



Trends of Physics Education Research on The Topic of Mechanics: A Bibliometric Analysis

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ABSTRACT

This study aims to map the publication trends of international journal articles related to the topic of mechanics in physics education using bibliometric analysis of the Scopus database. Bibliometric analysis was conducted on the Scopus database with the help of the RStudio application with the biblioshiny package. We analyzed 196 relevant documents filtered with various settings that support the research objectives. The analysis showed a rapid increase in the number of publications on mechanics in physics education since the 2000s (102 articles recorded in 2012–2021), driven by the development of quantitative methods. Physics Education, Physics Teacher, and Revista Brasileira de Ensino de Fisica were the journals with the most contributions. Active author mapping identified Pendrill A-M, Fones SW, and Rieber LP as the most prolific, while citation and h-index analyses showed the work of Rieber LP, Rodrigues H, Adams DM, and Gauld C as the most influential. Geographically, the United States, Brazil, and China dominated publications, with limited international collaboration. This study provided a comprehensive profile of mechanical research trends in physics education to guide future development efforts.

INTRODUCTION

Mechanics was a fundamental branch of physics that was very important to acquire. Mechanics was an important foundation when studying physics [1], as mastery of the principal concepts of mechanics, such as Newton's laws, energy, and momentum, enables a deep understanding of the principles of physics and their application in new contexts [2]. Since the ancient Greeks, mechanics has played a major role in the development of science [3]. In mechanics, many quantities related to mechanical phenomena are easily measurable.

No matter how complicated it may seem to express its qualitative aspects, whether it was the change in the shape of clouds, waterfalls, or the deformation and resistance of elastic bodies, with the help of

mechanics, we could know how to define these things with the help of numbers to calculate their movements, resistance, and deformation [4]. Such was the importance of mechanics that, in recent years, it has been important to introduce the basic concepts of the topic [5]. Although the application of mechanics in everyday life and physics learning were so important, there were still problems that occurred that were still being investigated by physicists.

In the application of mechanics in physics learning, significant challenges persist, particularly due to the abstract nature and complexity of its concepts. Students often struggle to comprehend mechanical principles [6], a difficulty that stems from the high level of causal reasoning required in this field. This challenge is especially pronounced for students with low causal thinking abilities. Besson in 2004 [7] highlighted that causal explanations, often conceived as ‘mechanisms’ accounting for physical transformations, are strongly present in common reasoning. However, there’s often a disconnect between this common causal reasoning and scientific usage, which can impede learning. Within the broader goals of physics education—specifically, developing scientific reasoning (Group A) and equipping students with methods to generate knowledge through empirical experience (Group B) [8]—mechanics plays a crucial role. It enables students to describe phenomena using physical principles, explain causal relationships, and apply mathematical tools to solve quantitative problems. Ding in 2014 [9] found that Reasoning skills and pre-instructional epistemology significantly influence student conceptual learning gains in physics. This underscores the importance of addressing not just content, but also students’ reasoning abilities and beliefs about scientific knowledge. The application of scientific principles, such as Archimedes' principle, requires a facilitation process that extends beyond mere content delivery. It involves addressing students’ personalities, making the learning experience more holistic and meaningful. White in 1993 [10] demonstrated that even younger students (sixth graders) can learn basic physical concepts and models given appropriately designed instruction, challenging the notion that formal operational thinking is a prerequisite for learning physics. By combining this approach with well-structured content, carefully selected contexts, and innovative tools like computer microworlds, educators who understand both the methods (knowing how) and the purposes (knowing why) of science education can create enjoyable and engaging lessons. This approach, grounded in research-based and evidence-based practices, has been shown to enhance the effectiveness of science education [11], potentially bridging the gap between common causal reasoning and scientific understanding in mechanics. However, the challenges in mechanics learning extend beyond this initial hurdle.

