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Adaptive Digital Modules and Artificial Intelligence in Physics Education: Bibliometric Analysis Using Scopus Data

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Abstract

This research aims to analyze global trends in the development of adaptive digital modules based on artificial intelligence (AI) in fluid physics learning through a bibliometric approach. As the 21st-century demand for critical thinking skills and technological understanding grows, AI-based modules are becoming increasingly relevant in supporting differentiated learning. However, a comprehensive mapping of scientific publications in this field remains limited, leading to gaps in understanding current research directions and potential collaboration opportunities. This research uses bibliometric software to identify publication patterns, researcher collaboration networks, and key trends in the development of AI-based physics learning modules. The data used is taken from the Scopus database and includes related publications from 2019 to 2024. The research method involves two main steps: data collection of publications using the keywords "adaptive digital module AND AI AND physics education" and metadata analysis to identify research trends and researcher collaborations. The analysis results show a significant increase in the number of publications on AI-based adaptive learning, particularly from countries such as China, the United States, and India. The findings also indicate that the main research topics include the development of AI technology to support adaptive learning, as well as the effectiveness of digital modules in the context of physics education. This research reveals the importance of international collaboration in the development of AI-based adaptive modules and recommends the use of other bibliometric methods as well as the expansion of database coverage for future research. Furthermore, this research provides important insights for the development of more effective learning strategies through AI technology in physics education.

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INTRODUCTION

The challenges of the 21st century are becoming increasingly complex along with the rapid development of digital technology, especially with the advent of the Fourth Industrial Revolution (Rifai et al., 2022; Santika, 2021; Schwab, 2017; Suh & Park, 2020). This era demands that the younger generation possess adaptive skills that enable them to face future changes and challenges more prepared (Purfitasari et al., 2019). Education plays a crucial role in preparing students to face these challenges, and one relevant approach is through the integration of technology in the learning process (Ertmer & Ottenbreit-Leftwich, 2010; OECD, 2020; Subroto et al., 2023; Voogt et al., 2015). In facing this digital revolution, the

younger generation needs to learn how to think critically, collaborate, and innovate using technology as a tool. The use of technology in learning can also help students develop the skills needed in an increasingly digital workplace. Therefore, it is important for educational institutions to continuously develop learning methods that are relevant to the demands of the times so that students can become individuals ready to face future changes and challenges.

Artificial Intelligence (AI) now plays an important role in various fields, including education (Chen et al., 2020; Holmes et al., 2019; Tjahyanti et al., 2020; Zawacki-Richter et al., 2019). In this field, AI enables the development of adaptive and personalized digital learning modules, providing a learning experience tailored to the needs and abilities of each student (Khoiriah et al., 2023). In the context of physics education, AI-based adaptive digital modules present more interactive and responsive learning methods, which are expected to help students understand concepts in physics that are often considered complex while also enhancing their critical thinking skills (Yusuf, 2020). With the presence of AI, students can learn more effectively and efficiently because the learning modules can be tailored to their individual levels of understanding (Purnawanto, 2023). Additionally, AI can also provide immediate feedback to students, allowing them to correct their mistakes quickly and more thoroughly (Octavianus et al., 2023). Thus, the use of AI in physics education can help create a generation that is more adept at understanding complex scientific concepts.

The use of digital technology in learning has been proven to enhance the quality of education, both in terms of effectiveness and time efficiency (Almahasees et al., 2021; Eka & Hotmaulina, 2023; UNESCO, 2019; Tang et al., 2020). This certainly provides significant benefits for educators in preparing students to face the increasingly complex and rapidly changing challenges of the world. With the presence of AI, teachers can focus more on facilitating interactive and collaborative learning processes, thereby creating a more engaging and effective learning environment (Chen et al., 2020; Holmes et al., 2020; Hakeuet et al., 2023; Luckin et al., 2016). In addition, the use of digital technology can also help bridge the gap in access to education, ensuring that every individual has an equal opportunity to develop their potential.

