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Bibliometric Study: Trends of Development Digital Media to Improve 21st Century Students' Skills in Physics Learning

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ABSTRACT

Objective: *This bibliometric study aims to analyze trends in the development of digital media to enhance 21st-century skills among students in physics learning. It seeks to map research patterns, identify key contributions, collaborations, and emerging themes, while highlighting gaps in the application of interactive digital tools like animations, virtual reality (VR), and augmented reality (AR) to foster critical thinking, creativity, collaboration, and communication in physics education.* ***Method:*** *This study used method with a bibliometric literature review was conducted using data from the Scopus database and analyzed using VOSviewer and Microsoft Excel.* ***Results:*** *The study's results, which show a significant increase in publication trends post-2020, peaked at 47-79 articles annually, driven by COVID-19-induced shifts to online learning. Key co-occurrence networks revealed dominant keywords like "digital media," "critical thinking," "visualization," "teaching," "students," "collaborative learning," "e-learning," "three-dimensional," and "technology," clustered into interconnected themes.* ***Novelty:*** *This study provides the first comprehensive bibliometric mapping of digital media trends specifically tailored to physics education in enhancing 21st-century skills. It offers actionable recommendations for integrating interactive visualizations in physics curricula, bridging gaps in Indonesian education amid technological advancements.*

INTRODUCTION

21st-century skills include critical thinking, creativity, collaboration, and communication, which are important elements in modern education to prepare students to face global challenges in the digital age (Trisnawati & Sari, 2019). In the context of education, these skills enable students to not only master academic material but also analyze information in depth, produce innovative solutions, and adapt to technological changes (Ngongo et al., 2019). Therefore, the current educational framework emphasizes the importance of developing 21st-century skills to create a competitive generation capable of contributing to a knowledge-based society (Hidayatullah et al., 2021). In physics education, these skills are particularly relevant to help students understand complex concepts and apply them in real-world situations.

However, the reality in the field shows that 21st-century skills are still underdeveloped (Juliandarini, 2022) among students. International assessment results, such as the Programme for International Student Assessment (PISA), indicate that students in Indonesia often face difficulties in applying critical thinking, problem-solving, and creativity, especially in materials that require an understanding of abstract concepts (Budiarti, 2023; Lestari, 2022; Mita, 2019). Even in current learning, teachers and students tend to focus on memorization without honing their ability to connect concepts with

practical applications or developing collaboration and communication skills (Mukhtar, 2023). This is an important part of 21st-century skills and can hinder their ability to compete in the global era.

The low level of mastery of 21st-century skills in physics learning is mainly due to the limitations of the learning media used (Susanti, 2024). Conventional approaches such as lecture methods and static textbooks are less able to stimulate students to develop critical thinking, creativity, or collaboration skills (Widya et al., 2021; Indrawati, 2022). Non-interactive learning media often fail to visualize abstract physics concepts, making it difficult for students to understand and apply the material in depth. As a result, the learning process becomes less interesting, and students lose motivation to develop essential 21st-century skills (Yulianci et al., 2021).

Although the world has entered an era of rapid technological advancement, the application of technology-based learning media or digital media in physics learning is still limited (Rahmi & Asrizal, 2021). In fact, digital media, including virtual reality (VR), augmented reality (AR), and three-dimensional (3D) animation, offer interactive visualizations that can create interactive learning experiences (Azhar et al., 2021; Daineko et al., 2020). Digital media allows students to explore physics concepts through simulations, encourages creativity, and facilitates collaboration through visual-based discussions (Ahmad, 2020). However, the application of digital media in physics learning in Indonesia is still minimal, due to limitations in technology access, teacher training, and a lack of effective integration strategies. Unfortunately, research that specifically examines the application of digital learning media to improve 21st-century skills in physics learning is still minimal. Most studies on physics learning using digital technology focus more on the use of online platforms such as websites, YouTube, online classes with Zoom meetings or Gmeet, and the use of PhET Simulations (Budi et al., 2021; Elisa et al., 2017; Perdana et al., 2019). In fact, most researchers developing digital media only develop digital books (e-books), without exploring their potential more deeply (Saraswati et al., 2020; Setiadi et al., 2022). The lack of systematic analysis of existing literature has led to a gap in understanding the trends, challenges, and opportunities for applying this medium. Therefore, bibliometric analysis is needed to map research developments, identify the contributions of key researchers, and find research gaps that can be the focus in the future.