Despite these efforts, students’ misunderstanding of fundamental mechanical concepts remains a pervasive issue across learners in this domain. Students’ misunderstanding of the concept of gradual mechanics was a universal pattern among students in this mechanics topic [12] [13]. In addition, when Newton first formulated his laws of motion, which have been of particular interest to leading physicists and philosophers over the past two centuries, there was still wide disagreement over what was stated and its logical status [14]. Furthermore, the problem of irreversibility in classical mechanics became a well-known problem among physicists and is very important in elementary physics [15]. So that several researchers discussed this problem [16] [17] [18] [19] [20] [21] [22] [23] [24] [25] [26] [27]. Therefore, given some of the problems that have been found, it was important to find a solution. One of the efforts in solving the problem was the concept that learning mechanics must use the right strategy so that the results were also more effective [28], as well as several other problems. Given the complexity of the identified issues, it is imperative to continue seeking innovative solutions, particularly in light of children’s cognitive development at an early age.

In this context, it is essential to recognize that children aged 5 to 9 are at a developmental stage where they begin to grasp basic physical concepts and cultivate problem-solving skills. During this period, it allows them to explore physics concepts through play with existing objects, such as magnets, forces, energy, throwing, and simple machines, which could potentially lead to learning in STEM subjects [29]. In this approach, such as using structured schemes to analyze mechanical problems, can enhance students’ problem-solving skills while also encouraging a deeper understanding of the subject [30].

However, it is important to remember that perceptions and understandings of physics concepts can vary greatly between teachers and students. For example, let us take a moment to reflect: “What is the definition of force?” Try to look at this question from the perspective of a physics teacher, and then from the perspective of a 12-year-old student, the difference is very noticeable [31]. Awareness of these differing perspectives is crucial in designing effective and relevant teaching approaches for students of various ages and levels of understanding, while simultaneously driving advancements in physics education research.

In line with these developments, mechanics has long been a focal point of physics education research, leading to the development of diverse innovative approaches to address the challenges in learning mechanical concepts. In response, many previous studies have proposed analytical and numerical approaches to solve problems related to mechanics [32] [33]. Among them was the use of Scilab software that effectively solves classical mechanics problems; in its application, it was able to simulate bullet motion by combining equations in kinematics and dynamics and then visualizing in graphical form [34]. In line with this, research with a modeling and simulation program called STEPP (Scaffolded Training Environment for Physics Programming) was designed to train students to analyze a physical system into variables such as time, position, and velocity and then use these variables to define states (such as running a marathon) and transitions or changes between states of the system (such as crossing the finish line) [35]. In addition, a study by designing and implementing physics learning scenarios (especially classical mechanics) by utilizing a haptic device called four visuo-haptic devices found that this haptic device allows kinesthetic and tactile user interaction with a virtual environment simulated on a computer [36]. Based on the previous research that has been presented, it could be seen that the topic of mechanics has been widely researched and a variety of approaches—analytical, numerical, simulation, and experiments—have been proposed to answer problems in mechanics. Therefore, a comprehensive bibliometric study was needed to map in more detail the trends and contributions of research on the topic of mechanics.

One comprehensive analysis of the literature was done by utilizing bibliometric mapping. Bibliometrics was a type of qualitative and quantitative scientific evaluation with a comprehensive analysis of authors, countries, h-index, number of citations, publication time, other issues of relevant articles, and contributions of academic groups and individual researchers that could be evaluated objectively [37] [38] [39]. In addition, bibliometric studies were able to map research topics and trends [40] [41]. In this case, researchers utilized bibliometric studies to reveal various emerging trends related to article publication performance, scientific journals, and collaboration patterns between researchers, as well as the composition of research constituents in a particular field contained in the literature [42]. Therefore, bibliometric studies have a role in advancing science and research in a particular field, so they could be used as an effective method for increasing the contribution of literature to physics learning, especially in the topic of mechanics.

