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Fluid Mechanics Education in Engineering: Challenges and Trends from a Bibliometric Analysis

Gokhan Yildirim[1,2], Xiao Pan[1], Ataur Rahman[1,*]
[1]School of Engineering, Design and Built Environment, Penrith Campus, Western Sydney University, Building XB, Kingswood, NSW 2751, Australia
[2]Department of Environmental Engineering, Faculty of Engineering, Aksaray University, Aksaray, 68100, Turkiye
* Corresponding author's E-mail: a.rahman@westernsydney.edu.au

Abstract

This study explores the challenges and trends in engineering fluid mechanics education through a bibliometric analysis of literature from Scopus spanning from 1978 to 2024. The analysis aims to identify key themes, prevailing challenges, effective methodologies, and emerging trends in this field. The results highlight "fluid mechanics," "engineering education," and "students" as the most interconnected and frequently occurring topics, underscoring their central importance. Engineering dominates the field with 51.8% of the total documents, followed by contributions from social sciences (17.3%) and computer science (10.1%). Geographically, the United States leads with 795 publications and a total citation count of 571, followed by significant contributions from China (90 publications), Portugal (70), Spain (60), Germany (32), and Australia (31). The document types include 342 conference papers (67.5%) and 131 journal articles (25.8%), reflecting diverse dissemination of research findings. Innovative pedagogical approaches, such as active learning and e-learning, are emphasized for their potential to address educational challenges. The findings provide valuable insights for educators and researchers aiming to improve teaching methodologies and curricula, ultimately enhancing student learning outcomes and better preparing future engineers for professional challenges.

Keywords: Fluid mechanics, engineering education, bibliometric analysis, active learning, e-learning

INTRODUCTION

Engineering education, particularly in specialized fields such as fluid mechanics, presents unique challenges and opportunities for educators and students alike. Fluid mechanics, as a foundational subject within various engineering disciplines, requires a robust understanding of both theoretical concepts and practical applications. However, the pedagogical approaches to teaching this subject have often been met with difficulties in terms of student engagement, comprehension, and application of knowledge. Fluid mechanics is one of the oldest branches of physics, and the literature on this subject is vast and complex. Despite its significance, fluid mechanics has not sufficiently captured the interest of Science, Technology, Engineering and Mathematics (STEM) educators compared to other subjects such as quantum mechanics (Vaidya, 2020). This gap highlights the need for innovative and effective teaching methodologies that can engage students and enhance their understanding of complex fluid dynamics concepts. Previous studies have highlighted several challenges in engineering education, such as the need for improved student engagement, the integration of technology in teaching, and the development of curricula that balance theory and practice (Felder & Brent, 2005; Prince, 2004). In fluid mechanics, these challenges are compounded by the abstract nature of the subject and the complexity of the mathematical models involved. To address these issues, various innovative pedagogical approaches

have been proposed and implemented. Techniques such as active learning, flipped classrooms, and the use of simulation tools have shown promise in enhancing student understanding and retention (Bishop & Verleger, 2013; Freeman et al., 2014; Rahman, 2017). Additionally, project-based learning and the integration of virtual labs have been explored as means to provide hands-on experience in a controlled, virtual environment (De Jong, Linn, & Zacharia, 2013).

Vaidya (2020) also emphasizes the interdisciplinary nature of fluid mechanics, which is taught across various science departments including physics, mathematics, environmental sciences, and engineering, each highlighting different aspects and applications of the subject. Despite these advancements, there remains a significant gap in understanding the overall trends, patterns, and key themes within the literature on fluid mechanics education. This study aims to fill this gap through a comprehensive bibliometric analysis, following the methodological workflow proposed by Zupic and Čater (2015). By analyzing data collected from Scopus, this research seeks to identify the prevailing challenges, effective methodologies, and emerging trends in the field of fluid mechanics education. The insights gained from this analysis will not only contribute to the existing body of knowledge but also provide valuable guidance for educators and researchers striving to improve the quality of engineering education. Ultimately, the goal is to enhance student learning outcomes and better prepare future engineers for the complex problems they will face in their professional careers.

DATA AND METHODS

A standard workflow for science mapping in bibliometric analysis involves five stages: (1) defining the research aim, (2) collecting data, (3) analyzing data, (4) visualizing results, and (5) interpreting findings.