This article aims to conduct a bibliometric analysis of the application of animation-based learning media in physics education to improve students' 21st-century skills, using data from leading scientific databases such as Scopus or Web of Science. Through this approach, this study is expected to provide a comprehensive overview of research trends, collaboration patterns, and emerging themes, as well as identify opportunities for more effective application of learning media. The findings from this analysis are expected to serve as a reference for educators, curriculum developers, and researchers in designing innovative and technology-based physics learning strategies, while supporting the achievement of sustainable education goals in Indonesia.

RESEARCH METHOD

The method used in this study was a literature review with a bibliometric approach. This approach was used to analyze trends, patterns, and developments in research on the topic being studied. Data for this study were collected from the Scopus database using the search keywords "digital media" and "21st century skills." Then, data filtering was carried out by using only sources from articles and conference papers, excluding sources from books, notes, surveys, letters, and so on, as well as the year range between 2001 and 2025. Then, the data obtained was stored in CSV format so that it could be analyzed using Vosviewer and Microsoft Excel. The bibliometric research flow used is described in Figure 1.

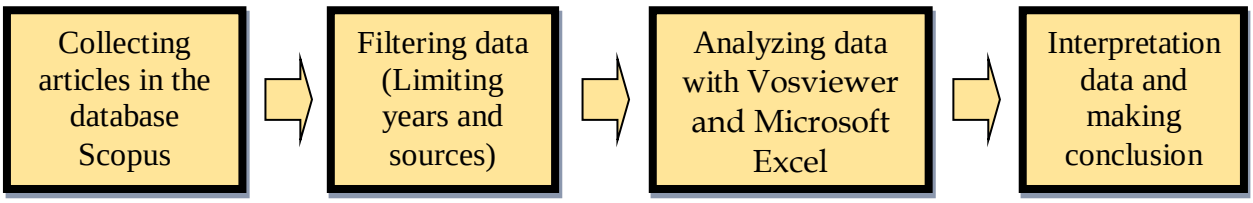

Figure 1. Research flowchart

This research process begins with the collection of articles from the Scopus database as the primary source for obtaining relevant literature. Next, the data is filtered by limiting the publication year and reference sources to align with the research focus. The filtered data is analyzed using VOSviewer software for bibliometric mapping and Microsoft Excel for quantitative data processing. The final stage involves in-depth interpretation of the analysis results to draw comprehensive conclusions, resulting in an accurate mapping of research trends that can serve as a basis for further study development.

RESULTS AND DISCUSSION

Results

Publication Trends

Based on data obtained from the Scopus database on trends in digital media development and 21st-century skills from 2001 to 2025, there were 597 relevant research articles, as shown in Figure 2.

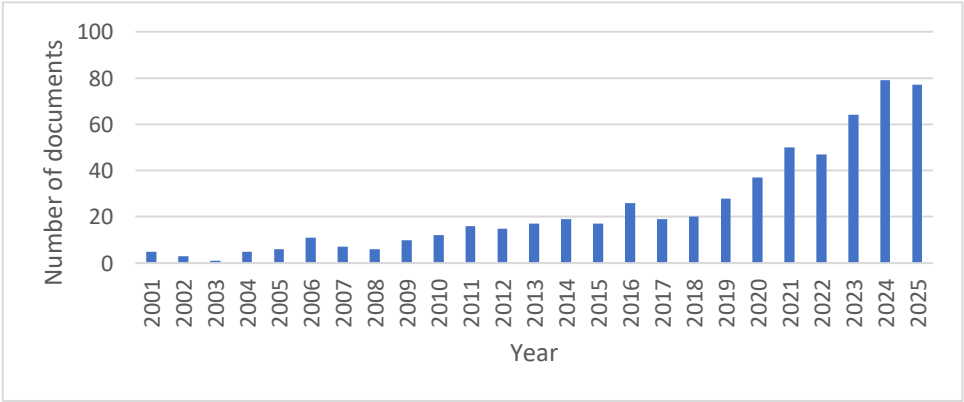

Figure 2. Number of relevant articles in database Scopus

Figure 2 shows the number of articles relevant to trends in digital media development and 21st-century skills. At the beginning of the 21st century, specifically from 2001 to 2005, 1-6 research articles related to the topic were published each year. Then, from 2006 to 2015, there was an increase in the publication of research articles, ranging from 6 to 17 articles each year. Between 2016 and 2019, the number of research article publications increased to 19-28 per year. In 2020, there was another increase of 37 article publications. After that, 2021-2025 saw a significant increase in research article publications to 47-79 research articles per year. This significant increase occurred due to the Covid-19 pandemic, which led to changes in the methods and models of learning carried out by teachers and students, as they conducted online learning activities or Work From Home (WFH). In general, there was an increase in research article publications each year due to technological advances in this era of globalization, which had an impact on the field of education.

