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A Decade of Bibliometrics Exploration on Wind Tunnel as Learning Media in Fluid Mechanics

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Abstract. *This study addresses the lack of research on the use of wind tunnels as learning media in fluid mechanics, an important area of research. Conducted using the Scopus database from 2015 to 2024, the review aims to identify trends in publication and citation, rank influential countries, journals, authors, and institutions, and visualize keyword usage and conceptual structures through bibliometric analysis using an R Package. To find relevant literature using the Scopus database, we searched for documents using mesh terms based on the query of two terms, "Wind Tunnel" and "Science Education" and used the Boolean operator "OR" to include synonyms of the terms. The articles retrieved were authored by 6528 researchers, published in 267 journals, representing 68 countries, and growing at 3.98% annually. Findings indicate a significant increase in scientific output, particularly in 2021. The top journal, Physics of Fluids, leads in publications, while China emerges as the most productive country. Key concepts include wind tunnels, Reynolds number, and aerodynamics, reflecting the relevance of both experimental and computational approaches. The results provide insights into the current state of wind tunnel research in science education and highlight opportunities for future interdisciplinary exploration, emphasizing the need for educational curricula to incorporate contemporary topics in fluid mechanics.*

Keywords: *Fluid Mechanics, Learning Media, Wind Tunnel*

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INTRODUCTION

Fluid mechanics is a crucial field of study in several facets of human life. By comprehending the fundamental principles of fluid mechanics, it becomes evident that an airplane is constructed with a streamlined shape and smooth surface to enhance its efficiency during flight. Conversely, a golf ball is intentionally designed with a rough surface to optimize its efficiency. Furthermore, a rocket is capable of generating immense thrust to propel a spacecraft, and it is conceivable that one could even devise a model airplane with similar characteristics (Supriyono, 2019). Future professionals and workers must get education that aligns with emerging technological and societal paradigms, such as globalization. Additionally, the impact of digitalization on information should be taken into account. (Cheng, 2005; Li, 2022). A wind fan is one of the most basic applications of fluid mechanics. A wind fan is a type of fluid engine that transforms electrical energy into the movement of air. A fan may manipulate the airflow by adjusting its angles to effectively draw and steer the desired amount of fluid (Ghurri, 2014). Therefore, it can be asserted that a profound understanding of fluid mechanics is indispensable in contemporary technical and social frameworks.

Fluid mechanics is one of the disciplines that is very pleasant to be studied extensively by students (Anderson, et.al., 2020). Mechanics is a scientific discipline that studies the concepts of force and motion, whereas fluid refers to a substance that exists in the form of a liquid or gas (Ghurri, 2014). Fluid mechanics is a branch of applied mechanics that focuses on the study of the characteristics and movement of liquids and gases, whether they are stationary or in motion (Supriyono, 2019). Fluid mechanics is a scientific discipline that investigates the characteristics and movement of liquids and gases, both while they are stationary and in motion.

Based on the literature, it is often believed by students that fluid mechanics courses are challenging (Albers & Bottomley, 2011; Minichiello, et.al., 2020; Diniya, et.al, 2024). Fluid mechanics courses in the United States are typically offered at the beginning of the semester. Nevertheless, students seldom opt for fluid mechanics courses at the start of the semester due to the perceived difficulty and complexity. The abstract nature of the ideas in fluid mechanics necessitates a profound comprehension of mathematics (Minichiello, et.al., 2020; Webster, Majerich, and Madden, 2016). This also leads to decreased student engagement and performance (Albers & Bottomley, 2011). Students face challenges when learning fluid mechanics, which include comprehending abstract concepts like fluid flow, applying and prioritizing the fundamental principles of mass conservation (as expressed in the continuity equation) and energy conservation (such as the Bernoulli equation), understanding concept definitions and equations, and analyzing variations in viscosity. Additional challenges encountered involve the use of the continuity

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equation, addressing inquiries regarding gravity, dissipative effects, and pressure drop. Students have challenges in technical reasoning, which includes tasks like utilizing equations with several variables, differentiating between spatial variations and temporal changes, and comprehending idealized implications (Schäfle & Kautz, 2021).

The occurrence of this challenge arises from the continued utilization of conventional approaches in the study of fluid mechanics (Pérez-Sánchez, et.al., 2019). Fluid mechanics encompasses numerous abstract ideas that necessitate a high degree of abstraction to accurately grasp flow configurations (Webster, Majerich, and Madden, 2016). Furthermore, introductory physics textbooks provide limited coverage of fluid-related subjects, with only a few mentions in experiment guides (Cooper, et.al., 2016). Several studies have been conducted to help students understand fluid principles. These studies include the use of flipped classrooms (Webster, Majerich, and Madden, 2016), flow experiments on pipes (Pal, 2019), the use of experimental tools to explore viscosity (Pérez-Sánchez, 2019), the use of interactive and engaging mI-PIV tools (Minichiello, et.al., 2021), the implementation of Project Based Learning (PBL) (Pérez-Sánchez & López-Jiménez, 2020), the use of Didactics games (Liuta, et.al., 2019), and the practice of critical thinking skills in fluid topics through Critical Thinking Activities (Cossu, Awidi & Nagy, 2024).