1. *Defining the Research Aim:* The primary objective of this study is to explore the challenges in Engineering Fluid Mechanics education by examining the relevant literature.
2. *Collecting Data:* Data was gathered from Scopus using a carefully constructed query designed to capture publications related to fluid mechanics education, while excluding irrelevant topics.
3. *Analyzing Data:* The collected data was subjected to various bibliometric analyses to identify trends, patterns, and key themes within the literature.
4. *Visualizing Results:* The results of the analysis were visualized using appropriate tools to provide clear and insightful representations of the data.
5. *Interpreting Findings:* Finally, the visualized data was interpreted to derive meaningful conclusions and insights into the challenges faced in fluid mechanics education.

The query used to capture the challenges in Engineering Fluid Mechanics education is presented below:
Inclusion Criteria:

- *"fluid mechanics" AND education*: Ensures the core focus is on fluid mechanics education.
- *(student OR teaching OR learning OR challenges OR methods OR technology OR pedagogy OR engagement OR "curriculum development" OR "online learning" OR "virtual labs" OR "interactive teaching" OR "project-based learning" OR "inquiry-based learning" OR "flipped classroom" OR "active learning" OR simulation OR "educational software" OR "learning management systems" OR "remote labs"):* Captures a wide range of educational challenges and methods relevant to fluid mechanics.

Exclusion Criteria:

- *NOT (flow OR biology OR entropy OR thermodynamic* OR cardiovascular OR dredg* OR bioc* OR "fluid power" OR coastal)*: Excludes topics that are not relevant to educational challenges in fluid mechanics.

Language Limitation:

- *LIMIT-TO (LANGUAGE, "English")*: Ensures that only English language documents are included.

RESULTS AND DISCUSSION

Our dataset spans from 1978 to 2024, encompassing 170 sources and 507 documents. The annual growth rate of the dataset is 5.9%, with an average of 5.98 citations per document. The document types include 342 conference papers (67.5%), 131 journal articles (25.8%), 10 conference reviews (2%), 8 books (1.6%), and other types making up 3.2%. In addition, Figure 1 illustrates distribution of documents by subject area and publications over time. Figure 1a illustrates the disciplinary distribution of the documents. Engineering dominates the field, accounting for 51.8% of the total documents, highlighting its central role in the engineering fluid mechanics teaching research landscape. Social Sciences follow with 17.3%, indicating significant interdisciplinary interest and contributions. Other notable disciplines include Computer Science (10.1%), Chemical Engineering (3.9%), Physics and Astronomy (3.4%). Figure 1b shows that there is a noticeable increase in publications starting in the early 2000s, peaking around 2003 and showing periodic fluctuations since then. The overall trend indicates a growing interest and sustained research activity in this area over the past few decades, with significant peaks around 2003, 2008, and 2018.