Bibliometric Map

The following is a visualization of the database results obtained. For more details, see Figure 3 below.

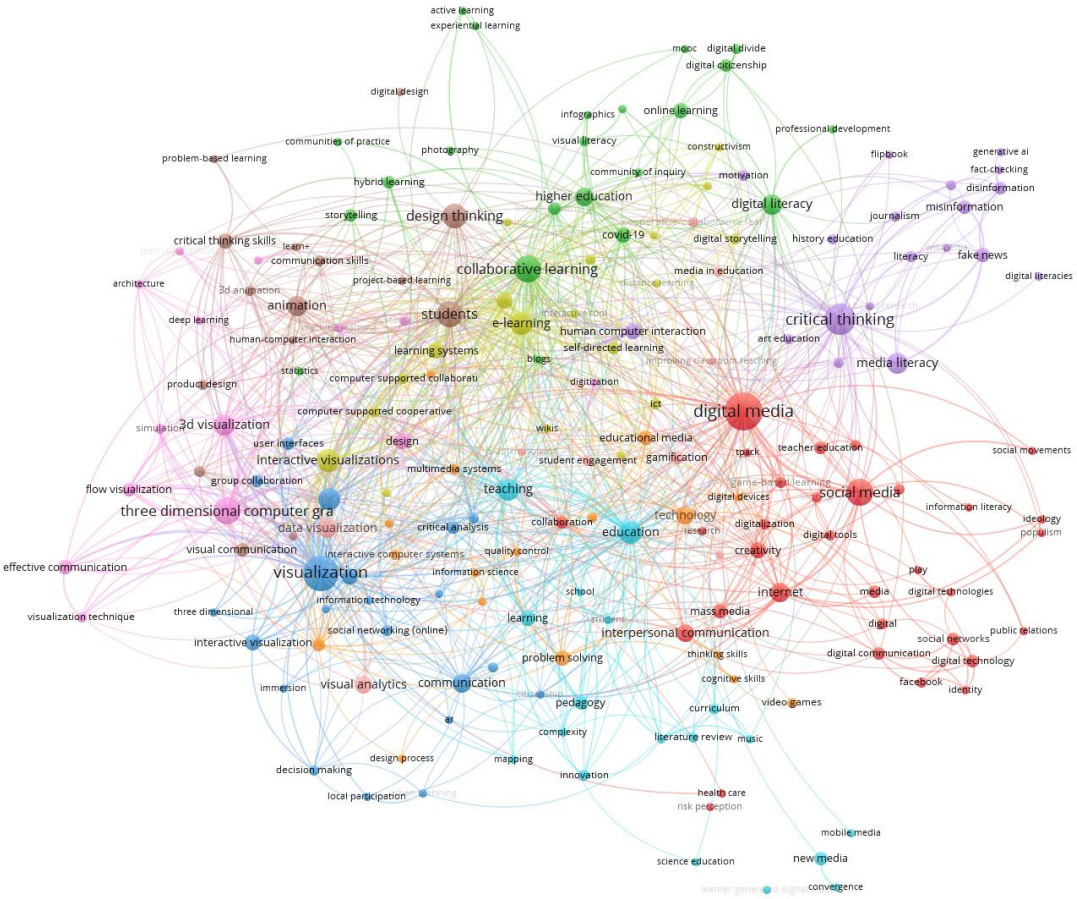

Figure 3. Visualization of the relationship trends between digital media and 21st Century student skills

Figure 3 shows a visualization of the co-occurrence network of keywords that frequently appear in research article publications. The larger the circle, the more frequently the keyword is used and appears in research articles. The color of the circle

indicates that the keyword belongs to different clusters. There are nine largest (dominant) keyword circles of different colors: "digital media" in red, "critical thinking" in purple, "visualization" in dark blue, "teaching" for light blue, 'students' for brown, "collaborative learning" for green, "e-learning" for yellow, "three-dimensional" for pink, and "technology" for orange.