Research that specifically explores AI-based adaptive digital modules in the context of physics education is still limited (Chen et al., 2020; Fitri & Dilia, 2024; Holstein et al., 2020; Zawacki-Richter et al., 2019). Previous studies have generally focused on the development of digital modules or the integration of artificial intelligence in education separately, without combining both elements in a unified framework. For example, some researchers have investigated the effectiveness of adaptive learning systems, such as rule-based or data-driven platforms, while others have examined AI applications in personalized learning (Khosravi et al., 2022; Wang & Heffernan, 2010; Zawacki-Richter et al., 2019). However, there is a scarcity of research that bridges adaptive digital modules and AI specifically within the domain of physics education, especially using bibliometric approaches to map the research landscape. Although some research has discussed the application of AI in education in general, studies focusing on the development of adaptive digital modules specifically for physics have not been extensively conducted (Puspitasari, 2019). Therefore, this research is expected to fill that gap and provide a new perspective on the implementation of AI technology in the development of more adaptive physics learning (Brown, 2022). With this research, it is hoped that a new breakthrough will be created in the field of physics education that can enhance the effectiveness of learning for students (Anderson & Lee, 2020). The use of AI technology in the development of adaptive digital modules is also expected to help students understand physics concepts more easily and enjoyably (Kim & Santoso, 2021). Thus, it is hoped that physics learning will no longer

be considered a difficult subject but will become more interesting and stimulate students' interest in learning (Gao et al., 2021).

This research will conduct a bibliometric analysis to identify global trends in research on AI-based adaptive digital modules in physics education using data from the Scopus database. The period of 2019 to 2024 is considered crucial because it marks a significant acceleration in the integration of artificial intelligence into educational technologies, particularly after the global shift to digital learning caused by the COVID-19 pandemic. Since 2019, there has been a notable increase in publications focusing on AI, adaptive learning, and digital modules in various fields, including physics education. This timeline captures the most recent developments, innovations, and research trends, making it highly relevant for identifying current gaps and future directions in the application of AI-based adaptive digital modules. This analysis aims to provide a comprehensive overview of research developments, collaboration patterns among researchers, popular themes, and future research directions in this topic (Jones et al., 2023). The results of this study are expected to serve as a reference for researchers, educators, and policymakers in developing more effective and adaptive physics learning strategies in line with technological advancements (Zhang, 2022). Additionally, by using data from the Scopus database, this analysis is expected to provide a deeper understanding of the emerging research directions in the field of AI-based adaptive digital modules. Thus, researchers, educators, and policymakers can more easily identify opportunities for collaboration and future research development (Johnson & Alibegovic, 2021). Based on these objectives, the following research questions are proposed: (1) What are the global publication trends related to AI-based adaptive digital modules in physics education from 2019 to 2024? (2) Which countries and institutions are the most active in this research area? (3) What are the most influential authors, keywords, and journals within this field? (4) How has the focus of research evolved over the years, and what themes are emerging as future directions?

METHODS

This research was conducted using a bibliometric approach to analyze publication trends related to the development of AI-based adaptive digital modules in physics education. The database used is Scopus, which has an advantage in its extensive coverage in the fields of science, technology, and social sciences compared to other databases (Yaniasih, 2020). In addition, Scopus also provides reliable and accurate information regarding the number of citations and authors related to this research topic. Article searches were conducted on December 28, 2024, using the keywords "adaptive digital module AND AI AND physics education" from 2019 to 2024. The collected data includes the metadata of relevant articles, including titles, abstracts, authors, affiliations, keywords, and citation counts.

The search results yielded 783 articles, which were then downloaded along with their metadata and saved in CSV format. The downloaded data was re-examined to ensure that the selected articles were relevant to the topic of developing AI-based adaptive digital modules in the context of physics learning. Articles that did not meet the criteria, such as those that only discussed digital modules without AI elements or focused on fields other than physics, were removed from the dataset to ensure the accuracy of the analysis.

This research uses R software with the bibliometrix package to analyze the collected Scopus data. The research procedure is divided into two main stages: data collection and data analysis. Data collection is conducted through the Scopus database, while data analysis includes the processing of metadata to identify research patterns, keyword trends, and collaborations among researchers in the field of AI-based adaptive digital module development (Putri & Andriani, 2023). This analysis aims to uncover trends and directions

in research on the development of adaptive digital modules utilizing AI for effective physics learning. The analysis process is shown in Figure 1.