This research was relevant to several studies. Yanuarti & Suprpto in 2021 [43] examined the history of science (physics) over the past 10 years based on the Scopus database. The results showed the number of articles in a span of 10 years, the top sources of journals, and the countries that dominate as research centers in this field. Second, research by Bitzenbauer in 2021 [44] on bibliometric analysis of quantum physics education over the past two decades provides an overview of quantum physics education research in terms of scientific production, preferred publication venues, researchers and countries most involved (including collaboration), and research topics. Third, Suprpto et al in 2021 [45], analyzed the 100 most cited papers in the field of physics education in the last thirty years. This study aims to provide insight into citation patterns, authorship patterns, years, journals, and countries with the help of bibliometric analysis. Fourth, Kizilcik in 2023 [46], made a bibliometric analysis in terms of research trends, trendsetting institutions, and staff of physics education departments in Turkey. After searching the Scopus database, there was no physics research on the topic of mechanics in social science that utilizes bibliometric studies. Therefore, this study was pioneering research on this topic. Thus, this study aims to provide an overview of annual article percentages ranging from the initial publication of articles on mechanics in physics education in Scopus-indexed journals in 1962 to 2023, the most popular journals on the subject, the number of articles by authors and their H-index, the

most cited articles worldwide, the number of articles (SCP, MCP, and MCP ratio values) by country, collaboration networks between authors, and the most frequently used keywords.

METHOD

This research used bibliometric analysis with the aim of evaluating published academic work. Bibliometrics was the application of mathematical and statistical methods used to assess scientific publications that allow us to identify research trends [47]. A bibliometric approach was used to trace the evolution of a research domain, including topics and authors, based on the social, intellectual, and conceptual structures within the discipline. Bibliometric analysis could be done in R Studio with the biblioshiny package [48] [49]. The stages in this research were as follows:

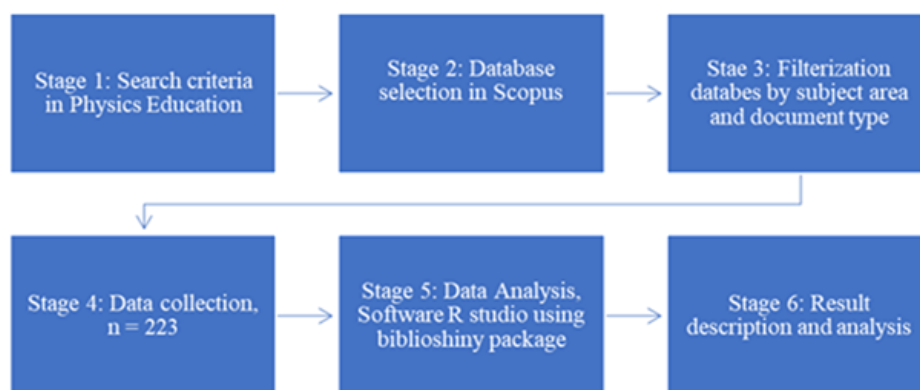


Fig 1. Bibliometric Flow

This research involved several stages. The first stage involved searching scientific sources related to physics education using carefully selected keywords. The second stage involved searching in the Scopus database, a leading scientific resource with some filtering settings. We applied Newton's Laws OR Kinematics OR Dynamics OR Force OR Force OR Momentum OR Impulse OR Energy OR Gravity OR Circular Motion OR Rotation OR Rotational Motion OR Vibrations OR Waves for "Article title, abstract, and keyword" filterization. We chose these keywords because they were common representations of the main topics of mechanics in physics. The keywords included the most basic and common sub-topics in mechanics, such as Newton's laws, motion, kinematics, and dynamics. Using these core keywords, the search was expected to produce a comprehensive mapping of publications on various aspects of mechanics research in the international scientific literature. The selection of appropriate and representative keywords was important so that the coverage and results of the mapping match the desired topic and research objectives.

In the third stage, we filtered by subject area and document type, leaving 223 documents after this stage. We chose "Physics education" for the subject area and "Article" for the document type. The main reason we focused on physics education category and journal article document type was to get a more specific picture of the topic of mechanics in an educational context. Although Scopus does not have an education-specific category, physics education category was chosen as the most relevant to cover the field of education. Furthermore, journal articles were prioritized over other document types as they had undergone a rigorous selection and review process by the journal before they were published. This ensures that the information obtained from journal articles comes from reliable and high-quality sources. Thus, the scope of this study was expected to produce a comprehensive and in-depth mapping of mechanics research in educational and social dimensions, particularly based on Scopus-indexed international journal articles.