Learning in higher education exhibits distinct characteristics compared to learning in both elementary and secondary school. The type of the courses taught and the competency needs that must be reached substantially influence learning in higher education (Forest & Kinser, 2002). Based on the learning method, higher education employs an adult learning strategy known as andragogy (Rahmawati & Hiryanto, 2023). Ideally, with this approach at the initial meeting the lecturer explains what and how the course will be taught, and prepares various components of learning tools that will be used during the lecture process (Susanto et al., 2024). In addition, quality learning will occur if the learning process is carried out effectively, purposefully, and in accordance with the learning objectives to be achieved. One of the factors that can affect the learning process is the use of media in learning (Herlina, 2015). The selection of appropriate learning media must certainly be able to improve learning understanding for students in receiving the learning material provided (Septiani & Setyowati, 2020). As the available digital media, tools and services are subjected to a constant dynamic of change and renewal, it is hardly possible to come up with a uniform definition of media (Dolch, et.al., 2021; Topsümer, et.al., 2023).

The research on advancements in the field of fluid mechanics is still relatively sparse. Despite its critical importance in various engineering and scientific applications, there is a noticeable lack of comprehensive studies that address the latest developments and innovative approaches within this domain. This gap in research highlights the need for more focused investigations and publications to enhance our

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understanding of fluid dynamics and its applications. Increased scholarly attention could lead to significant advancements and a more robust body of knowledge in fluid mechanics.

Therefore, this study aims to fill this gap by conducting the systematic literature review of employing wind tunnel in Fluid Mechanics for science education based on the Scopus database from 2015 to 2024. The specific objectives of this analysis are: (1) to identify the growth, publication, and citation trends of employing wind tunnel as learning media over time; (2) to rank the most productive and influential countries, journals, authors, institutions and (3) to visualize the most frequently used keywords and the conceptual structure of employing wind tunnel in Fluid Mechanics using word-cloud and co-word network methods. This analysis will provide a comprehensive overview and insight into the current state and future research of employing wind tunnel in Fluid Mechanics for science education

METHOD

The study employs a bibliometric methodology to discover and map research patterns in the domain of epistemic identity. Research trends provide insights into the patterns and directions of future research (Mazov et al., 2020; Dogan, 2023). This bibliometric study utilizes databases from Scopus that have been extracted in RIS and BibTex formats.

The bibliometric analysis application utilizes R Studio and the Biblioshiny Program. An analysis is conducted in R Studio to examine annual scientific output, the journals with the highest productivity, the most often cited publications, the most influential authors, the most efficient countries, the most powerful institutions, keywords, trends in topics, co-authorship, and country-specific co-writing.

RESULT AND FINDINGS

The number of articles published each year on this theme tends to increase from 2015-2024. The number of documents published each year can be seen in Figure 1 below.

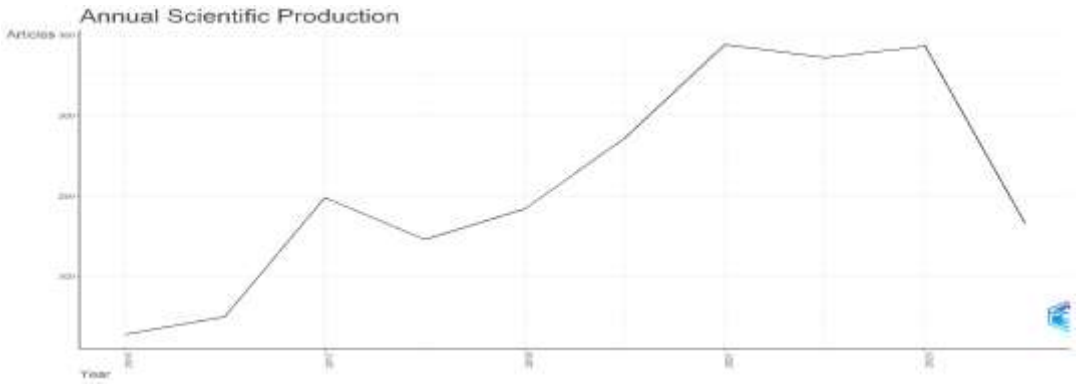

Figure 1. Annual Scientific Production

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Figure 1 shows that scientific production has increased almost every year from 2015-2024. The most scientific production was in 2021 with a total of 344 articles, in 2023 with 343 articles and in 2022 with 336 articles. This data shows that research with the keywords “wind tunnel” and “learning media” in general continues to increase.

Most Productive Journals

The most productive journals are those that consistently publish a significant number of high-quality scientific articles. These journals usually have a rigorous peer-review process and have a good reputation in the scientific community. The top ten journals published from 2015-2024 under this theme can be seen in Figure 2.