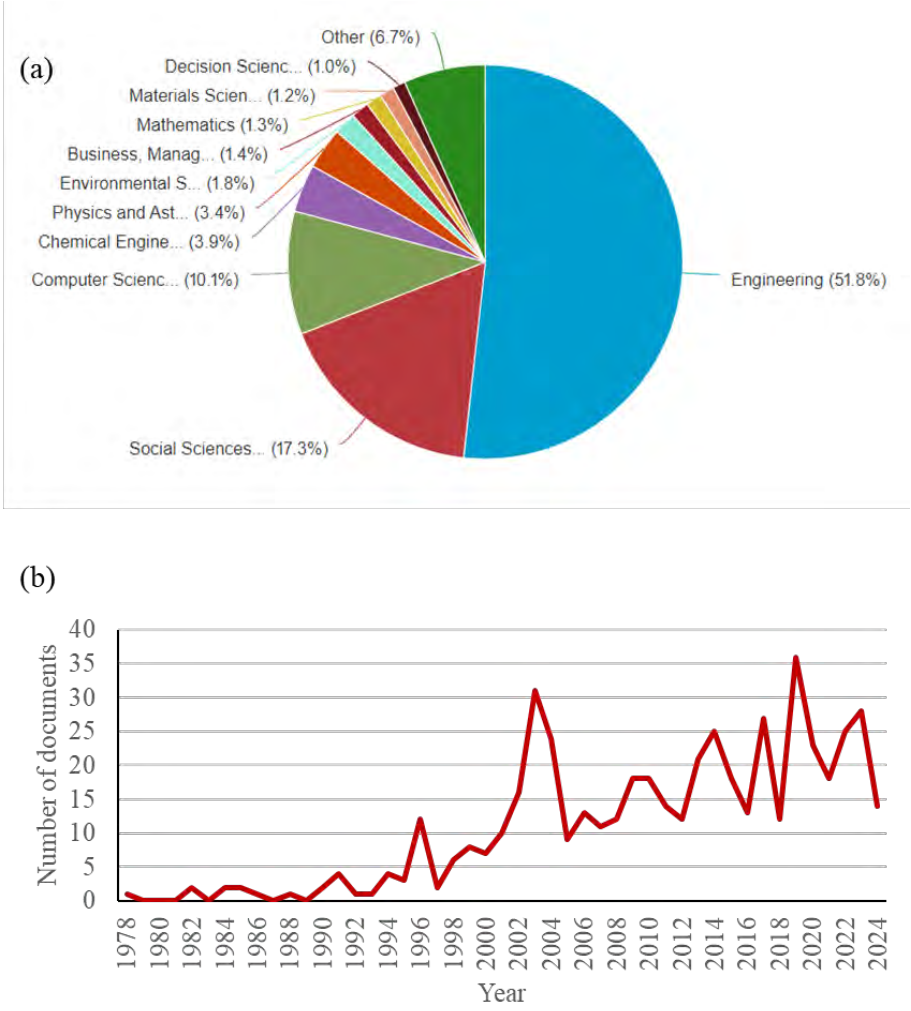

Figure 1 (a) Documents by subject area and (b) number of documents per year between 1978 and 2024

The network visualization highlights "engineering education," "teaching," and "fluid mechanics" as central themes with strong interconnections among various related topics. Different colored clusters represent distinct areas of focus, such as education methodologies, technical subjects, and curricula, showing the breadth and interrelated nature of discussions in engineering education.

