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Bibliometric analysis of velocity and acceleration objects in rectilinear motion

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ABSTRACT

The development of velocity and acceleration teaching aids for linear motion has attracted increasing attention due to the growing integration of digital technologies in physics education. However, a comprehensive bibliometric mapping of this research field remains unavailable. Therefore, this study aims to analyze publication trends, thematic structures, and emerging research directions related to velocity and acceleration teaching aids in linear motion physics. This study employed a quantitative bibliometric approach. A total of 376 journal articles published between 2019 and 2024 were retrieved from the Google Scholar database through Harzing's Publish or Perish software. The data were analyzed using Microsoft Excel for publication trend analysis and VOSviewer for co-occurrence, network, overlay, and density visualizations. The results revealed that publication output increased substantially during the study period, reaching its peak in 2023 with 94 publications (25%). Co-occurrence analysis identified five major thematic clusters, including teaching aids, Arduino-based experimentation, linear motion concepts, acceleration, and velocity measurement. Overlay visualization indicated that Arduino, acceleration analysis, and digital experimentation emerged as recent research trends. Density visualization showed that motion, velocity, and acceleration remain the most established research themes. This study contributes a comprehensive bibliometric mapping of velocity and acceleration teaching-aid research, highlighting emerging opportunities for IoT-integrated laboratories, sensor-based experimentation, remote laboratories, and AI-assisted physics learning. The findings provide a strategic reference for researchers and educators in developing future digital physics laboratory innovations.

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INTRODUCTION

Linear motion is one of the fundamental topics in physics education, yet students frequently experience difficulties in understanding the relationships among displacement, velocity, acceleration, and graphical representations of motion. These concepts require students not only to understand mathematical relationships but also to interpret dynamic physical phenomena that occur over time. Consequently, misconceptions related to velocity, acceleration, and motion graphs remain common among students at various educational levels. To address these challenges, researchers have developed various teaching aids and experimental devices, including Arduino-based systems, ultrasonic sensor applications, digital measurement instruments, and computer-assisted laboratory environments. Such technologies enable students to observe motion phenomena more directly, collect real-time data, and visualize abstract concepts in a more meaningful manner.

Physics education relies heavily on laboratory activities to help students understand physical phenomena through direct observation, experimentation, and data analysis. Laboratory practicum enables students to test hypotheses and verify scientific concepts while developing problem-solving skills and conceptual understanding (Maiyena et al., 2018). Recent studies have shown that technology-based experimental tools can further enhance the effectiveness of physics learning by providing more realistic and interactive learning experiences (Flegr et al., 2023; Muzayyanah et al., 2021; Pratidhina et al., 2022; Y. Wang et al., 2025). Moreover, practical activities supported by digital technologies can facilitate data-driven learning experiences and improve students' engagement in scientific inquiry processes.

Advances in electronics and digital technology have facilitated the development of innovative physics teaching aids and laboratory instruments (Boimau et al., 2019). Digital measurement systems offer several advantages, including ease of use, reduced measurement errors, improved data visualization, and more efficient data storage and processing (Laumann et al., 2024). Among these technologies, Arduino Uno microcontrollers integrated with digital sensors have gained considerable attention due to their affordability, accuracy, and ease of implementation in educational settings (Loukatos et al., 2022; Najahy et al., 2023; Pabuçcu Akış, 2024; Prabowo & Irwanto, 2023; Sze et al., 2022). Ultrasonic sensors have been widely applied in physics experiments and teaching aids because they enable accurate measurements of distance, motion, and wave-related phenomena (Prabowo & Irwanto, 2023; Sze et al., 2022; Zulfikar, 2023). The combination of Arduino platforms and digital sensors has also encouraged the development of low-cost, portable, and scalable laboratory systems that can support both face-to-face and remote learning environments.