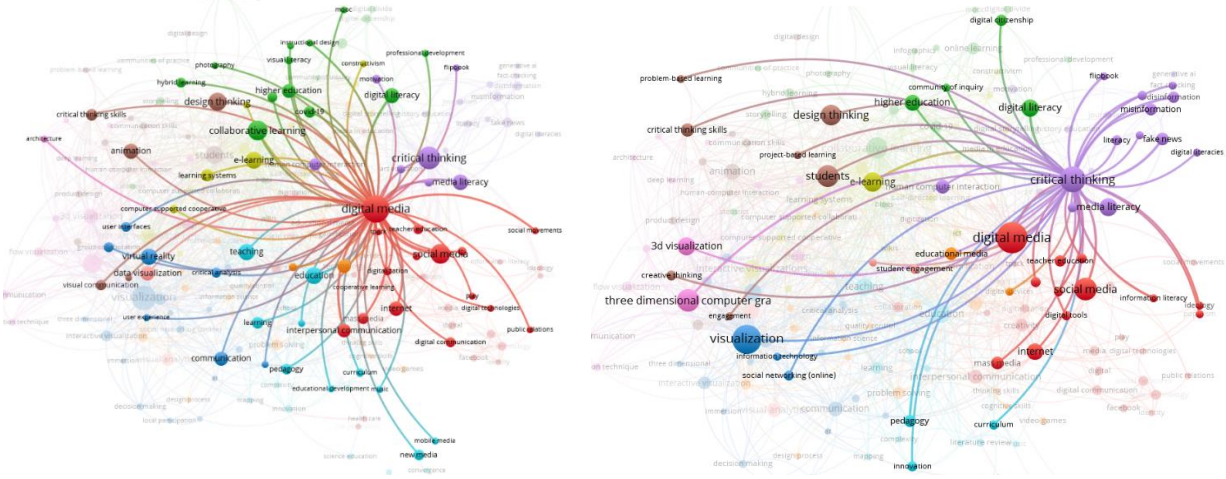

Figure 4. Visualization of keywords digital media and critical thinking

The largest (dominant) keyword in the red circle is "digital media," and the circle that is almost the same size is the keyword "social media." This means that these two keywords are closely related and most frequently used in research articles. The keyword "digital media" is also directly related to or can be combined with other dominant keywords, namely critical thinking, collaborative learning, teaching, and e-learning. The largest (dominant) purple circle keyword is "critical thinking," and the circle that is almost the same size is the keyword "media literacy." This means that these two keywords are closely related and most frequently used in research articles. The keyword "critical thinking" is also directly related to or can be combined with other dominant keywords, namely digital media, students, visualization, e-learning, and three-dimensional (3D).