After the filtering, the third stage produced 223 documents that were ready for analysis. The next step involves evaluating the documents, taking into account previously established methods, and including an assessment of the relevance of the research found. At this stage, RStudio software was used for bibliometric analysis and research novelty mapping. Finally, the final stage includes presenting the results, conclusions, and quantitative assessment of the research after the data has been processed and analyzed. The results section contains an in-depth explanation of the findings and a visual representation of the research results [50].

RESULTS AND DISCUSSIONS

Number of articles produced over time

The number and percentage of annual articles based on the restrictions for research purposes are presented in Table 1.

Table 1. Number and percentage of annual articles

Year	Number of Articles	Percentages
1962–1971	1	0%
1972–1981	7	3%
1982–1991	10	4%
1992–2001	26	12%
2002–2011	48	22%
2012–2021	102	46%
2022–2023	29	13%
Total	223	100%

Table 1 shows that the oldest article on mechanics in physics education indexed in the Scopus database was published in 1962, while the largest number of articles were published between 2012 and 2021 (n=102). More than 80% of all publications were published since 2002, this significant rise in articles from the early 2000s suggests a growing academic interest and an expansion in research activities related to mechanics in physics education, reflecting broader trends in the increased scholarly focus on educational research and potentially the integration of new pedagogical approaches and technologies in physics education.

The most popular journals

Table 2. Journals of most interest in the subject

Journal Name	Number of Articles
Physics Education	37
Physics Teacher	27
Revista Brasileira De Ensino De Fisica	10
Science And Education	8
International Journal of Mathematical Education In Science And Technology	6
Physical Review Special Topics - Physics Education Research	5
The Physics Educator	5
Ergonomics	4
International Journal Of Science And Mathematics Education	4
Revista Mexicana De Fisica E	4

Table 2 lists the journals with the most publications on the topic of mechanics in physics education research category in the Scopus database. Overall, our findings showed an increasing trend of interest

and publications in mechanics research in physics education in the last two decades, mainly driven by the development of advanced quantitative data analysis methods and techniques that enable the application of mechanistic approaches to social fields. Nevertheless, the concepts and theories of social mechanics were still not fully established, and further studies were needed to strengthen their methodological and empirical foundations.

We identified a total of 101 journals that had published articles with search keywords related to the topic of mechanics in physics education category. The journal with the highest number of publications was Physics Education (n = 37 articles), followed by Physics Teacher (n = 27) and Revista Brasileira de Ensino de Fisica (n = 10). This finding illustrates the preference of certain journals as a publication platform for mechanical topics. Therefore, researchers interested in conducting related research were advised to target relevant and influential journals in this field to reach the right audience. Furthermore, Table 3 presents the ranking of authors with the most publications and their h-index, which could be used as a reference in identifying experts and major contributors to mechanical research in physics education. Overall, this mapping of journal preferences and active authors was important for understanding the existing publication landscape and as a guide for new researchers in choosing an appropriate publication platform to disseminate their research findings to the relevant academic community.

Most cited and most impactful authors

Table 3 shows the number of articles produced by some authors and their Indexes

Table 3. Findings on the number of articles by authors and their H-indexes

Authors	Articles	Authors	H-index
Pendrill A-M	4	Pendrill A-M	3
Fones SW	3	Rieber LP	3
Rieber LP	3	Adams DM	2
Rodrigues H	3	Coelho RL	2
Soares A	3	Cross R	2
Adams DM	2	Gauld C	2
Alabidi S	2	Panza N	2
Alarabi K	2	Portes D	2
Andrade-Neto AV	2	Rodrigues H	2
Coelho RL	2	Smith TI	2

Based on analysis of the Scopus database, 467 authors were identified who have published articles on the topic of mechanics in physics education category, either individually or collaboratively. On average, each author published 0.48 articles, and each article was written by 2.09 authors, indicating a high level of research collaboration. From the data in Table 3, the three authors with the highest number of publications are Pendrill A-M from Lund University (Sweden) with 4 articles, followed by Fones SW from Clemson University (USA) and Rieber LP from the University of Georgia (USA) with 3 articles each. This active author mapping provides valuable information on the key experts and contributors to mechanical research in physics education based on publication productivity. Furthermore, the right-hand side of Table 3, the h-index, shows the achievements and impact of each researcher's publications. From this information, a more comprehensive picture of the role and contribution of researchers to the development of mechanics topics in physics education can be obtained.