Research on linear-motion teaching aids has expanded significantly in recent years. Previous studies have developed various Arduino-based and sensor-assisted learning tools, including distance measurement systems, motion-analysis devices, inclined-plane experiments, collision apparatus, and automated control systems (Alam & Maulana, 2020; Li et al., 2018; Satria & Devi, 2023; Umam et al., 2021). These studies consistently reported improvements in measurement accuracy, real-time data acquisition, visualization of motion phenomena, and students' understanding of velocity and acceleration concepts. The growing adoption of Arduino platforms, ultrasonic sensors, and digital laboratory technologies indicates an increasing research interest in technology-enhanced physics experimentation. Recent studies have also reported substantial growth in research related to Arduino-based physics experiments, digital laboratories, and sensor-assisted learning environments (Pabuçcu Akış, 2024; Prabowo & Irwanto, 2023).

Although previous studies have contributed significantly to the development of individual teaching aids, they have primarily focused on product design, implementation, and learning effectiveness. As a result, the broader intellectual structure, thematic evolution, publication trends, and emerging research directions in this field remain unclear. Furthermore, while bibliometric approaches have been increasingly applied to map research developments in science education and educational technology, no study has specifically examined the development of velocity and acceleration teaching-aid research in linear motion physics. Consequently, a comprehensive understanding of research hotspots, thematic relationships, and future opportunities in this field is still lacking.

Bibliometric analysis provides a powerful approach for examining knowledge structures, thematic evolution, and future research opportunities within a scientific field. Through systematic mapping, researchers can obtain a comprehensive overview of research development and identify underexplored areas that require further investigation. Google Scholar was selected as the primary database because it provides broad coverage of educational and interdisciplinary publications, while Harzing's Publish or Perish facilitates systematic retrieval and citation analysis of scholarly documents. Therefore, this study aims to conduct a bibliometric analysis of research on velocity and acceleration teaching aids in linear motion published between 2019 and 2024. Specifically, the study seeks to analyze publication growth patterns, identify dominant thematic clusters, examine emerging research trends, and explore potential future directions in this field. Data retrieved from Google Scholar through Harzing's Publish or Perish were analyzed using Microsoft Excel and VOSviewer. Unlike previous studies that primarily focused on the design, implementation, or effectiveness of individual teaching aids, this study provides the first comprehensive bibliometric mapping of velocity and acceleration teaching-aid research, thereby offering a strategic roadmap for future innovations in digital, sensor-based, IoT-supported, and intelligent physics laboratories.

RESEARCH METHODOLOGY

This study employed a quantitative bibliometric research design to examine the development of research on velocity and acceleration teaching aids in linear motion. Bibliometric analysis is a widely used approach for evaluating scientific publications and mapping the intellectual structure, thematic evolution, and research trends within a particular field (Garfield, 2009; Genc & Kocak, 2024; Mukherjee et al., 2022). Through citation and keyword analyses, bibliometric methods provide a systematic overview of research development and help identify dominant themes, emerging topics, and future research opportunities.

The bibliographic data were retrieved from the Google Scholar database using Harzing's Publish or Perish software. Google Scholar was selected because of its broad coverage of educational and interdisciplinary publications, while Publish or Perish facilitates efficient retrieval and citation analysis of scholarly documents. The data collection process was conducted in January 2025 and covered publications published between 2019 and 2024. The search was performed using keywords related to "teaching aids" OR "physics experiment", "velocity" OR "speed", "acceleration", "linear motion", and "Arduino".

To ensure the relevance and quality of the dataset, inclusion and exclusion criteria were established. The inclusion criteria consisted of: (1) journal articles published between 2019 and 2024; (2) publications related to velocity, speed, acceleration, or linear motion teaching aids; (3) studies focusing on physics education, laboratory experiments, or technology-assisted learning; and (4) articles indexed by Google Scholar and retrievable through Publish or Perish. The exclusion criteria included: (1) duplicate records; (2) conference proceedings, books, theses, and dissertations; (3) articles with incomplete bibliographic information; and (4) publications not directly related to velocity and acceleration teaching aids in linear motion.