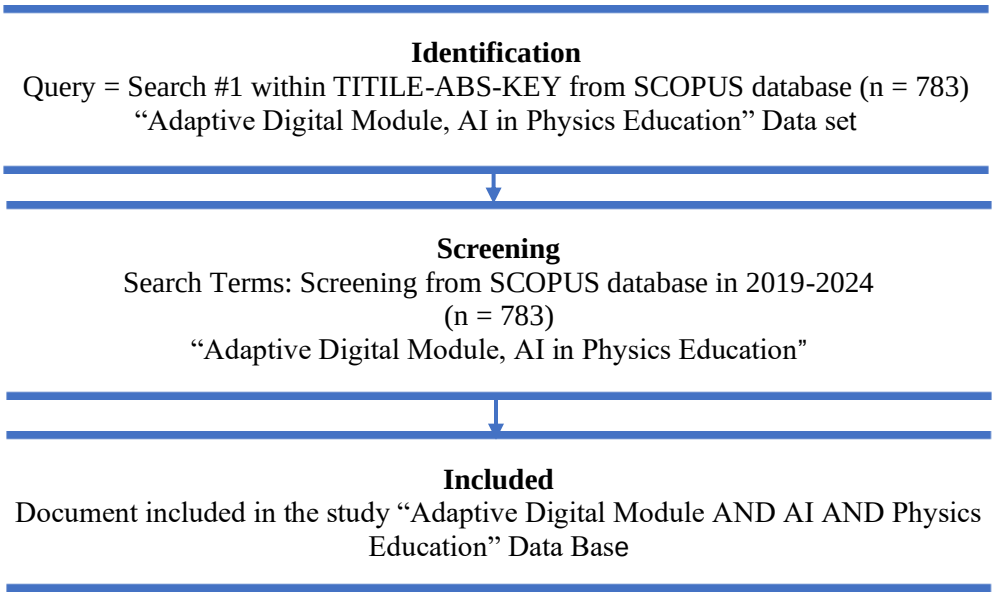

Figure 1 Bibliometric research design with R software

This bibliometric analysis involves two main approaches: dynamic analysis and structural analysis. Dynamic analysis evaluates the development of publications over time, keyword trends, keyword frequency, and the impact of articles through citations and h-index. Structural analysis involves mapping keyword co-occurrence networks, cluster analysis, and thematic mapping to identify thematic relationships and collaboration patterns among researchers.

The analysis process is carried out using the biblioshiny application from bibliometrix, with the following steps: Step 1, install the R software and the bibliometrix package by typing the commandinstall.packages("bibliometrix"), followed by library(bibliometrix) and biblioshiny() to open the application. Step 2, after the application is running, click the "Data" menu and select "Import file" to upload the metadata file that has been downloaded from Scopus in CSV format. Step 3, select the Scopus database and browse for the desired file, then click "Start" to begin the data analysis. The final step, Step 4, is to select the "Documents" menu and proceed to "Conceptual Structure," "Social Structure," and "Word Cloud" to visualize the analysis results, including keyword network maps and collaborative relationships in the research.

RESULTS AND DISCUSSION

The development of digital technology and artificial intelligence (AI) has opened new opportunities in the development of learning materials that are more adaptive and responsive to the needs of learners (Suparman, 2022). In the context of physics education, this AI-based adaptive digital module is capable of providing a personalized and interactive learning experience (Anderson & Lee, 2020). However, research related to the development of this module is still limited to certain aspects, such as the general use of AI technology without specifically linking it to the needs of physics material. Furthermore, research trends on the effectiveness of adaptive digital modules in physics education have not yet been systematically mapped. Therefore, a bibliometric study is needed to identify research patterns, researcher collaborations, and future research directions in the development of AI-based adaptive digital modules for physics materials (Jones et al.,

2023). Thus, researchers can be more focused in developing effective modules that meet the needs of students. Through this bibliometric study, it is hoped to provide clear guidance for the direction of future research and to improve the quality of physics learning through AI-based adaptive digital modules (Brown, 2022). Table 1 presents descriptive statistics from the bibliometric study related to "AI Adaptive Digital Modules in Physics Education" covering the period from 2019 to 2024. The data is divided into two main categories, namely dynamics and structure.

