number of citations indicates a widespread level of recognition and acceptance

within the scientific community of research on PhET Simulation in Education. International collaboration can produce research of higher quality and wider impact because it involves diverse perspectives and expertise. Lastly, the research focus trend refers to research areas that received special attention in the study of PhET Simulation in Education during the period 2006 to 2024.

3.1 Trends in the number of publications

Trends in the number of publications are displayed by grouping the number of publications based on the year of publication. Publication trends from 2006 to 2024 related to PhET Simulation research in Education can be seen in Figure 2.

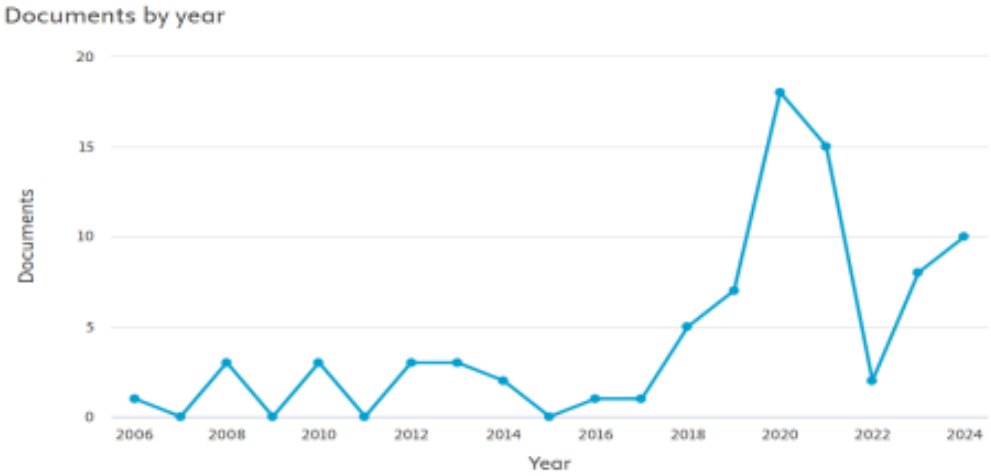

Figure 2. Publication Trends

The graph displayed shows the trend of publication of documents related to PhET Simulation based on data from Scopus in the time period 2006 to 2024. In general, the pattern formed reflects how academic attention to PhET Simulation has developed over time. In the initial period, especially between 2006 and 2016, the number of publications was still relatively low and tended to fluctuate. Annual publications range from zero to four documents, indicating that research on PhET Simulation is still in the early exploratory stages. Some small spikes appeared in some years, such as 2008 and 2012, but declined again, especially around 2016 which showed the lowest number of publications in the analyzed period. Starting in 2017, there has been a gradual increase in the number of publications, reflecting increasing academic interest in PhET Simulation as a technology-based learning tool. This trend indicates that more researchers are beginning to explore the benefits of interactive simulations in improving understanding of science and mathematics concepts. This period marks the transition from initial exploration to the stage of wider adoption in educational research. A significant spike occurred in 2020 to 2021, with the number of publications reaching the highest figure throughout the period observed. This increase was likely driven by the COVID-19 pandemic, which prompted a massive shift toward online learning and forced educators to look for innovative solutions, including the use of technology-based simulations such as PhET. In addition, educational policies that increasingly encourage the integration of digital technology in learning are also accelerating this trend (Utami et al., 2019)(Ardiyati et al., 2019). Many studies focus on the effectiveness of PhET in supporting distance learning and its impact on student understanding of concepts and engagement (Siswoyo & Muliyati, 2021) (Rahmawati & Astuti, 2020). After reaching a peak in 2020–2021, the number of publications experienced a drastic decline in 2022.

This phenomenon can be attributed to several possibilities, including the reduced urgency of using simulation-based learning technology after the return of face-to-face learning, a shift in research focus to other pedagogical approaches, or the large number of studies that have been previously published during the pandemic, resulting in a decrease in the number of new research. However, the trend begins to show recovery in 2023 and 2024, where the number of publications increases again although it has not reached the peak that occurred in 2020 and 2021. This indicates that research on PhET Simulation is still continuing, although perhaps in a more specific context or with a more targeted approach.