The article selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. Initially, all records identified through the keyword search were collected from Google Scholar using Publish or Perish (Identification stage). Duplicate and irrelevant records were subsequently removed (Screening stage). The remaining publications were assessed for relevance based on titles, abstracts, and keywords (Eligibility stage). Finally, articles meeting all inclusion criteria were retained and included in the bibliometric dataset for further analysis (Included stage). Figure 1 presents the PRISMA flow diagram illustrating the article selection process.

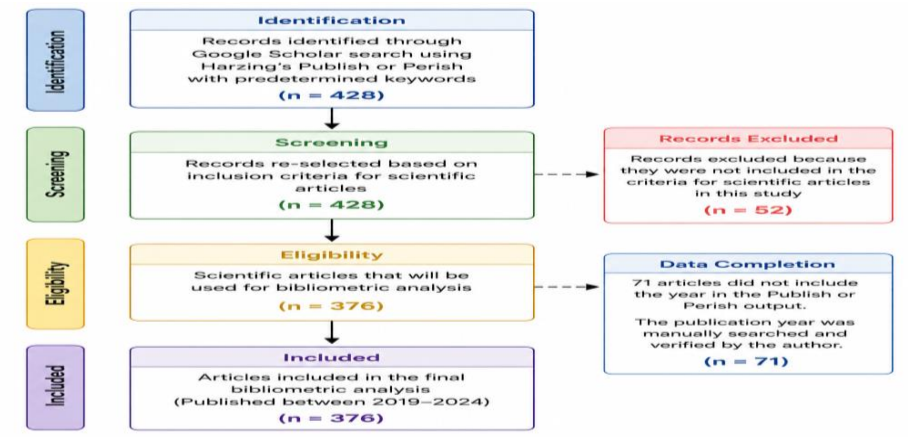

Figure 1. Prisma flow diagram

Following the screening and data-cleaning process, the final dataset was prepared for bibliometric analysis. Microsoft Excel was used to organize the bibliographic data and analyze publication trends, including annual publication growth and percentage distributions. Furthermore, VOSviewer was employed to visualize and analyze relationships among keywords through co-occurrence analysis, network visualization, overlay visualization, and density visualization (Genc & Kocak, 2024; Mukherjee et al., 2022; J. Wang & Kim, 2023). These analyses enabled the identification of dominant research themes, thematic clusters, emerging research trends, and underexplored areas within the field of velocity and acceleration teaching-aid research.

RESULTS AND DISCUSSIONS

The results of the data obtained from the Harzing's Publish or Perish application search with predetermined keywords obtained 428 pieces of data, the data was re-selected and there were 52 pieces of data that were eliminated because they were not included in the criteria for scientific articles in this study, so that the scientific articles that will be used amounted to 376 articles. In the search for article data using Harzing's Publish or Perish there were 71 articles that did not include the year, so the author manually searched for the year of publication of the article. From the article data that had been sorted from the past 5 years, the database was processed using MS Excel to find the average growth of articles each year.

Table 1. Distribution of publications from 2019 - 2024

Year	Number of Publications	%(N=376)	Cumulative Frequency	Average Growth Rate
2019	79	21,01	0.2101	–
2020	62	16,49	0.3750	-21.52
2021	53	14,10	0.5160	-14.52
2022	67	17,82	0.6941	26.42
2023	94	25,00	0.9441	40.30
2024	21	5,59	1.0000	-77.66
Total	376	100	–	–

Based on the publication data analyzed using Microsoft Excel on Tabel 1, research on velocity and acceleration teaching aids in linear motion has been consistently published throughout the 2019–2024 period, indicating sustained scholarly interest in this field. As shown in Figure 1, publication output fluctuated over the study period, with the highest number of publications recorded in 2023 (n = 94; 25.00% of the total publications). This increase reflects growing research attention toward technology-enhanced physics learning, particularly the development of Arduino-based teaching aids, sensor-assisted experimentation, and digital laboratory systems designed to improve students' understanding of motion concepts.