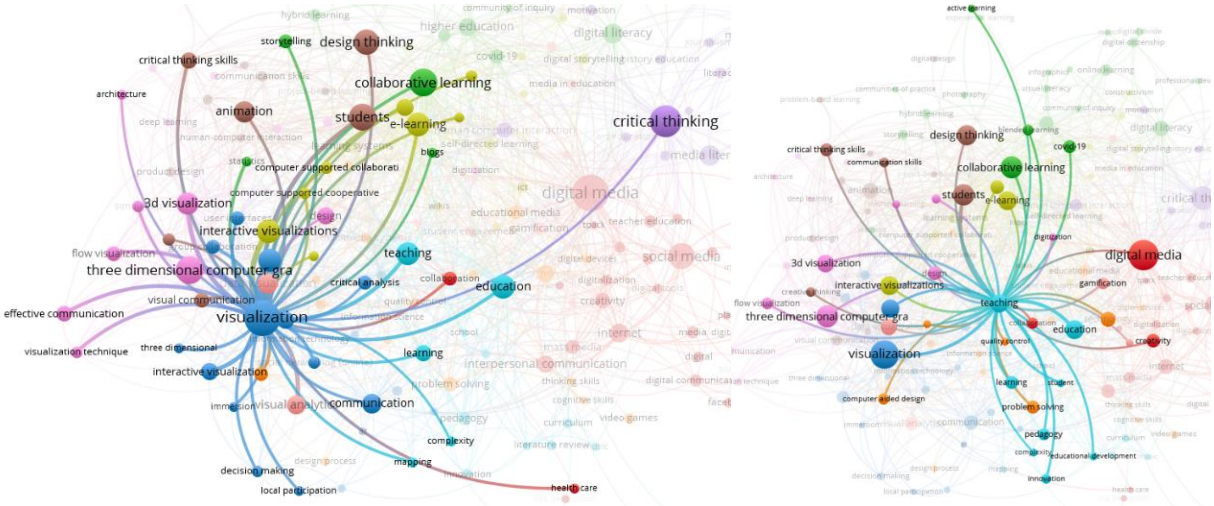

Figure 5. Visualization of keywords visualization and teaching

The largest (dominant) keyword in the dark blue circle is "visualization," and the circle that is almost the same size is the keyword "virtual reality." This means that these two keywords are closely related and most frequently used in research articles. The keyword "visualization" is also directly related to or can be combined with other dominant keywords, namely critical thinking, three-dimensional (3D), students, collaborative learning, e-learning, and teaching. The largest (dominant) keyword in the light blue circle is "teaching," and the circle that is almost the same size is the keyword "education." This means that these two keywords are closely related and most frequently used in research articles. The keyword "teaching" is also directly related to or can be combined with other dominant keywords, namely digital media, visualization, students, three-dimensional (3D), collaborative learning, and e-learning.

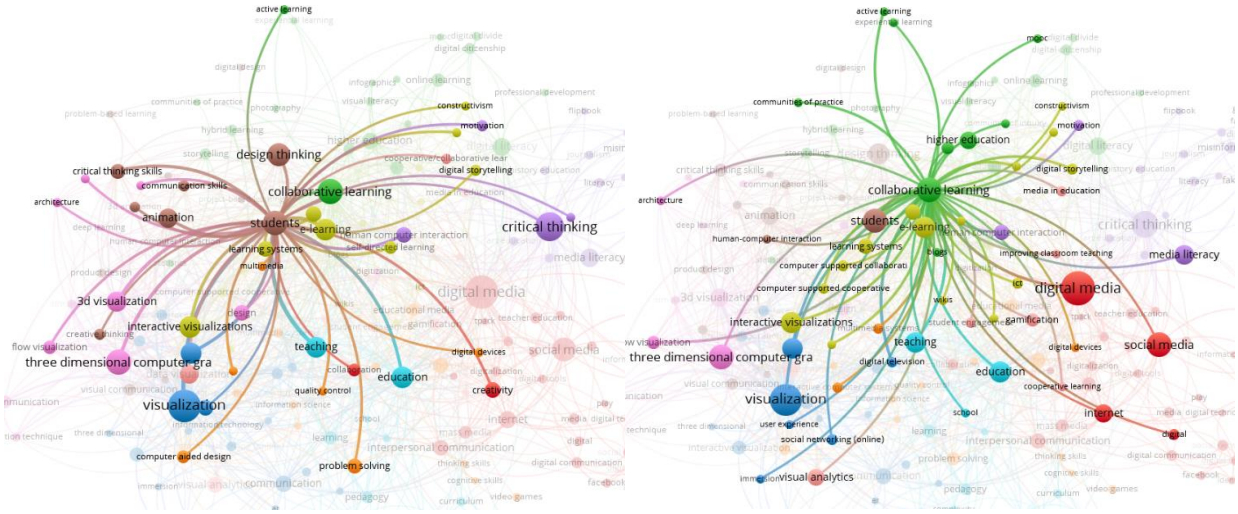

Figure 6. Visualization of keywords students and collaborative learning

The largest (dominant) brown circle keyword is "students," and the circle that is almost the same size is the keyword "design thinking." This means that these two keywords are closely related and most frequently used in research articles. The keyword "students" is also directly related to or can be combined with other dominant keywords, namely collaborative learning, visualization, critical thinking, teaching, and e-learning. The largest (dominant) green circle keyword is "collaborative learning," and the circle that is almost as large is the keyword "higher education." This means that these two keywords are closely related and most frequently used in research articles. The keyword "collaborative learning" is also directly related to or can be combined with other dominant keywords, namely students, digital media, visualization, three-dimensional (3D), teaching, and e-learning.