Table 1 represents the citation trends of research related to PhET Simulation based on several bibliometric metrics, namely number of publications (TP), total citations (TC), number of unique citations (NCP), H index, and G index. The data shows that although the number of publications in early years such as 2006 and 2008 was relatively low, the total citations obtained were quite high, with a peak in 2008 (TC = 401) and 2006 (TC = 232). This indicates that the early publications on PhET Simulation had a significant academic impact and became the main reference for research further research. After a period of fluctuation between 2010 and 2015, publication trends experienced a steady increase starting in 2016, with a significant spike in 2020 (TP = 18, TC = 171), which is likely related to the increased adoption of simulation-based learning technologies during the COVID-19 pandemic.

Table 1. Trends Citation

Year	TP	TC	NCP	H	G
2024	10	3	2	1	1
2023	8	44	4	3	6
2022	2	18	2	2	2
2021	15	45	12	4	6
2020	18	171	15	8	13
2019	7	79	7	4	7
2018	5	124	5	4	5
2017	1	11	1	1	1
2016	1	9	1	1	1
2015	-	-	-	-	-
2014	2	121	2	2	2
2013	3	60	3	3	3
2012	3	27	1	1	3
2011	-	-	-	-	-
2010	3	148	3	3	3
2009	-	-	-	-	-
2008	3	401	3	2	3
2007	-	-	-	-	-
2006	1	232	1	1	1

TP: Total Publication; TC: Total Citation; NCP: Number Citation Paper; H: h-index; G: g-index

The H and G indices in 2020 also reached the highest numbers (H = 8, G = 13), indicating that the publications in that year were not only numerous but also had a wide citation impact. In recent years, citation patterns have shown interesting dynamics. Even though the number of publications in 2023 and 2024 is quite high, the total citations obtained are still relatively low, namely 44 and 3 citations respectively. This can be explained by the nature of academic citations in that it takes time before a publication gains wider visibility and recognition in the scientific community.

Meanwhile, publications from previous years, such as 2018 and 2014, still received a high number of citations (TC = 124 and TC = 121), which confirms that previous research remains the main reference. Thus, although research on PhET Simulation continues to grow in terms of the number of publications, the accumulation of citation impact requires a longer period, indicating that the academic relevance of a publication depends not only on the timing of publication but also on the significance of its scientific contribution in the broader research ecosystem.

The article from Perkins et al (2008) is one of the most influential references in the field of physics education, as evidenced by the highest number of citations compared to other articles, namely 263 times. This high number of citations reflects the significant impact of research on innovation in physics teaching methods. One of the main focuses in this article is the importance of shifting from traditional teaching methods towards approaches based on deeper conceptual understanding. For complete information please check Table 2.