A decline in publication output was observed between 2019 and 2021 on Figure 1, followed by a substantial increase from 53 publications in 2021 to 67 publications in 2022 and reaching 94 publications in 2023. The increase of 27 publications between 2022 and 2023 suggests an expanding interest in the integration of digital technologies into physics education. This trend may be associated with the increasing accessibility of Arduino microcontrollers, ultrasonic sensors, data acquisition systems, and Internet of Things (IoT)-based learning environments, which have created new opportunities for developing innovative teaching aids and laboratory activities.

In contrast, 2024 recorded the lowest number of publications (n = 21; 5.59%). However, this finding should be interpreted with caution because the bibliographic data were collected before the completion of the publication year, meaning that not all 2024 publications may have been indexed in Google Scholar at the time of data retrieval. Therefore, the lower publication count is more likely attributable to incomplete database coverage rather than a decline in research interest. Overall, the publication trend demonstrates the increasing importance of digital and sensor-based technologies in the development of linear-motion teaching aids and highlights the growing role of technology-supported experimentation in contemporary physics education.

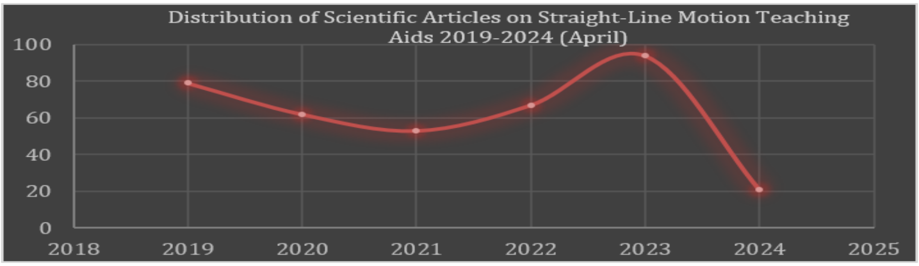

Figure 1. Distribution of publications 2019 – 2024

The increasing publication output indicates expanding scholarly attention to velocity and acceleration teaching aids. To further explore the intellectual structure and thematic relationships within this field, a keyword co-occurrence analysis was conducted using VOSviewer. The resulting network visualization reveals the dominant research clusters and thematic connections among studies published during the 2019–2024 period on Figure 2. Analyzing the linear motion teaching aids using the binary calculation method in VOSViewer, 2,723 terms/words were obtained with a minimum limit displayed for each word, which was set at 4 times, resulting in 52 words within the threshold. After that, the author filtered the terms/words relevant to the linear motion teaching aids by obtaining 21 terms classified into 5 clusters.

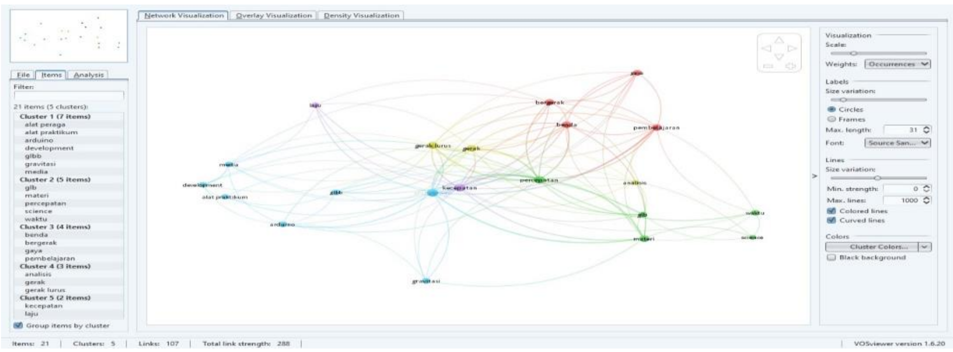

Figure 2. Network visualization

Figure 2 presents the network visualization generated using VOSviewer based on keyword co-occurrence analysis. The analysis identified 21 keywords grouped into five interconnected clusters with a total of 107 links and a total link strength of 288, indicating strong relationships among the research topics within the field of velocity and acceleration teaching aids. The dense connections among clusters suggest that studies on linear-motion teaching aids are multidisciplinary, integrating concepts from physics education, experimental learning, and digital technology.