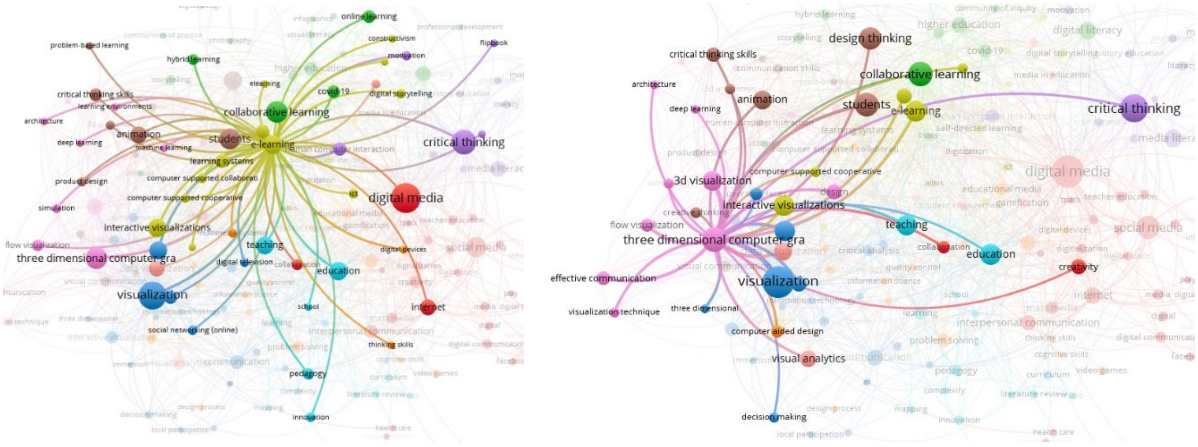

Figure 7. Visualization of keywords e-learning and three-dimensional (3D)

The largest (dominant) green circle keyword is "e-learning," and the circle that is almost the same size is the keyword "interactive visualization." This means that these two keywords are closely related and most frequently used in research articles. The keyword "e-learning" is also directly related to or can be combined with other dominant keywords, namely visualization, three-dimensional (3D), teaching, digital media, collaborative learning, students, and critical thinking. The largest (dominant) green circle keyword is "three-dimensional," and the circle that is almost the same size is the keyword "3D visualization." This means that these two keywords are closely related and most frequently used in research articles. The keyword "three-dimensional" is also directly related to or can be combined with other dominant keywords, namely, visualization, students, teaching, critical thinking, collaborative learning, and e-learning.

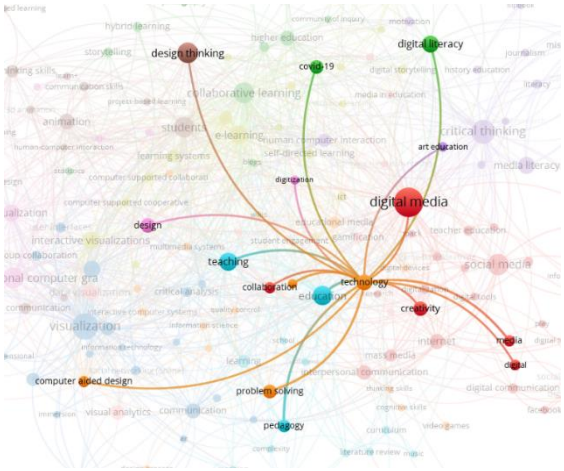

Figure 8. Visualization of keywords technology

The largest (dominant) keyword in the green circle is "technology," and the circle that is almost the same size is the keyword "computer-aided design." This means that these two keywords are closely related and most frequently used in research articles. The keyword "technology" is also directly related to or can be combined with another dominant keyword, namely, critical thinking.