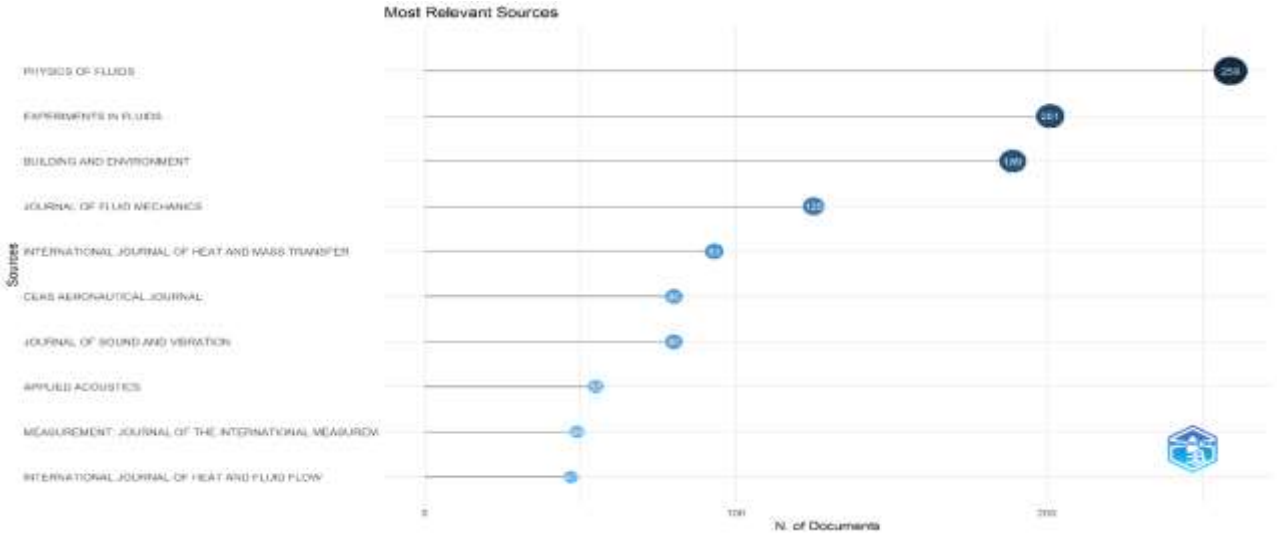

Figure 2. The Most Productive Journal

Based on Figure 2, Physics of fluids occupies the highest position of the top ten journals with articles totaling 259 documents or 9,98% of the total documents. The next sequence is Experiments in Fluids with 201 articles. The next is Building and Experiment with 189 articles. In full, the ten most productive journals on this theme from 2015-2024 can be seen in Table 1.

Most Cited Articles

The most cited articles are articles that are often used as references by other authors in their writings. These articles are usually of high quality and are considered a reliable source of information. The most cited articles from 2015-2024 in this theme with the keyword "wind tunnel" can be seen in Table 1.

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Table 1. Ten Most Cited Articles

No	Title	Author	Year	Total Citation	TC per year
1.	A wind tunnel study of effects of twisted wind flows on the pedestrian-level wind field in an urban environment	ZHANG X	2018	45	6,429
2	Predicting the influence of subtropical trees on urban wind through wind tunnel tests and numerical simulations	WANG J	2020	25	5
3	Modeling snowdrift on roofs using immersed boundary method and wind tunnel test	WANG J	2019	25	4,167
4	Design, validation, and benchmark tests of the aeroacoustics wind tunnel in sustech	LIU Y	2021	25	6,25
5	Turbine vane end wall film cooling with barchan-dune shaped ramp in a single-passage transonic wind tunnel	LIU Y	2020	22	4,4
6	Geometrically nonlinear aeroelastic stability analysis and wind tunnel test validation of a very flexible wing	LIU Y	2016	21	2,333
7	Measurements of the unsteady lift force on a 5:1 rectangular cylinder based on active-passive hybrid wind tunnel tests	LI S	2023	19	9,5
8	Measurements of the unsteady lift force on a 5:1 rectangular cylinder based on active-passive hybrid wind tunnel tests	LI X	2023	19	9,5
9	Differential-pressure fiber-optic airflow sensor for wind tunnel testing	LIU Y	2020	18	3,6
10	Wind tunnel measurement of aerodynamic characteristics of trains passing each other on a simply supported box girder bridge	LI X	2021	18	4,5

Recent studies utilizing wind tunnels have highlighted the significant impact of environmental factors on urban design and safety. One study examined how twisted wind flows affect pedestrian comfort in urban areas, emphasizing the necessity for urban planners to consider wind dynamics in their designs. Another article focused on the role of subtropical trees, revealing that tree canopies can effectively reduce wind speeds and alter flow patterns, thereby enhancing comfort and safety in densely populated spaces. Additionally, research on snow accumulation on roofs used wind tunnel tests to model snow drift patterns, providing valuable insights for architectural designs that mitigate structural risks in winter.

Innovative advancements in wind tunnel testing techniques have also emerged, particularly in the fields of aerodynamics and energy efficiency. A notable development is the aeroacoustics wind tunnel at Shenzhen University of Science and Technology (SUSTech), designed for advanced studies on aerodynamic noise and its implications for urban planning and transportation. Furthermore, research on turbine vane cooling demonstrated how a barchan-dune-shaped ramp can enhance cooling effectiveness, contributing to

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improved turbine performance. Additionally, studies on flexible wings and unsteady lift forces have deepened the understanding of aerodynamic performance, essential for modern aviation and civil engineering applications.

Technological advancements in wind tunnel instrumentation, such as the differential-pressure fiber-optic airflow sensor, have improved measurement accuracy in aerodynamic experiments. This innovation allows for more reliable data collection, enabling researchers to gain nuanced insights into fluid dynamics. Lastly, studies measuring the aerodynamic interactions of trains on bridges underscore the importance of considering airflow in railway engineering to optimize performance and safety during high-speed operations. Collectively, these findings emphasize the multifaceted applications of wind tunnel research across various disciplines, illustrating its importance in enhancing both safety and efficiency in urban and transportation design.

While the articles predominantly focus on the technical aspects of wind tunnels and their applications in various fields such as aerodynamics, structural engineering, and environmental studies, they do not specifically address the inclusion of wind tunnel studies in science education programs. However, the insights derived from these studies can significantly enhance educational curricula by providing practical applications of fluid dynamics and engineering principles. Incorporating wind tunnel experiments into science education could foster a deeper understanding of physical concepts and inspire future innovations in the field.

Most Influential Authors

The most influential authors are those with the most publications. A total of 6258 authors have been identified as having published articles in this topic. The ten most influential authors in this theme can be seen in Figure 3.