Table 1 Bibliometric statistical data of ai adaptive digital modules and physics education

Dynamics		**Structure**	
Timespan	2019 - 2024	Authors	2823
Source (Journal, Books, etc.)	526	Author of single-authored docs	77
Documents	783	Single-authored documents	81
Average citations per document	6.047	Co-Authors per document	4.28
Keyword Plus (ID)	6714	International co-authorships %	17.37
Author's Keywords (DE)	2473	References	0

Aspect dynamics, there are 526 sources including journals, books, and other publications with a total of 783 documents collected. The average citation per document is 6.047, indicating a relatively high reference rate in this literature. Additionally, there are 6,714 Keyword Plus (ID) entries and 2,473 Author's Keywords (DE) that illustrate the diversity of topics studied.

In terms of structure, there are 2,823 authors involved in this study. As many as 77 authors are single authors, with a total of 81 single-authored documents. The average number of Co-Authors per document is 4.28, indicating a tendency for collaboration in this research. The percentage of international collaboration in authorship reaches 17.37%, indicating significant contributions from researchers in various countries.

The graph of article production related to "AI Adaptive Digital Modules in Physics Education" can be seen in Figure 2, which shows a consistent increase from 2019 to 2023. In 2019, the number of published articles was around 50, then gradually increased to more than 150 articles by 2022. The peak occurred in 2023, with the number of publications exceeding 200 articles.

However, in 2024, there was a decrease in the number of articles, although the figure still indicated significant interest in this topic. The increase in publications reflects the growing attention towards the use of AI technology in the development of digital modules, particularly in the context of physics education.

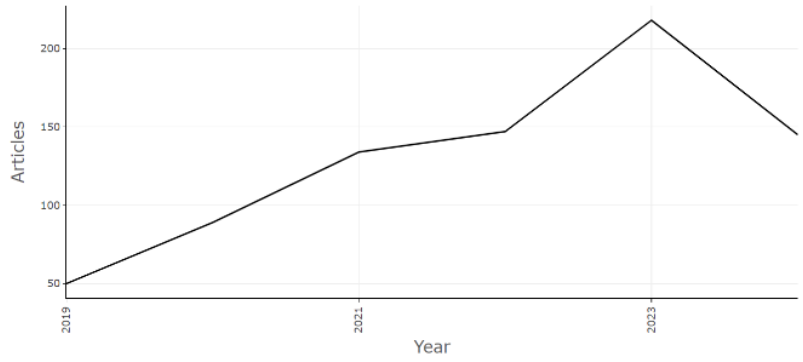

Figure 2 Production of the article "AI adaptive digital modules in physics education" 2019-2024

This finding is in line with the work of Zawacki-Richter et al. (2019), who identified a sharp increase in AI-related educational research after the pandemic, although their study was more focused on higher education in general rather than subject-specific domains like physics. Similarly, the findings support the trend observed by Khosravi et al. (2022), who emphasized the rapid adoption of adaptive learning systems but did not delve specifically into physics content. Therefore, this current study provides a more targeted perspective.

The production of scientific articles related to "AI Adaptive Digital Modules in Physics Education" can be seen in Table 2, which shows the top 20 countries in scientific publications. These countries are ranked based on the frequency of publications during the specified period. China ranks first with 1,073 publications, making it the largest contributor to the related literature. India is in second place with 287 publications, followed by the United States in third place with 282 publications. Countries such as Germany (186) and the United Kingdom (121) also made significant contributions, occupying the fourth and fifth positions respectively. These results are consistent with previous bibliometric findings by Zhang et al. (2021), who highlighted China and India as emerging leaders in AI research in education. However, unlike prior studies, this analysis highlights the rise of specific interest in the physics domain, which was under-represented in earlier works.

Other countries that are also active in this research include Italy, South Korea, Japan, and Spain, each contributing between 60 to over 110 publications. This list shows a wide geographical distribution of related research, covering countries from various continents. Countries at the lower ranks, such as Malaysia, Singapore, and Norway, despite having fewer publications, still play an important role in supporting the development of literature on this topic. With significant contributions from various countries, research on AI and physics education has shown a strong global trend over the past decade.