The right column of Table 3 ranks the top 10 authors by h-index value, which has an alternative metric to measure the impact of a researcher's publications. Interestingly, this list was dominated by different names than those based on the number of publications, such as Cross R, Gauld C, Panza N, Portes D, and Smith TI. This indicates that, despite the lower number of publications, these researchers

produced papers that had a significant impact and were widely cited by the academic community. Thus, mapping by h-index complements the analysis of publication productivity to provide a more comprehensive understanding of each researcher’s achievements and contributions. Furthermore, Figure 2 shows the citation spike patterns of the top authors’ articles, which was important for monitoring trends and the development of their influence on the field of mechanics research in physics education. Overall, the integration of these bibliometric metrics could provide a comprehensive profile of key scholars in the field.

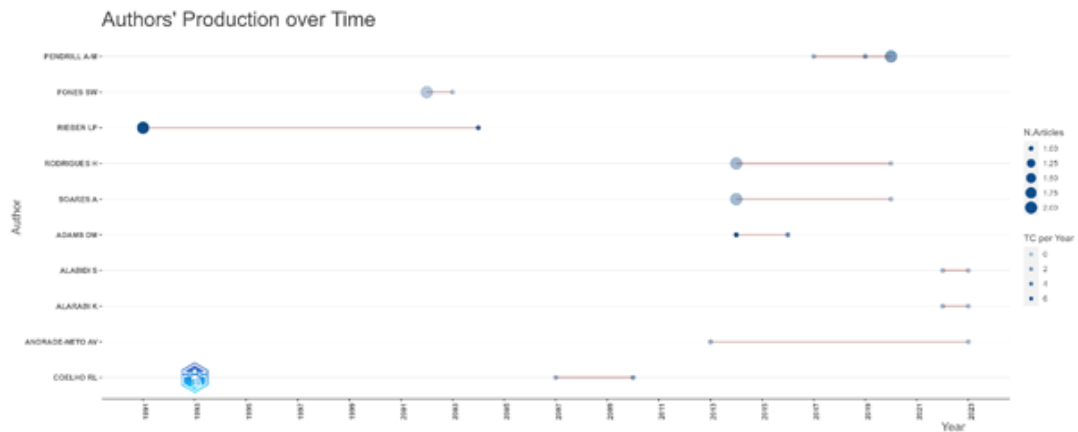


Fig 2. Top author production over time

The lines in Figure 2 show the production of authors who published articles on mechanics over time. The dots indicated the citation burst value for the article by the author in the indicated year. The dark dots in Figure 2 refer to high citation burst values.

Figure 2 presents the trends in publication productivity and citation patterns of the top authors who published articles on the topic of mechanics in physics education. The continuous line showed the number of publications per author throughout the year, while the dots represent the citation burst value for each article in a given year. Dark dots indicate high citation spikes. This pattern was important for monitoring the development and impact of publications from leading researchers over time. For example, it could be seen that despite not having the largest number of publications, some researchers, such as Rieber LP and Rodrigues H, managed to produce high-impact works that were widely cited, as seen from the dark dots on their citation spikes. This analysis of citation trends integrated with publication productivity can provide deep insights into the achievements and contributions of researchers on the topic of mechanics in a social science context.