Table 2. Top-10 Publications with the Most Citations

Author	Title	Journal	Citation
(Carl E. Wieman, Wendy K. Adams, Katherine K. Perkins, 2008)	PhET: Simulations That Enhance Learning	News From Science	263
S. B. McKagan, K. K. Perkins, M. Dubson, 2008)	Developing and researching PhET simulations for teaching quantum mechanics	American Journal of Physics	137
(C.E. Wieman, W.K.Adams, 2010)	Teaching Physics Using PhET Simulations	AAPT Physics Education	121
E.B Moore, J.M. Chamberlain, R. Parson, K.K. Perkins (2014)	PhET Interactive Simulations: Transformative Tools for Teaching Chemistry	Journal of Chemical Education	101
S.Astutik, B.K. Prahani (2018)	The Practicality and Effectiveness of Collaborative Creativity Learning (CCL) Model by Using PhET Simulation to Increase Students' Scientific Creativity	International Journal of Instruction	64
K. Ndihokubwayo, J. Uwamahoro, I. Ndayambaje (2020)	Effectiveness of PhET Simulations and YouTube Videos to Improve the Learning of Optics in Rwandan Secondary Schools	African Journal of Research in Mathematics, Science and Technology Education	49
L. Yuliati, C. Riantoni, N. Mufti (2018)	Problem Solving Skills on Direct Current Electricity through Inquiry Based Learning with PhET Simulations	International Journal of Instruction	47
A.P.Correia, N. Koehler, A. Thompson, G.Phye (2019)	The application of PhET simulation to teach gas behavior on the submicroscopic level: secondary school students' perceptions	Research in Science & Technological Education	40
H.J. Banda, J. Nzabahimana (2023)	The Impact of Physics Education Technology (PhET) Interactive Simulation-Based Learning on Motivation and Academic Achievement Among Malawian Physics Students	Journal of Science Education and Technology	31
K.Perkins, E. Moore, N. Podolefsky, K. Lancaster, C. Denison (2012)	Towards research-based strategies for using PhET simulations in middle school physical science classes Available to Purchase	Physics Education Research Conference	28

This research shows that students who only rely on lecture-based learning tend to experience difficulties in understanding physics concepts in depth. In contrast,

interactive approaches such as technology-based simulations, including the use of PhET Simulation, have been shown to significantly improve conceptual understanding. By providing an interactive, exploratory experience, these simulations allow students to directly observe and manipulate variables in physics phenomena, thereby increasing their engagement and learning effectiveness. Furthermore, this research highlights that the integration of technology in learning, especially through PhET Simulation, not only improves students' understanding but also helps overcome misconceptions that often occur in physics. This simulation provides an opportunity for students to conduct virtual experiments that can save time and resources compared to conventional laboratory experiments. This article also highlights the need for curriculum design that supports the use of interactive technology to increase the effectiveness of science teaching. By referring to various evidence-based studies, this article concludes that simulation-based approaches and other interactive methods are more effective solutions than traditional methods in improving student learning outcomes in physics and science in general. Therefore, this article is the main reference in developing more innovative and technology-based learning strategies.

3.2 Trends in Research Collaboration Between Countries

Figure 3, illustrates research collaboration between countries related to PhET Simulation in Education. In this image, there are circles representing countries that have contributed to scientific publications related to that topic.

Figure 3. Relations Between countries

Figure 3 shows the existence of cooperation between countries as evidenced by the existence of relationships between circles of countries as in the picture. Figure 3 shows that there are four possible clusters differentiated based on the color of the circle. More detailed information regarding top-10 documents and citations in the context of PhET Simulation in education can be seen in Table 3.

Table 3 displays research collaboration between countries in the context of PhET Simulation in Education. The threshold used was a minimum of 2 documents, so only countries with at least 2 publications were shown in the analysis. There are 11 countries that meet this threshold. It can be seen that Indonesia is the country with the largest number of documents, namely 40 publications. The United States has the second largest number of publications. The United States has a large influence in terms of publication citations. This shows that research from this country is highly recognized and cited by researchers in various countries. Apart from that, the United States is also the country with the largest total link strength, namely 203 total link

strengths. This shows that both Indonesia and the United States have a significant role in PhET Simulation research in Education.

Table 3. Top-10 documents and citations in the context of PhET Simulation in education

Selected	Country	Documents	Citations	Total Link Strength
√	United states	20	1053	203
√	Indonesia	40	290	167
√	Canada	3	400	108
√	Rwanda	3	72	88
√	Portugal	2	2	69
√	Brazil	2	2	62
√	Malaysia	4	13	47
√	Morocco	2	11	24
√	United Arab Emirates	2	2	21
√	Israel	2	3	7
√	South Korea	2	3	0

3.3 Research Focus

The focus of research related to PhET Simulation in Education can be seen in Figure 4. The novelty of the research can be seen in Figure 5. The image is displayed using the help of the VOSviewer application with a threshold of 3. This means that the keywords displayed have been used at least 3 by different documents