Cluster 1 (blue) focuses on educational technology and experimental tools, consisting of keywords such as alat peraga (teaching aids), praktikum (laboratory practicum), Arduino, gravitasi (gravity), and GLBB (uniformly accelerated motion). This cluster highlights the dominant role of technology-assisted experimentation in physics learning and reflects the increasing use of Arduino-based systems and practical laboratory activities to support students' understanding of motion concepts (Onu et al., 2024; Pabuçcu Akış, 2024; Prabowo & Irwanto, 2023; Pratidhina et al., 2022; Ullah et al., 2022). Cluster 2 (green) contains keywords related to fundamental physics concepts, including linear motion, acceleration, waktu, materi, and science. This cluster represents the conceptual foundation of the research field and indicates that most studies are directed toward improving students' understanding of basic motion concepts through instructional interventions and teaching aids. Cluster 3 (red) includes keywords such as object, force, and learning. The presence of these terms suggests that many studies investigate the interaction between physical phenomena and pedagogical processes. This cluster emphasizes the role of teaching aids in helping students visualize how forces influence object motion and in facilitating concept-based learning.

Cluster 4 (yellow) is characterized by keywords associated with analysis and motion. This cluster reflects research focusing on motion analysis, measurement processes, and data interpretation. The strong links between this cluster and the technology-related cluster indicate that digital measurement systems and sensor-based experiments are increasingly being used to analyze motion phenomena more accurately. Cluster 5 (purple) contains keywords related to kecepatan (velocity) and laju (speed), which are central concepts in linear-motion studies. Although this cluster contains fewer keywords, its connections with other clusters demonstrate that velocity and speed remain core variables in the development of teaching aids and experimental devices for physics education.

Overall, the network visualization reveals that research on velocity and acceleration teaching aids is primarily centered on the integration of physics concepts, laboratory experimentation, and digital technologies. The strong connections between Arduino-based experimentation, motion analysis, and learning processes indicate that technology-enhanced physics laboratories have become a dominant research theme. Furthermore, the interconnected structure of the network suggests opportunities for future studies involving IoT-supported experiments, smart sensors, remote laboratories, and AI-assisted data analysis to enhance physics learning and experimentation.

Figure 3 presents the overlay visualization generated using VOSviewer, which illustrates the temporal evolution of keywords in the field of velocity and acceleration teaching-aid research. In this visualization, the color of each node represents the average publication year associated with a keyword. Keywords displayed in blue and green indicate topics that were more frequently investigated in earlier years, whereas yellow-colored keywords represent more recent and emerging research topics (Genc & Kocak, 2024; J. Wang & Kim, 2023).

The overlay visualization reveals that keywords such as velocity, acceleration, linear motion, analysis, time, and Arduino appear in yellow shades, indicating their increasing prominence in recent publications. The emergence of these keywords suggests a growing research focus on the development of technology-assisted teaching aids designed to improve the measurement, analysis, and visualization of motion-related phenomena. In particular, the prominence of Arduino reflects the increasing adoption of microcontroller-based systems for physics experimentation due to their affordability, flexibility, and capability for real-time data acquisition.

The appearance of analysis as a recent keyword further indicates a shift from merely developing teaching aids toward evaluating their effectiveness, measurement accuracy, and educational impact. Similarly, the strong presence of velocity, acceleration, and linear motion demonstrates that researchers continue to prioritize fundamental motion concepts while integrating digital technologies into experimental learning environments. These findings suggest that contemporary research is increasingly directed toward sensor-based experimentation, automated data collection, and digital laboratory applications.