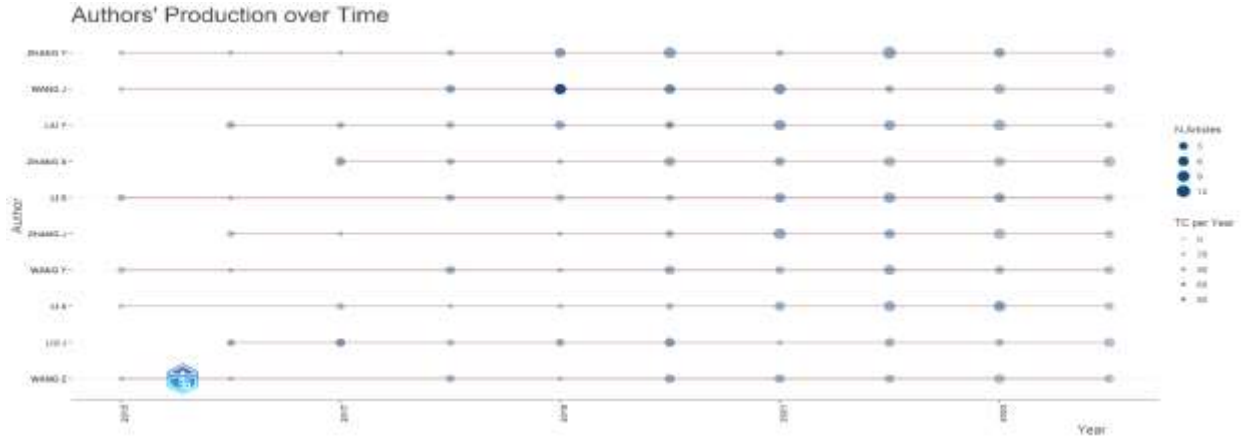

Figure 3. The Most Influence Author

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Figure 3 shows that from 2015 to 2024, a significant number of authors have contributed actively to the field of fluid mechanics, showcasing their research and findings in various publications. Among these authors, Zhang Y has been a prominent figure, consistently publishing insightful papers that delve into the complexities of fluid dynamics. Following closely are researchers such as Wang J, Liu Y, Zhang X, and Li S, each making notable contributions that advance our understanding of fluid behavior in different contexts. Their collaborative efforts and individual studies have enriched the academic discourse surrounding fluid mechanics, paving the way for future innovations and applications in the field.

Additionally, other influential authors like Zhang J, Wang Y, Li X, Liu J, and Wang Z have continued to build on the foundation laid by their predecessors. Their research spans a wide range of topics within fluid mechanics, from theoretical frameworks to practical applications in engineering and environmental science. The collective work of these researchers not only highlights the ongoing evolution of fluid mechanics as a discipline but also emphasizes the importance of interdisciplinary approaches in addressing complex challenges faced in real-world scenarios. Their active engagement in writing and publishing over the years reflects a dynamic and collaborative research environment that is essential for the growth and development of fluid mechanics.

The Most Relevant Institutions

The most influential institutions are those that publish the most articles in this theme. The ten most influential institutions can be seen in Figure 4.

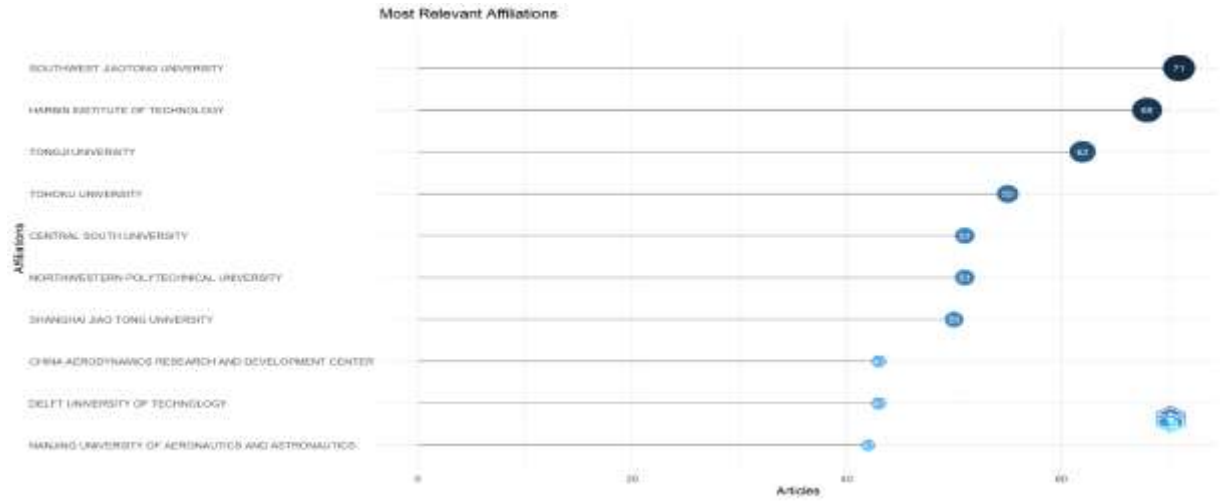

Figure 4. The Most Relevant Institutions

Figure 4 highlights the prominence of various institutions in publishing research on a specific topic, revealing that Southwest Jiaotong University leads with an impressive output of 71 articles. This substantial volume underscores the university's commitment to advancing knowledge in this field and indicates a robust

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research environment. The presence of numerous publications not only reflects the institution's dedication to scholarly work but also suggests that it has developed a strong academic community focused on this particular subject area.

Following closely is the Harbin Institute of Technology, which has published 68 articles, demonstrating its significant contribution to the discourse surrounding this topic. This positions Harbin Institute of Technology as a key player in the academic landscape, reinforcing its status as a leading research institution in China. Additionally, Tongji University ranks third with 62 articles, further illustrating the strength of Chinese institutions in this research area. The concentration of high publication outputs among these three universities indicates a collaborative and competitive atmosphere that likely fosters innovation and discovery.