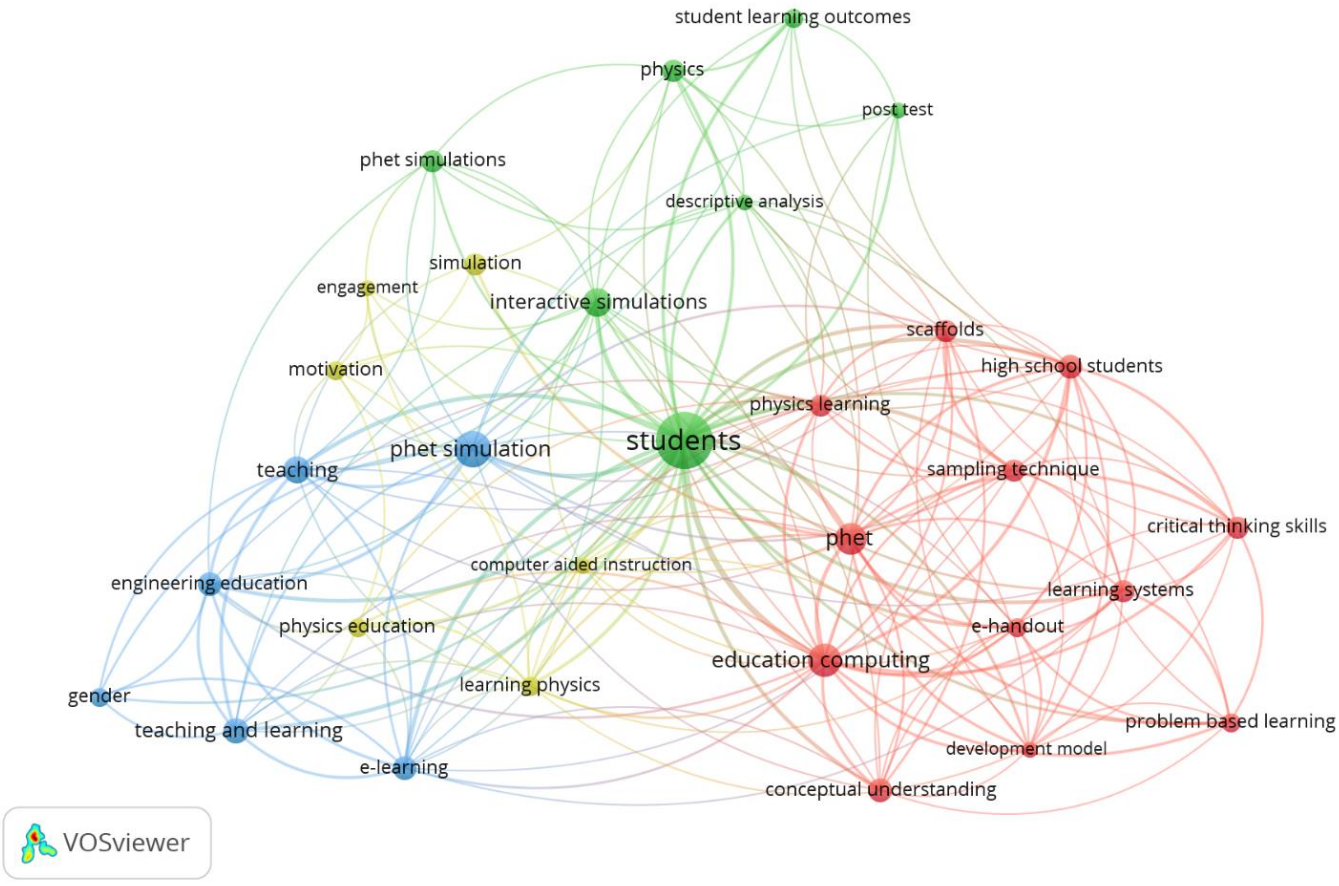

Figure 4. Research Focus

The results of the analysis using VOSviewer show that research related to PhET Simulation focuses on how interactive simulations can improve conceptual understanding, critical thinking skills, and student learning motivation, especially in the field of science education such as physics. The main keywords that frequently appear in this research include "students", "PhET simulation", "interactive simulations", and "education computing", indicating that simulation-based learning technology is becoming an important part of the modern education system. Apart from that, research also discusses the use of innovative learning models such as problem-based learning (PBL) and the role of technology in increasing student involvement in learning. Interactive simulations are proven to help students understand abstract concepts that are difficult to learn through conventional methods, as well as providing a more interesting and in-depth learning experience.

In addition, the relationship between education computing, critical thinking skills, and learning systems shows that learning technology continues to develop to support concept-based learning and higher order thinking skills. Interactive simulations not only contribute to academic learning outcomes, but also increase student engagement and motivation, as seen in the cluster linking motivation, engagement, and learning physics. In the future, research can focus more on comparing the effectiveness of simulation-based learning methods with conventional methods, developing more effective technology-based learning models, as well as analyzing the long-term impact of learning technology on student skills. Thus, the integration of interactive simulations in education has the potential to be an innovative solution in improving the quality of learning and students' critical thinking skills.