Furthermore, the close connections among Arduino, velocity, acceleration, and analysis indicate an emerging trend toward technology-enhanced physics learning. This trend aligns with broader developments in physics education, including the integration of Internet of Things (IoT) technologies, smart sensors, remote laboratories, and data-driven learning approaches. Therefore, the overlay visualization suggests that future research is likely to focus on intelligent laboratory systems, IoT-supported experimentation, and advanced digital tools that facilitate more accurate and interactive learning experiences in linear-motion physics.

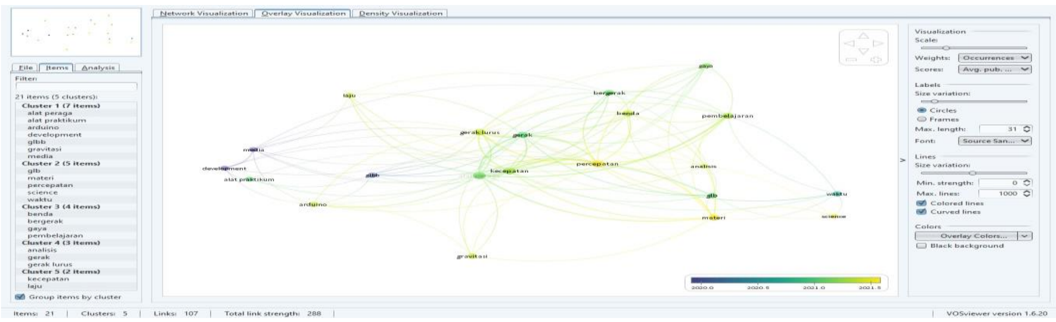

Figure 3. Overlay visualization

Figure 4 presents the density visualization generated using VOSviewer, which illustrates the frequency and concentration of keyword occurrences within the research field. In this visualization, brighter colors (yellow) indicate keywords with higher occurrence frequencies and stronger connections with other terms, whereas darker colors (green to blue) represent less frequently studied topics. Density visualization is particularly useful for identifying well-established research themes as well as underexplored areas that may offer opportunities for future investigation.

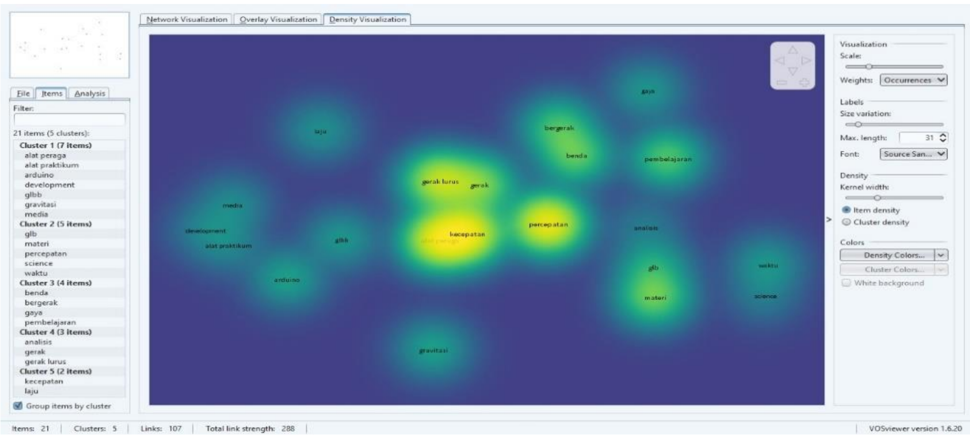

Figure 4. Density visualization

The results reveal that the keywords velocity, linear motion, motion, and acceleration exhibit the highest density levels, as indicated by the bright yellow regions at the center of the map. This finding suggests that these concepts constitute the core research themes within the literature on velocity and acceleration teaching aids. The high density of these keywords is expected because velocity, acceleration, and linear motion represent the fundamental concepts that underpin the design and implementation of physics teaching aids and laboratory experiments.