Table 2 Results of bibliometric analysis of scientific article production in several countries

Rank	Country	Freq
1	China	1073
2	India	287
3	Usa	282
4	Germany	186
5	Uk	121
6	Italy	111
7	South Korea	83
8	Japan	71
9	Spain	64
10	Australia	54
11	Poland	53
12	France	46
13	Brazil	38
14	Canada	36
15	Greece	35
16	Portugal	32
17	Saudi Arabia	28
18	Norway	23
19	Singapore	23
20	Malaysia	22

The distribution map can be seen in Figure 3. This distribution map displays the scientific contributions from various countries related to "AI Adaptive Digital Modules in Physics Education." The darker the blue color on the map, the higher the research contribution produced by that country. China, marked with the darkest blue color, has the most significant contribution to this research, followed by other countries such as India, the

United States, Germany, and England, which are also marked with darker blue colors. While previous bibliometric analyses (e.g., Chen et al., 2021) discussed the regional dominance of Asia in educational AI, this study confirms and extends that pattern within the niche field of physics education, suggesting a specialized trend that prior broad-spectrum studies have not yet covered.

Countries with light blue indicate lower contributions, while countries that are not colored blue show less involvement or no contribution in this research. This map visually depicts the geographical distribution of scientific research related to AI-based physics education and serves as an important tool for understanding global trends and the potential for international collaboration in this field.

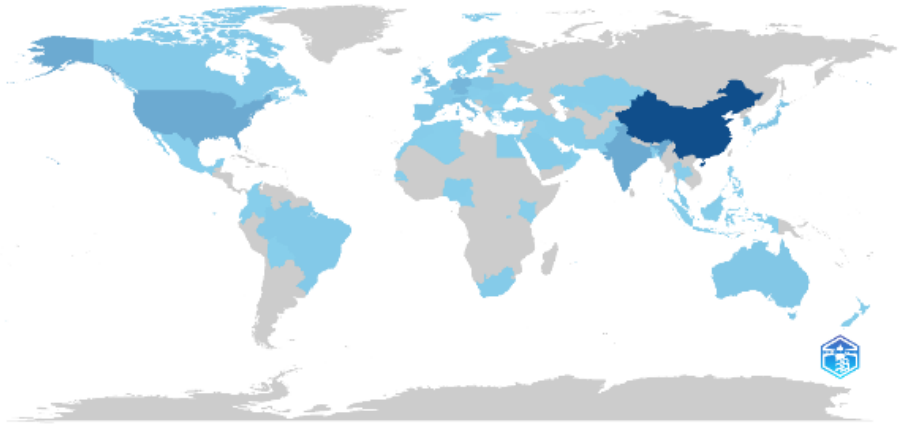

Figure 3 Publication production by country

The most cited countries in Table 3 show the 10 countries with the highest number of citations in research related to the development of adaptive digital modules in physics education that integrate artificial intelligence (AI). China leads with 1,251 citations, followed by the United States (323), and Korea (273). This aligns with the citation-based research impact discussed by Wang and Heffernan (2010), who noted that AI education research from Asian countries has increasingly influenced the global discourse in recent years. However, this study further refines that insight by focusing solely on the adaptive module subdomain in physics education. India, Spain, Japan, Singapore, the United Kingdom, Germany, and Canada also made the list, indicating significant contributions from countries in Asia, Europe, and North America. This data reflects strong global competition in AI-based physics education research, with a dominant contribution from Asia and North America.

Table 3 Countries with the most citations

Rank	Country	Total Citations
1	China	1251
2	USA	323
3	Korea	273
4	India	219
5	Spain	189
6	Japan	152
7	Singapore	132
8	United Kingdom	131
9	Germany	114
10	Canada	113

The most cited articles in research on the development of adaptive digital modules in physics education, particularly those integrating artificial intelligence (AI), are listed in Table 4. The number of citations indicates the significant contribution of each article to the scientific community. The article "Gürdür Broo D, 2022" from the Journal of Industrial Information Integration ranks first with 612 citations, far higher than other articles. Followed by the article by Chen (2021) from the AAAI Conference on Artificial Intelligence with 47 citations. The high citation count of these works shows that contributions that bridge industrial applications (like digital systems) and AI education models are being recognized. This echoes findings from Su et al. (2020), who argued that interdisciplinary applications (e.g., combining industrial tech and educational models) attract higher academic attention. These ten papers were selected and ranked using R software and the Biblioshiny bibliometric program based on the global citation count, reflecting their significant contributions to the development of AI-based physics education modules.