Based on Figure 2, the author with the highest citation spike was Rieber LP, with a value of 6.52 in 1991 and 5.1 in 2004. Although not the most cited overall, Rodrigues H recorded the highest citation spike in a year. Other authors with high citation spikes include Adams DM (6.40 in 2014 and 2.75 in 2016) and Pendrill A-M (2.25 in 2016 and 2.20 in 2019). This pattern indicated an increase in the academic community’s interest in and attention to the specific works of these researchers in the years of citation spikes. By monitoring article citation trends and identifying citation spikes, we could gain valuable information about influential research topics, findings, and ideas that deserve further attention. This comprehensive bibliometric analysis of citation patterns and collaboration between authors could reveal deep insights into the dynamics and direction of mechanical research development in physics education.

The most cited articles on mechanics in physics education category were given in Table 4.

Table 4. The most cited articles worldwide

Author	Year	TI	TC
Rieber LP	1991	Animation, incidental learning, and continuing motivation	170
Rieber LP	2004	Discovery learning, representation, and explanation within a computer-based simulation: Finding the right mix	102
Adams DM	2014	Integrating self-explanation functionality into a complex game environment: Keeping gaming in motion	64
Rieber LP	1991	Effects of visual grouping strategies of computer-animated presentations on selective attention in science	45
Coelho RL	2010	On the concept of force: How understanding its history can improve physics teaching	24
Adams DM	2016	Evaluating the cognitive consequences of playing portal for a short duration	22
Coelho RL	2007	The law of inertia: How understanding its history can improve physics teaching	17
Pendrill A-M	2019	Students making sense of motion in a vertical roller coaster loop	11
Pendrill A-M	2020	Smartphones and newton's first law in escalators and roller coasters	8
Andrade-Neto AV	2013	Rolling friction or why a body that rolls stops; [rolamento e atrito de rolamento ou por que um corpo que rola pára]	7

Based on the data in Table 4, the article with the highest number of citations was a publication by Rieber LP in 1991 [51] with 170 citations. The study explored the effect of using animation in learning on students' intrinsic motivation to learn the topic of Newton's laws of motion. The second most cited article was also by Rieber LP et al in 2004 [52] with 102 citations, which examined user interaction with a computer simulation of Newton's laws of motion. The third article was by Adams & Clark in 2014 [53] with 64 citations, which examined the effect of a simple computer game version on the understanding of Newton's law concepts. These top three articles showed that research integrating computer technology to improve understanding or motivation on the topic of Newtonian mechanics was in high demand and had a high impact. This implies a research trend to utilize technological advances to improve the teaching and learning of physics and mechanics concepts. This mapping of influential articles provides insight into the direction of mechanics research in physics education as well as future research opportunities.

Distribution of countries producing mechanical articles

Figure 3 shows a map of the countries with the highest production of mechanics in physics education category among countries that allow indexing of scientific publications in the Scopus database.

The map in Figure 3 presents the geographical distribution of the number of mechanics publications in physics education by country. The United States dominates with 129 articles, followed by Brazil (41) and China (40). A number of regions, such as inner Africa and some Eurasian countries, were marked in gray, indicating the absence of Scopus-indexed publication data from these countries. This distribution pattern may represent the level of interest and activity in mechanics research in the social and educational context of each country. Geographic mapping of publication counts was important for monitoring international collaborations and identifying opportunities for research development in under-researched areas. Future research efforts could be directed at expanding the study of mechanics in physics education in various parts of the world, especially in countries and regions that still lack publications.

Country Scientific Production

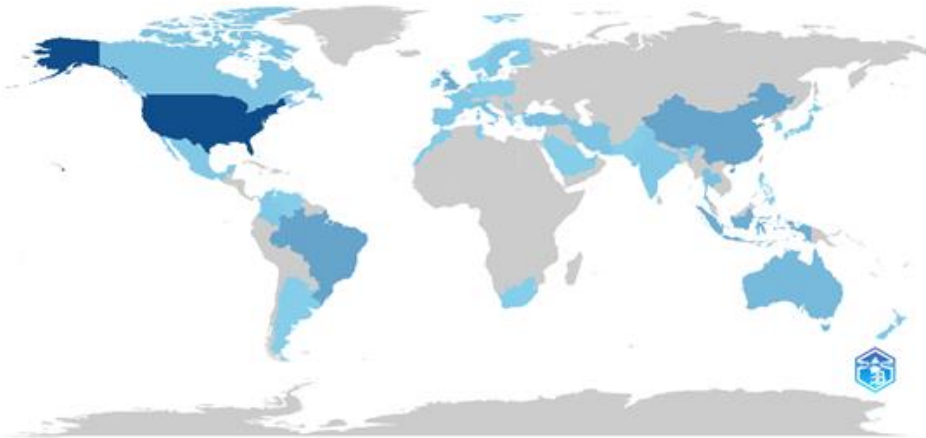


Fig 3. Countries' Scientific Productivity in Mechanics in Physics education Research