Several keywords surrounding the central themes, including object, learning, science, time, and analysis, appear with moderate density levels. Their presence indicates that researchers have increasingly explored the pedagogical and analytical aspects of motion-related learning, including the evaluation of teaching-aid effectiveness, conceptual understanding, and experimental data analysis. The connections among these terms suggest that contemporary studies are not limited to device development but also examine how teaching aids support learning outcomes and scientific inquiry processes.

In contrast, keywords such as Arduino, laboratory apparatus, development, media, gravity, and science exhibit relatively lower density levels. Although these topics are connected to the main research network, their lower occurrence frequencies indicate that they remain less extensively explored compared with the dominant motion-related concepts. This finding suggests that the integration of Arduino-based systems, digital sensors, and advanced laboratory technologies has not yet become a fully established research focus within the field.

The density visualization therefore highlights a significant research opportunity. While existing studies have concentrated on fundamental motion concepts, future investigations could expand toward Arduino-based physics experiments, Internet of Things (IoT)-supported laboratories, smart sensor integration, remote experimentation, and AI-assisted learning environments. These emerging areas have the potential to enhance the accuracy, accessibility, and interactivity of physics experiments while addressing the increasing demand for digital transformation in science education.

Overall, the density map demonstrates that research on velocity and acceleration teaching aids remains strongly centered on fundamental motion concepts, whereas technology-enhanced experimentation and digital laboratory innovations represent promising directions for future research. The coexistence of highly established themes and relatively underexplored technological topics indicates that the field continues to evolve toward more sophisticated and digitally supported approaches to physics learning.

The bibliometric findings reveal that research on velocity and acceleration teaching aids in linear motion is strongly centered on the integration of digital technologies into physics experimentation. The publication trend, keyword co-occurrence network, overlay visualization, and density analysis collectively indicate that concepts such as velocity, acceleration, linear motion, and motion analysis constitute the core research hotspots within the field. These topics exhibit the highest occurrence frequencies and strongest interconnections, demonstrating their central role in the development of physics teaching aids and laboratory activities. The present findings are consistent with previous bibliometric studies conducted by Prabowo & Irwanto (2023) and Pabuçcu Akış (2024), which reported a growing adoption of Arduino-based technologies in science and STEM education. However, unlike those studies that focused on Arduino implementation broadly, the present study specifically maps the development of velocity and acceleration teaching aids in linear-motion learning, thereby providing a more focused understanding of research trends in physics experimentation.

One of the most prominent themes identified through the bibliometric mapping is the widespread adoption of low-cost microcontroller platforms, particularly Arduino Uno integrated with HC-SR04 ultrasonic sensors (Loukatos et al., 2022; Pabuçcu Akış, 2024; Prabowo & Irwanto, 2023). The strong association between keywords related to Arduino, laboratory practicum, and motion concepts suggests that researchers increasingly employ microcontroller-based systems to facilitate real-time measurement, data acquisition, and visualization of physical phenomena. Previous studies have demonstrated that Arduino-based teaching aids enable accurate measurement of object displacement, velocity, and acceleration while simultaneously improving students' conceptual understanding of motion (Pratidhina et al., 2022; Sze et al., 2022). Similarly, digital learning environments supported by applications such as DELPHI have been developed to assist students in interpreting graphical representations of uniformly accelerated motion through dynamic visualizations (Lai & Cheong, 2022; Satria & Devi, 2023; Sriadhi et al., 2022; Vidak et al., 2024).