The data further reveals that eight out of the ten most productive institutions are based in China, showcasing the country's substantial investment in research and development. This dominance in publication output suggests that Chinese researchers are prioritizing this topic, potentially due to its relevance to regional challenges or global scientific inquiries. In contrast, the other two institutions in the top ten are from Japan and the Netherlands, specifically Tongji University and Delft University of Technology, respectively. This international representation highlights a growing interest in the topic beyond China, indicating that while Chinese institutions lead in quantity, the global academic community is also engaging with this important research area.

Countries production over time

The productivity of a country is closely related to the productivity of individuals engaged in scientific activities, particularly academic authors and their institutional affiliations. In this context, researchers play a crucial role in making significant contributions to national development, whether through evidence-based policymaking or in strategic decision-making that supports progress across various sectors (Kern et al., 2019; Kaya et al., 2019; Schildkamp, 2019). To illustrate this, Figure 6 presents a list of the top countries with the highest scientific attributions based on the contributions of their authors.

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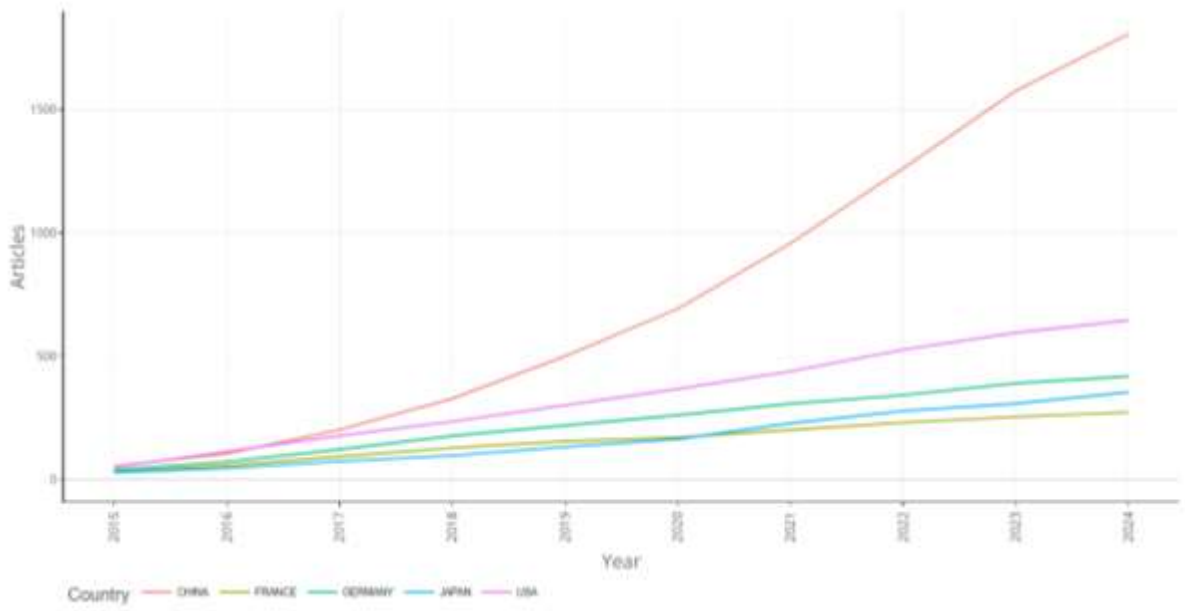

Figure 5.Countries Production Overtime

Based on the Figure 5 showing countries production over time, there is a clear trend in the increasing number of articles published by several countries from 2015 to 2024. China shows the most significant increase in scientific publications, with the graph rising sharply, especially after 2020. This increase positions China as the country with the highest article production, far surpassing other nations by 2024. Meanwhile, the United States (represented by the pink line) also experiences a significant rise, although at a slower pace compared to China. The number of articles from the USA continues to increase steadily each year, placing it second after China.

Countries such as Germany, Japan, and France show a slower increase in the number of published articles. Although there is growth, the publication output curve for these countries is flatter compared to China and the USA, indicating that their increase in publication volume is more moderate. This suggests that while these countries remain productive, their growth is not as rapid as the top two countries.

The gap in the number of articles published between China and other countries has widened since 2020, reflecting China's dominance in scientific productivity during this period. The USA maintains a strong second position with a stable number of publications, while countries like Germany, France, and Japan continue on a stable trajectory but with significantly lower production volumes. Overall, this graph demonstrates that China has experienced a remarkable surge in scientific publication productivity over the last decade, while other countries have seen more moderate increases.

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Most cited countries

The number of publications recorded from various countries has citation records obtained from each published article. The data regarding the countries with the most citations is presented in Figure 6.