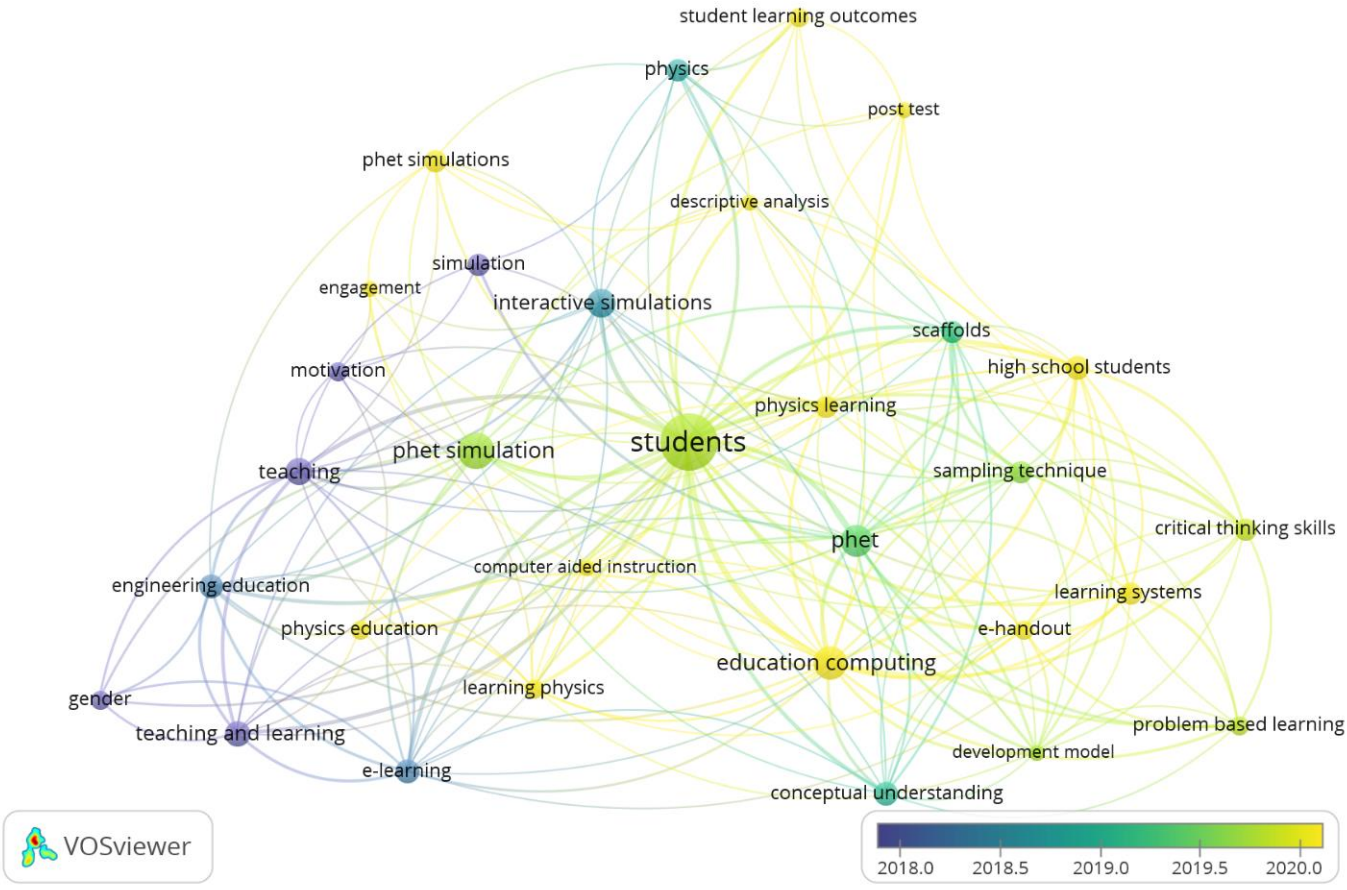

Figure 5. Novelty of Research

In terms of research novelty, it appears that recent studies are starting to focus on the use of more specific simulation-based learning models, such as problem-based learning (PBL) and integration with e-handouts and development models. In addition, the association with "computer-aided instruction" and "learning systems" indicates that research is now beginning to examine the effectiveness of simulations in a broader technology-based learning context. Recent studies also pay attention to aspects of conceptual understanding and the influence on the learning system in a more comprehensive manner. Thus, novel research that can be developed includes measuring the long-term impact of PhET Simulation on higher-order thinking skills, developing more adaptive simulation-based learning methods, as well as further exploration of the integration of PhET in various STEM learning models.

4. Discussion

The results of the bibliometric analysis reveal significant dynamics in research related to PhET Simulation in science and mathematics education. The surge in publications during 2020–2021, driven by the adoption of technology amid the COVID-19 pandemic, reflects the academic community's rapid response to the urgent need for digital learning tools. This increase not only highlights the necessity of implementing interactive simulations in remote learning environments but also affirms PhET's role as an innovative solution to address the limitations of conventional laboratory experiments. However, the decline in publications in 2022 suggests that the adoption of this technology may have been a reactive measure to the crisis, emphasizing the need for sustained efforts to maintain research momentum in the post-pandemic era. These findings are consistent with previous studies that underscored the growing reliance on digital tools during the pandemic, although their long-term sustainability depends on more systematic integration into curricula (Moore & Perkins, 2018; Rayan et al., 2023).