The network and density visualizations further indicate that research in this field has evolved beyond the development of conventional teaching aids toward more sophisticated forms of digital experimentation. The increasing prominence of keywords related to analysis, acceleration, velocity, and Arduino in the overlay visualization suggests a growing emphasis on technology-enhanced experimentation and data-driven learning. These findings are consistent with broader developments in physics education, where digital sensors, automated measurement systems, and interactive laboratory environments are increasingly used to improve measurement accuracy and support scientific inquiry processes. Furthermore, the use of microcontroller-based collision apparatus, digital distance-measurement systems, and gravity demonstration tools illustrates how digital technologies have expanded opportunities for visualizing abstract motion concepts and converting physical phenomena into real-time graphical representations (Alstein et al., 2026; Umam et al., 2021; Vidak et al., 2024; Y. Wang et al., 2025).

Despite the growing body of research, the bibliometric results also reveal several underexplored areas. Although Arduino and digital laboratory technologies have gained increasing attention, keywords related to Internet of Things (IoT), remote laboratories, artificial intelligence, learning analytics, and smart sensor systems remain relatively less prominent within the research network. This finding suggests that most studies continue to focus on standalone teaching-aid development rather than interconnected and intelligent laboratory ecosystems. Consequently, there remains considerable opportunity to expand research toward IoT-supported experimentation, cloud-based data acquisition, remote-access laboratories, and AI-assisted learning environments capable of providing automated feedback and adaptive instructional support.

Compared with earlier studies that primarily evaluated the effectiveness of individual teaching aids, the present bibliometric analysis provides a broader understanding of the intellectual structure and thematic evolution of velocity and acceleration teaching-aid research. The results indicate a gradual shift from traditional laboratory instrumentation toward digital, sensor-based, and data-driven experimentation. This transition reflects the broader digital transformation occurring in science education and highlights the growing importance of integrating hardware, software, and data analytics into physics learning environments.

Overall, the findings suggest that future research should move beyond the design of isolated experimental devices and focus on developing intelligent laboratory systems that integrate Arduino platforms, IoT technologies, smart sensors, remote experimentation, and artificial intelligence. Such innovations have the potential to enhance the accuracy, accessibility, interactivity, and scalability of physics experimentation while supporting the development of scientific reasoning and digital competencies among students.

CONCLUSION

This study provides the first comprehensive bibliometric mapping of research on velocity and acceleration teaching aids in linear motion by analyzing 376 articles published between 2019 and 2024. The results reveal a growing research interest in this field, with publication output reaching its highest level in 2023. Keyword co-occurrence analysis identified five interconnected thematic clusters, indicating that research on linear-motion teaching aids is strongly associated with physics learning, laboratory experimentation, motion analysis, and digital technology integration. The network, overlay, and density visualizations demonstrate that velocity, acceleration, motion, and linear motion constitute the dominant research hotspots within the field. Furthermore, Arduino-based experimentation, digital teaching aids, sensor-assisted measurements, and motion-analysis systems have emerged as increasingly important research themes. The overlay visualization suggests a recent shift toward technology enhanced experimentation, while the density visualization highlights both well-established themes and opportunities for future development. Theoretically, this study contributes to the literature by revealing the intellectual structure, thematic evolution, and research trends of velocity and acceleration teaching-aid research. The novelty of this study lies in its systematic bibliometric mapping of this specific research area, which has not been previously examined in a comprehensive manner. Practically, the findings provide valuable insights for educators, researchers, and instructional designers seeking to develop innovative physics teaching aids and laboratory environments that support conceptual understanding and experimental skills.

Despite these contributions, this study has several limitations. The analysis was restricted to publications retrieved from Google Scholar through Harzing's Publish or Perish and may not fully represent the entire body of international literature. In addition, the results were influenced by the selected search keywords and publication time range. Future research should expand bibliometric coverage by incorporating Scopus, Web of Science, and other international databases. Moreover, emerging topics identified in this study suggest promising directions for future investigation, including Internet of Things (IoT)-based laboratories, smart sensor systems, remote experimentation, learning analytics, and AI-assisted physics learning environments. These technologies have the potential to transform traditional laboratory practices into more intelligent, interactive, and data-driven learning ecosystems.

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