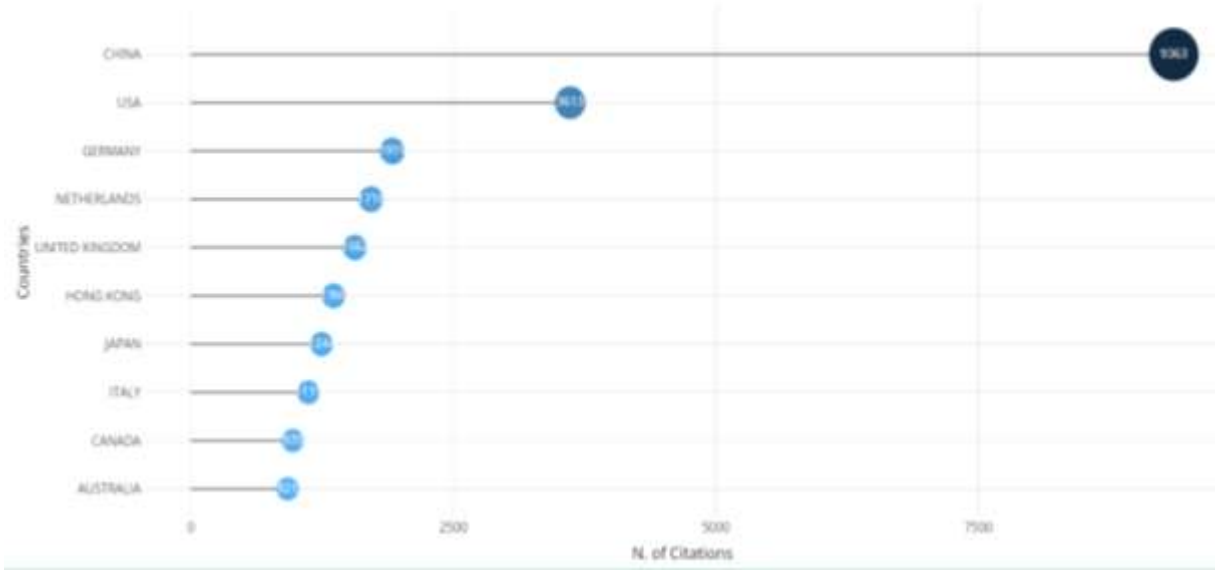

Figure 6. The Most Cited Countries

Based on Figure 6 presented, it is evident that China and the United States (USA) are the two countries with the highest productivity in terms of citation numbers in a particular field of study. China ranks first with a dominant number of citations, totaling 9,363. Meanwhile, the USA holds second place with 3613 citations, showing a significant gap compared to China. Other countries, such as Germany, the Netherlands, and the United Kingdom, follow in the next positions, with citation counts of around 1919, 1716, and 1562, respectively. Countries like Hong Kong, Japan, Italy, Canada, and Australia also contribute, but with lower citation numbers, ranging between 1360 and 921.

From this analysis, it can be concluded that research productivity, as measured by the number of citations, shows a considerable disparity between China and other countries. China is far more dominant in terms of citation numbers, which could indicate that research contributions from this country are more frequently referenced by other researchers. This may reflect China's strength and influence in certain fields of study. However, these figures only measure productivity based on citations, which may not directly reflect the quality or substantive impact of the research itself. It remains important to consider other factors, such as the quality of the research and the innovative contributions made by these countries.

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Most Relevant Words

Relevant terms are those that are most frequently utilized or closely related to the research topic being discussed or examined. The following presents a list of the most relevant words that are most commonly used within the topic as shown in Figure 7.

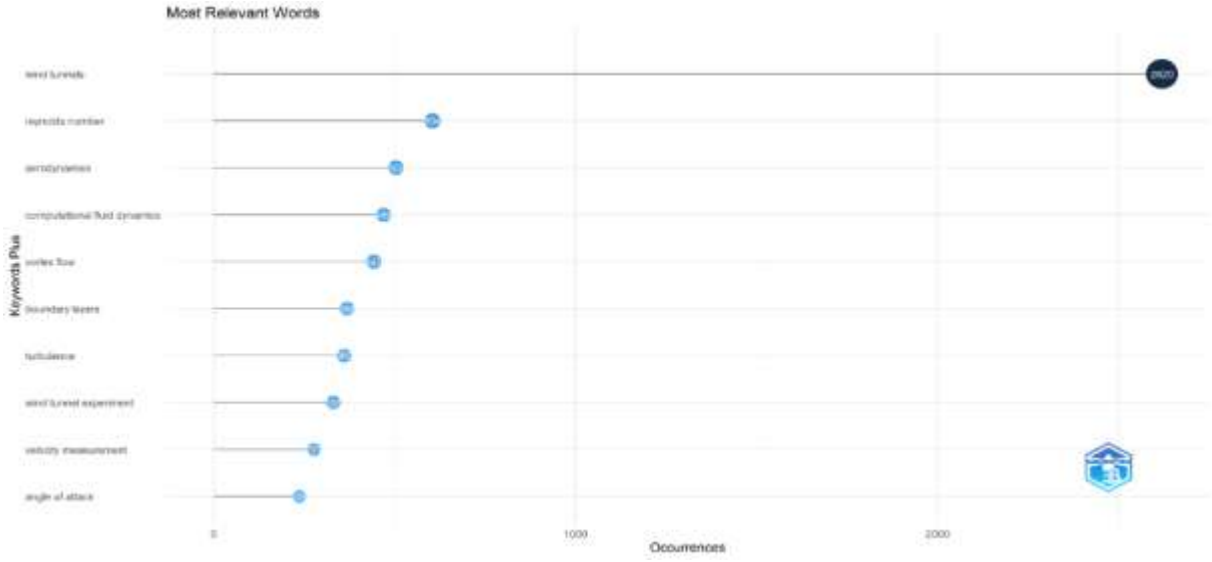

Figure 7. The Most Relevant Words

Figure 7 provide information regarding the words most relevant words. Based on this figure, the most frequently occurring keyword is wind tunnels, with 2,620 occurrences, indicating that wind tunnels are the most mentioned and possibly the most important topic in the analyzed data, likely in the context of experiments or simulations in fluid dynamics. In second place, Reynolds number appears 804 times. This is an important dimensionless quantity in fluid dynamics used to predict flow patterns in various fluid flow situations. Aerodynamics appears 503 times, referring to the study of the properties of moving air and its interaction with solid bodies, such as aircraft or vehicles. Next, Computational Fluid Dynamics (CFD) appears 469 times, which is a widely used computational method for analyzing fluid flows. Vortex flow, with 142 occurrences, represents a flow where the fluid moves in a circular or swirling pattern, common in studies of aerodynamics or fluid simulations. Boundary layers, appearing 366 times, describe the thin layer of fluid at the boundary of a solid object, where friction significantly affects fluid motion.