Indonesia's dominance in publication output (40 documents) contrasts with the United States' leading citation influence, which reflects disparities in both productivity and academic impact. While Indonesia has actively published empirical studies on PhET, research from the U.S. is often cited as a primary reference due to its focus on theoretical development and innovative methodologies, such as the integration of simulations into inquiry-based learning frameworks (Perkins & Wieman, 2008). This suggests the need to strengthen international collaboration in order to bridge productivity with research quality. Furthermore, the limited representation of countries with diverse cultural contexts in the literature indicates that the effectiveness of PhET may not yet be fully tested beyond Western and Southeast Asian education systems, opening opportunities for cross-cultural exploration (Alsalhi et al., 2024). The dominant research topics, such as enhancing conceptual understanding and integrating Problem-Based Learning (PBL) models, reaffirm PhET's role as a catalyst for pedagogical transformation toward active learning environments. These simulations facilitate independent exploration, enabling students to construct knowledge through direct interaction with abstract concepts, which aligns with constructivist learning theories. However, an excessive focus on short-term outcomes—such as improvements in test scores—tends to overlook the sustainability of learning. Longitudinal studies are needed to assess knowledge retention and the transferability of critical thinking skills to real-world contexts. The recommendation to integrate PhET into STEM-based models is also relevant, as the complexity of global challenges increasingly demands interdisciplinary, technology-supported approaches (Perkins, 2020).