Collaboration between authors

Figure 4 presents a comparison of the number of publications of mechanics articles in physics education based on the international collaboration status of the authors. Publications were classified as SCP (Single Country Publications) if they were written by researchers from one country and MCP (Multiple Country Publications) if they were collaborations between researchers from several countries. Figure 4 shows that most of the articles are SCP, with a relatively small proportion of MCP. This indicated that international collaboration in mechanics research topics in physics education was still limited. Details of the numerical data were presented in Table 5. Mapping the status of collaboration was important to monitor trends in research internationalization and identify opportunities for cross-country collaboration that could enrich the study of mechanics in social and educational contexts.

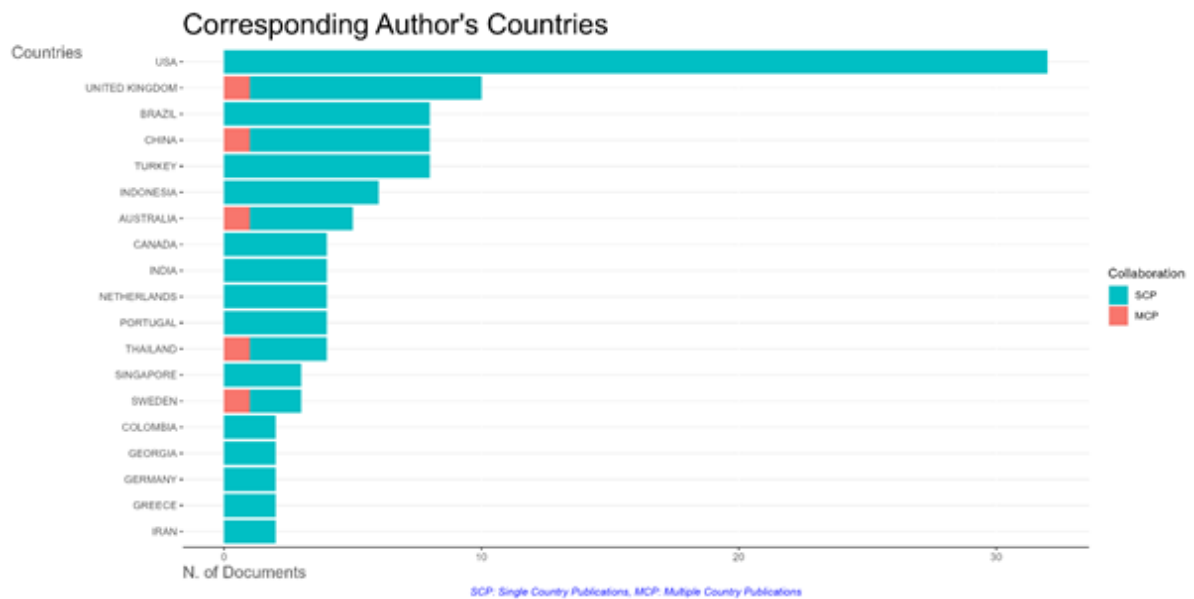


Fig 4. Author countries and number of articles produced

Table 5. Number of articles, SCP, MCP, and MCP ratio values by country

Country	Articles	SCP	MCP	Freq	MCP_Ratio
USA	32	32	0	0,143	0
UNITED KINGDOM	10	9	1	0,045	0,1
BRAZIL	8	8	0	0,036	0
CHINA	8	7	1	0,036	0,125
TURKEY	8	8	0	0,036	0
INDONESIA	6	6	0	0,027	0
AUSTRALIA	5	4	1	0,022	0,2
CANADA	4	4	0	0,018	0
INDIA	4	4	0	0,018	0
NETHERLANDS	4	4	0	0,018	0