Additionally, turbulence, which appears 360 times, refers to chaotic and irregular fluid motion, a major area of study in fluid dynamics and aerodynamics. Wind tunnel experiment appears 131 times, referring to practical experiments conducted in wind tunnels, which are often used to study fluid dynamics and aerodynamic properties. Velocity measurement, with 277 occurrences, refers to techniques for measuring the speed and direction of fluid flow. Finally, angle of attack, appearing 236 time.

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From this analysis, it can be concluded that wind tunnels dominate the occurrences, showing they are a critical aspect of the research. Other high-frequency keywords such as Reynolds number, aerodynamics, and CFD reflect essential concepts in fluid dynamics and aerodynamic analysis. Phenomena such as vortex flow, boundary layers, and turbulence also emerge as important topics in the study of fluid mechanics. The chart highlights both experimental and computational techniques, such as wind tunnel experiments and velocity measurement, indicating a balance between theoretical and practical approaches in this research. The presence of keywords like angle of attack also suggests that part of the research may be directed towards aerodynamics in aviation, aerospace, or automotive fields, focusing on lift, drag, and flow separation.

Topic Trend Analysis

Trend analysis reveals a logarithmic frequency of various keywords utilized in publications (Lu et al., 2021). This analysis provides insights into the evolving landscape of research topics and their prominence over time. The distribution and frequency of these keywords can significantly influence the direction of future studies and highlight areas that may require further exploration. The topic trend analysis can be observed in the following Figure 8.

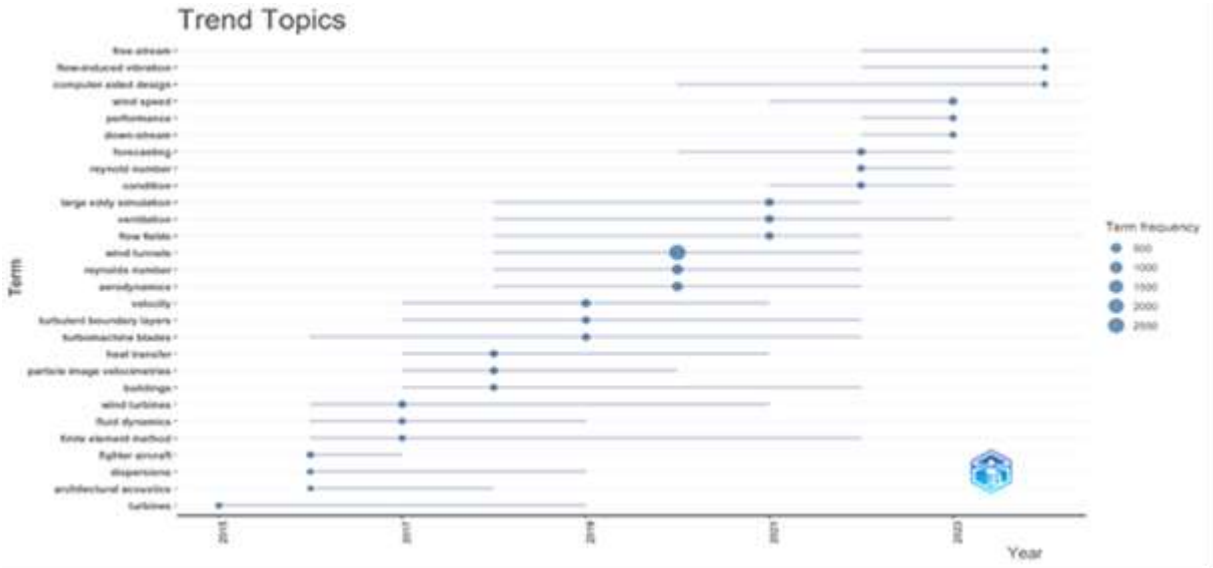

Figure 8. Trend Topic Analysis

Figure 8 illustrates the frequency of keywords used in the literature, highlighting that terms such as 'wind tunnel' (2620 occurrences), 'Reynolds number' (604 occurrences), and 'aerodynamics' (503 occurrences) have been frequently cited. Notably, the keyword 'wind tunnel' has remained in use up until 2022 but has not been referenced this year. In contrast, several keywords continue to be actively utilized in current research, including 'chemistry,' 'computer-aided design,' 'flow-induced vibration,' and 'free stream.'

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The emergence of keywords such as "chemistry," "computer-aided design," "flow-induced vibration," and "free stream" indicates an evolving academic landscape that embraces interdisciplinary approaches and the integration of modern technology in research.

This shift has important implications for the design of future educational materials in the field of fluid mechanics, particularly within science education programs. As these newer topics gain relevance, it will be essential to develop instructional resources that not only cover traditional concepts but also incorporate current trends and interdisciplinary connections. By integrating these contemporary topics into the curriculum, educators can enhance students' understanding of fluid mechanics, making the subject more engaging and relevant to real-world applications. Such an approach will not only enrich the educational experience for students in science programs but also better prepare them for future challenges in the rapidly evolving fields of engineering and technology.

Co-authoring by authors

Co-authoring by authors refers to the collaborative process of writing articles by two or more individuals, contributing their expertise and insights to produce a cohesive piece of research. This collaborative approach not only enhances the quality of the work but also encourages diverse perspectives, fostering a richer understanding of the subject matter.