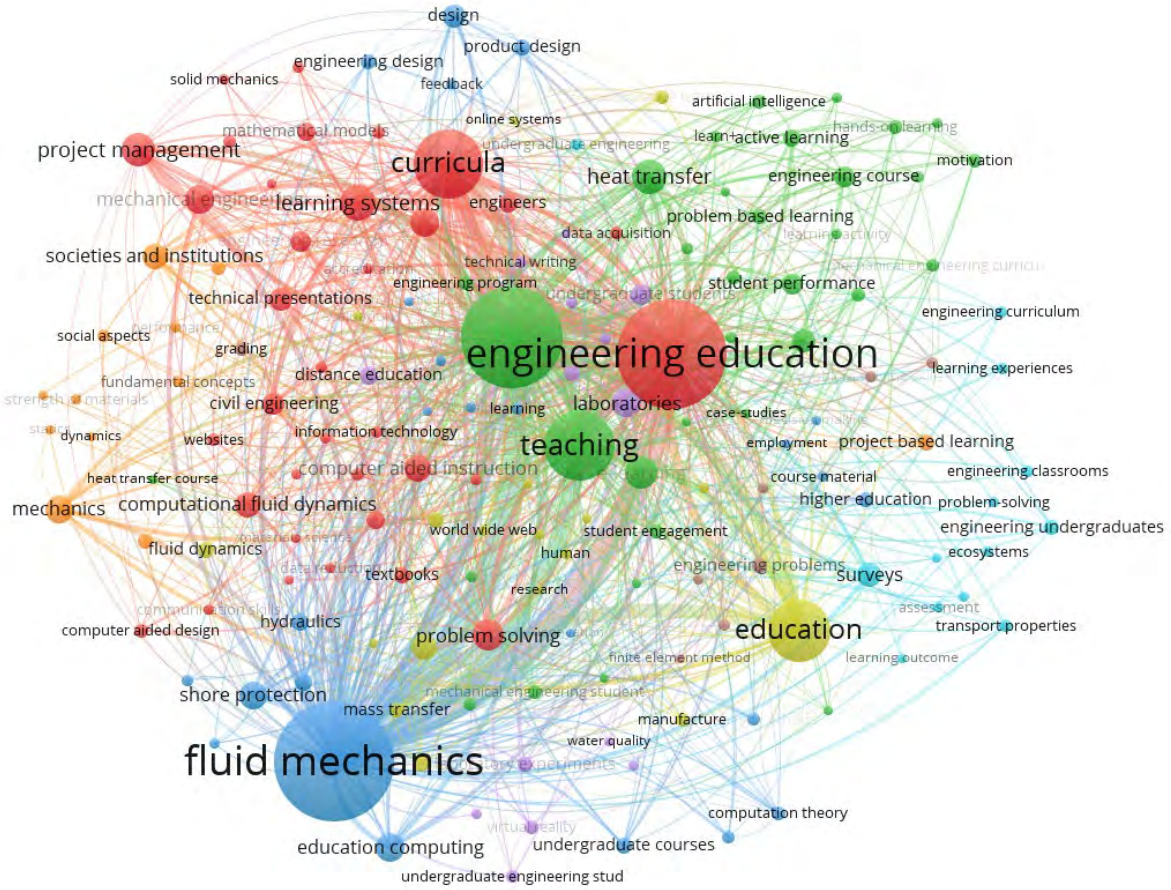

Figure 2 Co-occurrence analysis based on all keywords (Author keywords and keyword plus)

The keyword co-occurrence analysis (Table 1) identifies "fluid mechanics," "engineering education," and "students" as the most interconnected and frequently occurring topics, underscoring their central importance in the dataset. These themes, along with "teaching" and "curricula," form distinct clusters, illustrating the relationships and trends within the research field. "Fluid Mechanics" and "Engineering Education" are particularly influential terms, each with 157 links and total link strengths of 2353 and 2132, respectively, highlighting their pivotal roles in the research landscape. The average publication year for these keywords is around 2011, with moderate average citation rates, indicating their sustained relevance over time. Other notable keywords, such as "Students" and "Teaching," maintain significant link strengths despite fewer occurrences, reflecting their critical roles in educational methodologies and student engagement in engineering education. Additionally, "E-learning" is notable with an average publication year of 2018, pointing to its emerging importance and growing impact in the field. The average publication year and citation metrics for these keywords further highlight the evolution and impact of these research topics over time.

Table 1 Keywords co-occurrence analysis (Author keywords and keyword plus)

Rank	Keywords	Cluster	Links	Total link strength	Occurrences	Average pub. year	Average citations
1	Fluid mechanics	Blue	157	2353	394	2011.8	6.4
2	Engineering education	Red	157	2132	338	2010.8	6.8
3	Students	Green	158	1997	294	2012.5	5.1
4	Teaching	Green	151	1143	155	2010.5	4.9
5	Curricula	Red	151	1093	149	2010.7	4.9
6	Education	Yellow	133	797	124	2011.9	4.6
7	Learning systems	Red	88	320	48	2008.4	4.4

8	Heat transfer	Green	94	352	46	2012.3	3.8
9	Project management	Red	77	288	43	2006.3	3.8
10	E-learning	Green	78	290	40	2018.9	3.6
11	Problem solving	Red	80	271	39	2007.5	5.4
12	Laboratories	Purple	71	235	34	2011.9	6.2
13	Professional aspects	Red	86	271	34	2008.5	2.0
14	Mechanical engineering	Red	61	208	32	2004.5	6.4
15	Education computing	Blue	76	220	32	2016.1	2.1

Some recent trending keywords (not shown in the table) are as follows: learn+ (n=7, year=2022.7), problem-solving (n=6, year=2022.7), online learning (n=5, year=2021.4), active learning (n=14, year=2019.6), artificial intelligence (n=10, year=2018.7).

Figure 3 illustrates the global distribution of scientific production in the field of engineering fluid mechanics education, highlighting the contributions from various countries. The United States leads with the highest number of publications (795), showcasing its dominant role in this research area. China follows with 90 publications, indicating significant contributions as well. Other notable contributors include Portugal (70), Spain (60), Germany (32), and Australia (31), reflecting active research communities in these countries. Figure 3 emphasizes the widespread global interest and research activity in engineering fluid mechanics education, with significant contributions from North America, Europe, Asia, and Australia.