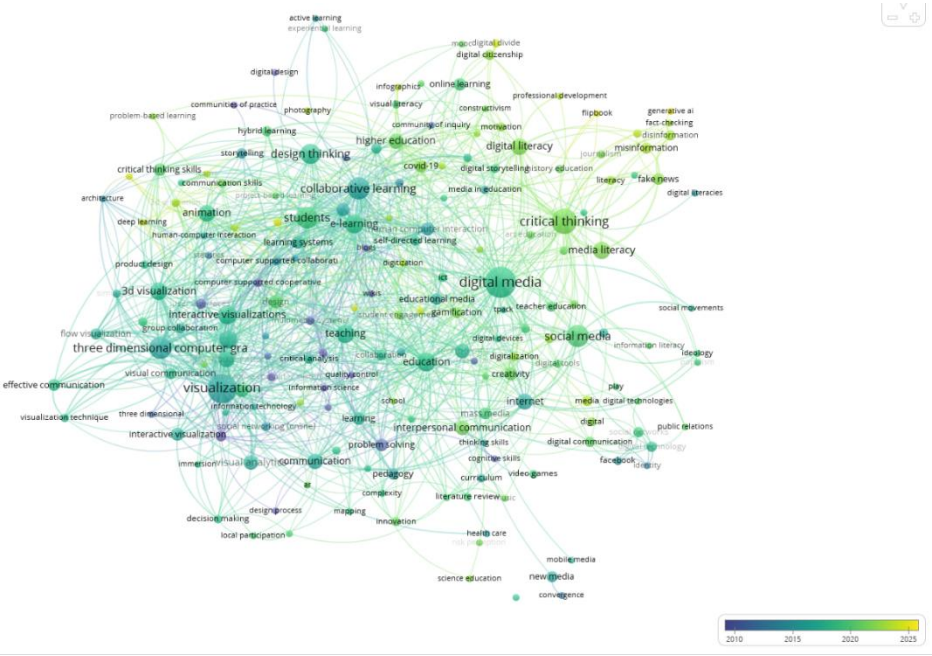

Figure 9. Visualization of the timeline trends between digital media and 21st Century student skills

Figure 9 shows the timeline of keywords that frequently appear and are used in research articles. Yellow indicates that the keyword appeared and was used recently around 2025, while dark blue indicates that the keyword has not appeared and been used in research articles for a long time. Dominant keywords such as critical thinking are yellowish green, which means they still frequently appear and are used around 2025, while other dominant keywords such as digital media, visualization, teaching, students, collaborative learning, e-learning, three-dimensional, and technology are green to dark blue, which means that around 2015-2020, these keywords rarely appear and are used in research articles. The collaboration network among authors on the same topic, focusing on the keywords Digital Media and 21st Century Student Skills in Indonesia. The color red connects the three collaborations between two authors in Indonesia. This indicates a close relationship between the authors. This can be used as a reference for finding literature sources related to the development of digital media and 21st-century skills for students.

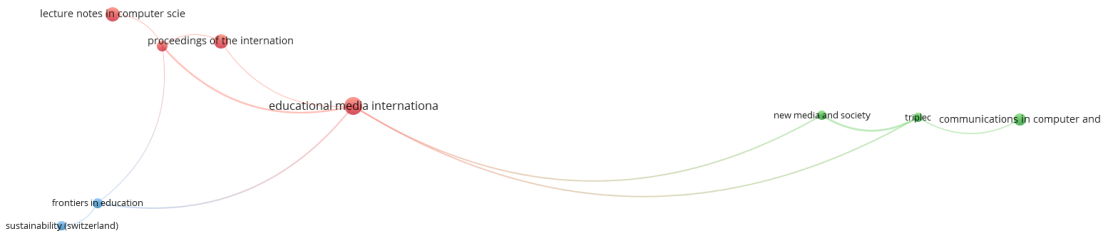

Figure 10. Visualization of document source for keywords digital media and 21st Century student skills

Figure 10 shows the relationship between the dominant document sources that have been obtained. These document sources come from various journals around the world. They can be used as references for finding literature sources related to the development of digital media and 21st-century skills for students. It can be seen that the most dominant document source is the journal "International Educational Media," which publishes research in the field of educational media that is currently developing, such as globalization, technological developments, and innovation.

Discussion

Based on the results of the bibliometric analysis that has been conducted, the trend of research publications on the development of digital media to improve students' 21st-century skills has increased significantly from 2001 to 2025. This increase was particularly evident after 2020, when the number of publications peaked at 47-79 articles per year. This phenomenon can be attributed to the impact of the COVID-19 pandemic. This is because it forced a paradigm shift in education towards e-learning and the massive use of digital media around the world. The pandemic has accelerated the adoption of technology in education, including in the field of physics, where abstract concepts require interactive visualization to facilitate student understanding. This finding aligns with the notion that global technological advances can advance the field of education. The development of animation and virtual reality software has encouraged researchers to explore the integration of digital media in education, thereby improving the quality of student learning.