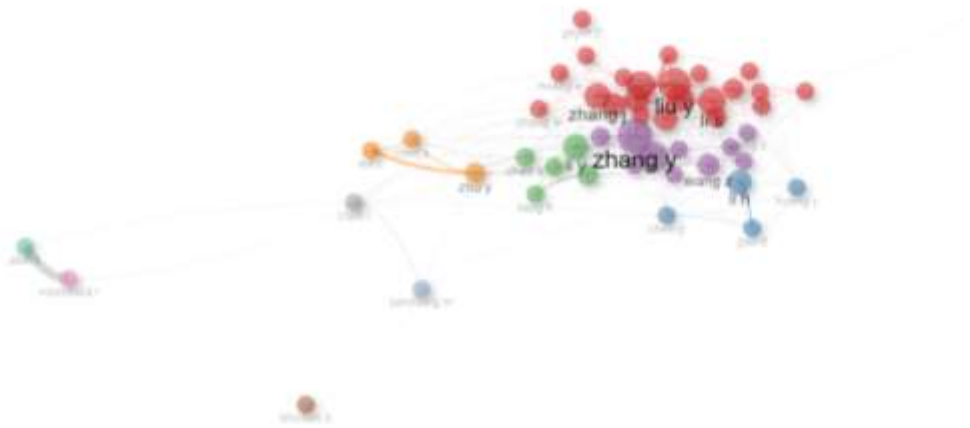

Figure 9. Co-authoring by author

Figure 9 illustrates the various collaborators or co-authors involved in this thematic area, highlighting their contributions and the interconnectedness of their work. The dynamics of co-authorship reflect a

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growing trend in academic research, where teamwork and collaboration are essential for addressing complex issues and advancing knowledge across disciplines.

Countries' Collaboration World Map

The Countries' Collaboration World Map represents a visual tool designed to illustrate the collaborative relationships between various countries across the globe. This type of map serves as a powerful means of conveying complex data about international partnerships, research collaborations, trade agreements, or any other forms of cooperation among nations.

Figure 9. Countries collaboration world map

Currently, there is a noticeable gap in the literature concerning wind tunnels and computational fluid dynamics (CFD) from Indonesian authors. Despite the global advancements and significant research in these fields, Indonesian scholars have not yet contributed extensively to the body of knowledge surrounding these crucial areas of study. The absence of published works in these fields by Indonesian authors presents an opportunity for researchers to explore and document findings relevant to the local industry and academic landscape. Engaging in these areas could foster collaboration with international experts and elevate the status of Indonesian research on a global scale.

Based on the analysis of the provided data, it can be concluded that scientific production in the field of fluid mechanics, particularly relating to wind tunnels and learning media, has shown a significant upward trend from 2015 to 2024. The peak in publications in recent years indicates a growing interest and relevance in these topics, suggesting that they are at the forefront of current research. Notably, journals such as Physics of Fluids and Experiments in Fluids have emerged as key contributors to this academic discourse, underlining their importance in disseminating high-quality research.

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Additionally, the data highlights influential authors and institutions, predominantly from China, who are leading the charge in this area, while also revealing the disparity in publication output between different countries. The increase in interdisciplinary keywords such as "chemistry," "computer-aided design," "flow-induced vibration," and "free stream" reflects a shift toward incorporating modern technological advancements and broader applications of fluid dynamics.

For the design of future educational materials within science education programs, particularly in fluid mechanics, it is essential to integrate both traditional principles and these emerging interdisciplinary topics. This approach will not only enhance students' engagement but also provide them with a comprehensive understanding of fluid mechanics as it relates to real-world applications, preparing them for future challenges in engineering and technology. Furthermore, the identified gap in contributions from Indonesian authors in this field presents an opportunity for local researchers to collaborate internationally, enriching the academic landscape and increasing the visibility of Indonesian research on a global scale.

While the findings demonstrate a robust increase in publications and citations, they are primarily limited to articles focusing on wind tunnels and related technologies. The emphasis on technical applications often overshadows the pedagogical aspects of incorporating these studies into educational programs. Moreover, the lack of substantial contributions from Indonesian authors in these domains highlights a gap that could restrict local advancements in fluid dynamics research. The analysis may also overlook emerging interdisciplinary connections that could enrich the topic further.

CONCLUSION

The analysis of scientific production from 2015 to 2024 indicates a consistent increase in research output related to "wind tunnel" and "learning media." The data reveals that China leads in both publication and citation metrics, significantly influencing the global academic landscape. High-impact journals such as Physics of Fluids and Experiments in Fluids dominate the field, contributing to the evolving discourse on aerodynamics, structural engineering, and environmental studies. The most cited articles emphasize the practical applications of wind tunnels in urban design and energy efficiency, showcasing their relevance across disciplines. Notably, the insights gleaned from these studies can inform the development of educational curricula in science programs, particularly in fluid mechanics, where integrating contemporary research trends can enhance student engagement and understanding.

The trends observed in this analysis suggest several implications for future research and educational practices. Firstly, there is a pressing need to bridge the gap between technical research and its application in science education. Educational resources should evolve to reflect contemporary topics such as computational fluid dynamics and their implications for real-world scenarios. By integrating these elements into curricula,

educators can foster a deeper understanding of fluid mechanics among students and stimulate interest in engineering fields. Furthermore, Indonesian researchers are encouraged to engage with international collaborations in wind tunnel studies, contributing to the global discourse and enhancing their own academic contributions. Such efforts could ultimately lead to a more comprehensive understanding of fluid dynamics in both local and international contexts.

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