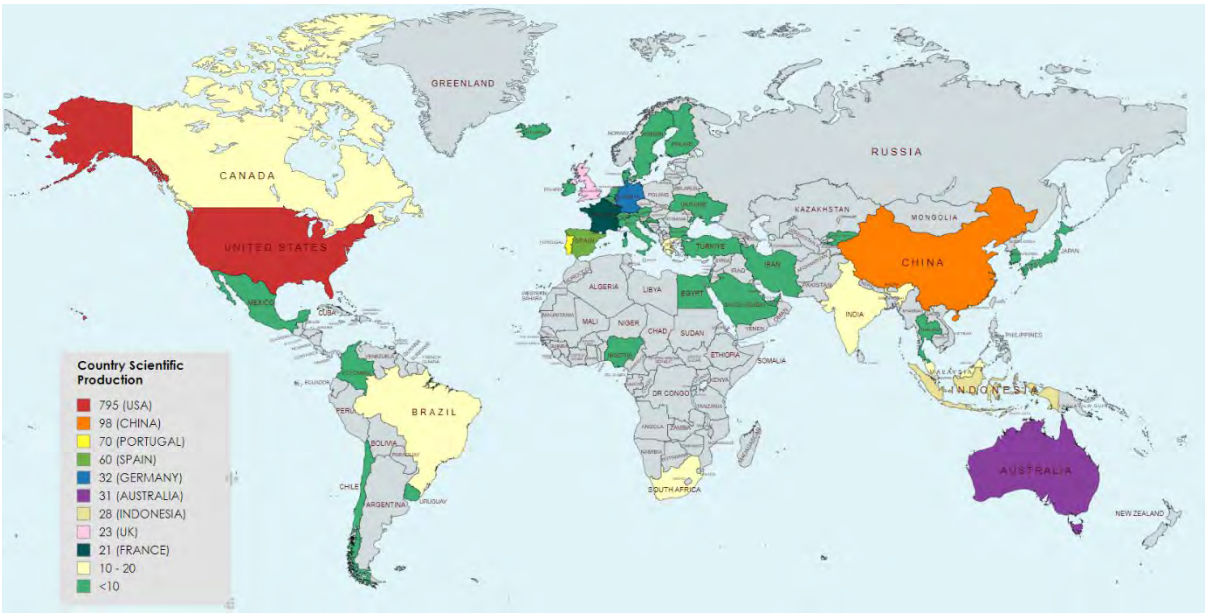

Figure 3 Country-wise Scientific Production

Table 2 highlights the United States as the most productive country in engineering fluid mechanics education, with 61 articles and the highest total citations (571), indicating a significant influence. China, while the second most productive country with 17 articles, has a relatively low average citation count of 1.3, suggesting a less impact per article. Notably, Australia and India, despite having fewer articles (5 and 4, respectively), exhibit high average citation counts (21.2 and 25.8), pointing to substantial impact per publication. The United Kingdom and Portugal also stand out for their balanced productivity and moderate citation impacts, reflecting their important contributions to this field.

Table 2 The most productive (based on corresponding author) and the most cited countries

Rank	Country	Articles	Articles %	SCP	MCP	TC	AAC
1	USA	61	12	58	3	571	9.4
2	China	17	3.4	16	1	22	1.3
3	Spain	11	2.2	10	1	52	4.7
4	Portugal	8	1.6	6	2	48	6
5	Germany	7	1.4	7	0	19	2.7
6	Australia	5	1	5	0	106	21.2
7	United Kingdom	5	1	4	1	62	12.4
8	India	4	0.8	3	1	103	25.8
9	Turkey	4	0.8	3	1	24	6
10	Canada	4	0.8	4	0	23	5.8
11	Indonesia	4	0.8	4	0	10	2.5

*SCP and MCP are single and multiple country publications, respectively. TC is total citations. AAC is average article citations.

Figure 4 illustrates a three-field plot, featuring sources on the left, countries in the center, and authors on the right. This visual representation highlights the relationships between these elements, using rectangular shapes in various colors to denote significant components. The diagram effectively shows the flow, connections, and transitions between sources, countries, and authors.