Table 5 shows that the United States, the United Kingdom, and Brazil top the list in terms of the number of publications of mechanics articles in physics education. However, these three countries also have a low MCP (Multiple Country Publication) ratio, which means that most of their publications were the result of collaboration between researchers from the same country (SCP). In contrast, despite having only 1 publication, some countries, such as France, Italy, Poland, and Spain, have an MCP ratio of 100%, indicating their openness to international collaboration. Overall, the level of international collaboration on this topic was still relatively low, with only 10 countries having MCP publications. To advance mechanics research in physics education, it was important to increase collaboration between researchers across countries and institutions. This could enrich perspectives and broaden the impact of research. This global collaboration map was useful for planning initiatives that could increase international networking and cooperation in this field.

The collaboration networks of the most collaborating authors were given in Figure 5.

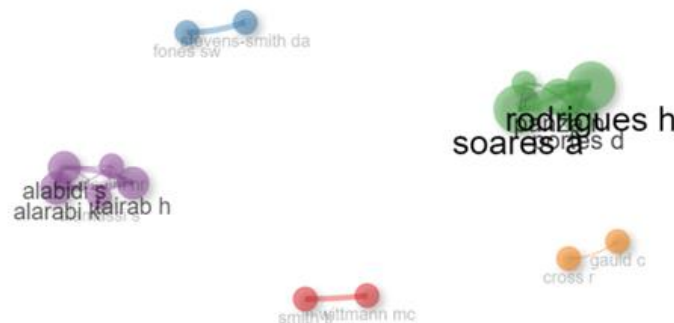


Fig 5. The collaboration network

Figure 5 maps the collaboration network between authors of mechanics articles in physics education based on a co-authorship connectivity analysis. It was noticeable that Soares and Rodrigues were the authors with the greatest number of collaborations, connected with many other author nodes. Altogether, four major clusters of collaborations were formed, as detailed in Table 6. This mapping of co-authorship collaborations was important for understanding the patterns of networks and groups of researchers active in social mechanics topics. By identifying core researchers and connections between authors, we could monitor the development of this research community and plan strategies to strengthen collaboration, for example, by bridging researchers from different clusters. This collaborative network analysis was also useful for identifying new cooperation opportunities to advance mechanics research in social and educational contexts.

Figure 7 presents a word tree map from a text mining analysis of abstracts of articles on mechanics in physics education. It could be seen that the words that appear most often include "human" (f = 8), "male" (f = 8), "adult" (f = 7), "biomechanics" (f = 6), "female" (f = 5), "students" (f = 5), "humans" (f = 4), "algorithm" (f = 3), "animation" (f = 3), and "article" (f = 3). This pattern was consistent with the word cloud results, which indicate a research emphasis on the topic of human biomechanics and its application in educational contexts. Algorithms, animations, and articles were also frequently mentioned, reflecting the use of computational and multimedia techniques in the study of social mechanics. This text mining-based mapping of abstracts was useful for understanding the main focus and trends in mechanics research topics in the current social dimension, as well as identifying potential future study developments.

CONCLUSION AND SUGGESTION

The results of the analysis showed a sharp increase in publications since the 2000s, dominated by the United States, although international collaboration was still limited. Most articles were published in physics education journals, with a prominent number of prolific authors. Based on text mining of keywords and article abstracts, the main research topic was focused on human biomechanics and its application in educational contexts. Overall, this bibliometric study provides a comprehensive picture of the development of publications and scientific communication in the field of mechanics in physics education. Based on these findings, it is recommended that further research expand its scope by including previously untouched topics. In addition, increasing cross-disciplinary and cross-country collaboration is highly recommended to enrich research approaches and methods used in the study of mechanics. Further research should also focus on the results of these studies to improve the physics education curriculum, ensuring that the latest innovations and findings can be promptly applied in the learning context.

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