Table 4 The most cited documents in the world

Rank	Paper	Total Citations
1	GÜRDÜR BROO D, 2022, J IND INFOR INTEGR	612
2	CHEN S, 2021, AAAI CONF ARTIF INTELL, AAAI	47
3	HE R, 2021, J CLEAN PROD	98
4	GONG C, 2020, IEEE INTERNET THINGS J	48
5	MUSTAQEEM, 2021, APPL SOFT COMPUT	35
6	LAAMARTI F, 2020, IEEE ACCESS	54
7	PROCHASKA JJ, 2021, J MED INTERNET RES	19
8	GUO T, 2022, FUTURE GENER COMPUT SYST	33
9	DING F, 2022, IEEE TRANS MULTIMEDIA	19
10	BOLDÚ L, 2021, COMPUT METHODS PROGRAMS BIOMED	10

Mapping of the main themes (Word cloud) in Figure 4 from research related to the development of adaptive digital modules in physics education that integrate artificial intelligence (AI). The size of the words in this visualization indicates the frequency and intensity of the topics that most frequently appear in the related literature. The keyword "artificial intelligence" dominates, indicating that the AI topic is the focal point of this research. In addition, words like "digital storage," "deep learning," "e-learning," and "machine learning" also stand out, indicating the importance of these technologies in the field of physics education.

Figure 4 Word cloud of adaptive digital modules and AI

Compared to previous keyword mapping by Zawacki-Richter et al. (2019), which emphasized broader AI applications, the results of this study offer more granular insight into the key terms used within the context of physics education, suggesting a shift toward more content-specific integration.

Other smaller keywords such as "decision making," "internet of things," and "learning systems" indicate topics that, although less frequently mentioned, remain relevant in discussions about AI-based education. This word cloud provides an overview of current research trends, helping researchers understand the main focus areas and those still holding potential for further exploration. This visualization plays a crucial role in identifying the main themes underlying previous studies, while also guiding researchers to explore less discussed or emerging aspects.

With the increasing attention on digital technology and AI in education, this research trend can provide deeper insights into how artificial intelligence plays a role in enhancing the learning process. The prominent keywords also highlight how technologies such as "deep learning" and "machine learning" are adopted to enhance the quality of learning, decision-making, and e-learning systems. This confirms earlier predictions by Shum & Ferguson (2012), who emphasized that AI will eventually move from a general support tool to a core mechanism for adaptive learning content development. This study presents emerging evidence of that transition, particularly in physics education. This also indicates that these topics can become the center of developing physics education that is more adaptive and responsive to the needs of the modern era.

CONCLUSION

This research presents a bibliometric analysis of the development of "AI-Based Adaptive Digital Modules in Physics Education." The analysis results show a significant increasing trend in publications related to AI-based digital modules, particularly from countries with substantial contributions such as China, India, and the United States. The geographical distribution of these scientific contributions reflects the potential for cross-country collaboration in the future, with several countries showing high research productivity from 2019 to 2024.

Although this research provides valuable insights into the dynamics and structure of global research in the field of AI-based adaptive digital modules, there are several limitations. This analysis only includes data from the Scopus database, which may not capture significant contributions from other databases such as Web of Science (WoS) or PubMed. Additionally, the use of the Bibliometrix software on R also limits the analysis results to the features provided by that program. The use of other bibliometric software such as VOSviewer or CiteSpace could provide additional perspectives that could enrich the research results.

This research shows a significant opportunity to further explore under-researched topics, such as how AI-based digital modules influence the physics education curriculum. With the continuous advancement of technology, future researchers can leverage this trend to develop more innovative and relevant learning strategies. The expansion of data coverage in the future and the adoption of additional analytical technologies can help generate a more comprehensive understanding of the impact of AI-based adaptive digital modules in education.

CONFLICTS OF INTEREST

The authors state that the writing and publication of this article are free from any conflicts of interest. All analyses and interpretations were carried out independently and objectively without any external interference.

AUTHOR CONTRIBUTIONS STATEMENT

All authors actively contributed to every stage of this research. Abdul Muhyi was responsible for conceptualizing the idea, collecting and analyzing the bibliometric data,

and writing the initial draft of the manuscript. Bambang Heru, Yuli Rahmawati, and Firmanur Catur Wibowo contributed to data validation, results visualization, and final editing of the manuscript. All authors have read and approved the final version of the article.

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