The co-occurrence network visualization of keywords shows a close relationship between "digital media" and other keyword elements. The keyword "digital media" appears as the most dominant, with a direct connection to "social media" in one color (cluster). This means that digital media not only functions as a visualization tool but also as a social platform that supports interaction, communication, and the dissemination of information in a good and broad manner. This is because digital media must also offer information that is easily understood by students (Mikamahuly, 2023). Therefore, digital learning media must be able to provide students with both interaction and accurate information to create a good learning environment. This is supported by the relationship between the keyword "digital media" and the keywords "collaborative learning," "students," and "teaching," indicating a necessary interaction and communication between digital learning media, students, and teachers' teaching methods. This relationship aligns with Indonesia's current educational goals, which prioritize two-way learning. The focus is not only on the delivery of material from teachers to students, but also on active interaction between students and teachers, reflecting a student-centered approach.

Then, the keyword "digital media" is related to the keyword "critical thinking," which is one of the 21st-century skills. This is because current learning also needs to empower 21st-century skills, namely critical thinking (Asniar, 2022). Therefore, media development can also be suitable for containing material that can train students' critical

thinking skills. In addition, the keyword "critical thinking" is directly related to the keyword "visualization," which has a strong connection to the keywords "three-dimensional" or "3D visualization" and is also related to the keyword "animation." The keyword "animation" is related to the keywords "3D animation," "augmented reality," and "virtual reality." Of these three keywords, the most dominant is virtual reality (VR), and the least dominant is 3D animation. Therefore, to train students' critical thinking skills, three-dimensional visualization with virtual reality (VR), augmented reality (AR), and 3D animation can be used (Novitasari, 2025; Ashari, 2023; Haryadi, 2022).

Furthermore, the keyword "digital media" is closely related to the keywords "e-learning" and "interactive visualization." This means that digital media must have interactive elements. Furthermore, the keyword "interactive visualization" is related to the keywords "critical analysis," "social networking (online)," and "self-directed learning." This means that digital learning media can incorporate elements of critical thinking skills analysis. Additionally, the media can be accessed by everyone online, and the digital media developed must be usable in students' independent learning without teacher assistance. This is supported by the keyword "technology", which is strongly related to "computer-aided design", where this keyword is related to the keywords "multimedia systems", "information analysis", and "review". Therefore, in developing media, various combinations can be created, incorporating elements of information from answer analysis and score acquisition to enable students to learn independently. With students able to learn independently, their learning achievements can improve (Tampubolon, 2020).

Based on the results of data and analysis, it is recommended that the development of digital media provide elements of interaction and communication between students, as well as improve students' critical thinking skills, which can be incorporated in the form of 3D animation because it is seen in the co-occurrence network of keywords that are not very dominant, meaning that there are still few who discuss or research it. To facilitate easily understandable interaction and communication, the material provided can be contextual or based on everyday events (Apriadi, 2021).

CONCLUSION

Fundamental Finding: This study analyzed trends in digital media development and 21st-century skills, which have increased significantly since 2020 due to the COVID-19 pandemic accelerating the adoption of digital learning technologies. From the findings of this analysis, digital media can be linked to critical thinking skills, collaborative learning, and three-dimensional visualization. **Implication:** These results emphasize the importance of utilizing digital media effectively to train 21st-century skills, particularly critical thinking in students, which can be facilitated through 3D animation in physics learning materials. **Limitation:** This study is limited to one database from Scopus. It has not analyzed the impact of learning outcomes resulting from the use of digital media and 21st-century thinking skills in physics learning. **Future Research:** Future research should

utilize a broader range of databases and conduct further analysis to examine the impact of digital media and 21st-century thinking skills on physics learning.

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AUTHOR CONTRIBUTIONS

Mohamad Wahdiansyah Arrahmat contributed to the conceptual framework, research design, and validation process; **Mita Anggaryani** was involved in methodology development, data analysis, sourcing references, and drafting the manuscript; **Oka Saputra** handled data management; **Noval Maleakhi Hulu** was involved in methodology development. All listed authors have reviewed and approved the final version of this submission.

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest, either financial or personal, that could influence the content or results of this study.

ETHICAL COMPLIANCE STATEMENT

This manuscript complies with research and publication ethics. The authors affirm that the work is original, conducted with academic integrity, and free from any unethical practices, including plagiarism.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors acknowledge the use of digital tools, including AI-based technology, as support during the research and writing of this article. Specifically, Grammerly is a writing aid that offers various advantages in improving English language quality. All written work produced with digital assistance has been critically evaluated and revised to ensure compliance with academic and ethical standards. Final responsibility for the manuscript rests solely with the authors.

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