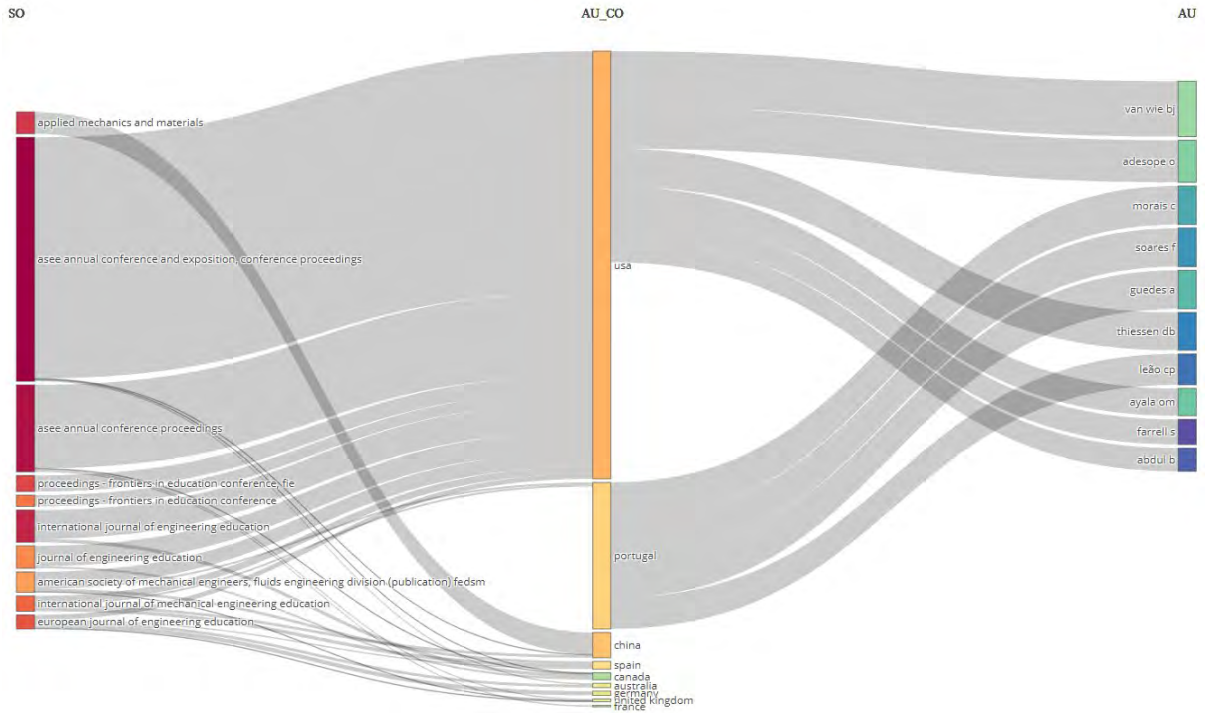

Figure 4 The Sankey diagram of sources, countries and authors.

Figure 4 shows that the United States is the leading contributor to research in engineering fluid mechanics education, with strong connections to major publication sources such as "Applied Mechanics and Materials" and "ASEE Annual Conference and Exposition, Conference Proceedings." Portugal and China also make notable contributions but are less interconnected compared to the USA. Key authors like Van Wie BJ and Adesope O are prominently linked to the USA, highlighting their significant impact in the field. The diagram underscores the dominant role of the USA in both publication volume and influential authorship, while also reflecting the important contributions from other countries and key conferences and journals.

CONCLUSION

This study aimed to explore the challenges and trends in engineering fluid mechanics education through a comprehensive bibliometric analysis. Our findings identified "fluid mechanics," "engineering education," and "students" as the most interconnected topics, highlighting their central importance. The disciplinary distribution indicates engineering's dominance, with significant contributions from social sciences and computer science, emphasizing the field's interdisciplinary nature. Geographically, the United States leads in publications and citation impact, showcasing its dominant role, followed by notable contributions from China, Portugal, Spain, Germany, and Australia. The document types are diverse, with conference papers and journal articles being predominant, reflecting the dynamic dissemination of research findings. Our results underscore the importance of innovative pedagogical approaches, such as active learning and e-learning, in addressing educational challenges. These insights can guide educators and researchers in improving teaching methodologies and curricula, ultimately enhancing student learning outcomes and better preparing future engineers for complex professional challenges.

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