The identified research gaps, including the role of educators in simulation-based learning and the variation in cultural contexts, call for more holistic methodological

approaches. The development of adaptive pedagogical strategies, such as simulation-based scaffolding and teacher training programs, could maximize the educational potential of PhET (Mahtari et al., 2020). Additionally, comparative studies on the effectiveness of PhET versus conventional teaching methods should consider variables such as students' socioeconomic backgrounds and technological infrastructure. The practical implications of these findings emphasize the need for educational policies that support teacher training in simulation-based instruction and investment in the development of more inclusive learning platforms. Consequently, PhET is positioned not only as a teaching aid but as an integral component of an education ecosystem that aims to cultivate 21st-century skills.

5. Conclusion

PhET Interactive Simulations have proven themselves to be significant innovative learning tools in improving the quality of science and mathematics education. This simulation offers interactive visualizations that allow students to explore abstract concepts dynamically, thereby strengthening conceptual understanding, critical thinking skills, and learning motivation. PhET's advantages, such as accessibility-based open-source, flexibility in various learning models (face-to-face and online), as well as its ability to replace difficult laboratory experiments, make it an effective solution in digital education transformation. Especially during the COVID-19 pandemic, PhET became a mainstay in distance learning, driving a surge in research publications in 2020–2021. However, study too identified gaps, such as the lack of long-term impact research, variations in cultural context, and the role of educators in facilitating simulation-based learning. Bibliometric analysis revealed a rapidly increasing PhET research trend since 2017, with a peak during the pandemic. Indonesia and the United States are the main contributors, where the US dominates in terms of citation influence, while Indonesia leads in the number of publications. Dominant research topics include improving conceptual understanding, integration with models' problem-based learning (PBL), as well as the relationship between interactive simulations and technology-based education systems. Although publications had declined in 2022, the recovery trend in 2023–2024 shows continued academic interest. The article by (Wieman et al., 2008) has been the most influential, emphasizing the shift from traditional methods to interactive approaches. Going forward, research needs to focus on long-term impacts, developing adaptive models, as well as exploring the integration of PhET in STEM learning to expand its contribution to the global education ecosystem.

Based on the findings and analysis conducted, there are several important directions that future research should consider. First, longitudinal studies are needed to examine the long-term impact of using PhET Simulations on students' conceptual understanding, knowledge retention, and development of critical thinking skills. To date, most studies have focused only on short-term effects, providing limited insight into the sustained outcomes of interactive simulation use. Second, it is essential to explore the effectiveness of PhET in diverse cultural contexts and educational systems. Cross-country and cross-cultural studies can offer a deeper understanding of the flexibility and challenges of implementing PhET within various curricular frameworks. Third, future research should focus on the development of adaptive and context-specific pedagogical models, including the active role of educators in designing and facilitating simulation-based learning. Integrating PhET with STEM-based learning models, problem-based learning (PBL), or flipped classroom approaches represents a strategic step toward enhancing instructional effectiveness and enriching students' learning experiences.

Authors Contribution: Fatma Suryani Harahap contributed to the conceptualization of the study, development of the methodology, data collection, and drafting of the initial manuscript. Eko Susetyarini was responsible for supervising the research process, validating results, conducting formal analysis, and reviewing and editing the manuscript. Elly Purwanti handled the software-related tasks, including data processing and visualization using bibliometric tools such as VOSviewer. Sulidar Fitri was involved in the literature search, investigation, and organization of bibliographic data. Nia Kurniaty Rukmana managed references, provided supporting resources, and contributed to the technical editing of the manuscript. Heni Mulyani Pohan oversaw project administration, ensured quality control, and gave final approval for the version to be published. All authors have read and agreed to the final version of the manuscript.

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