

# Educational Datafication in Smart Attendance Systems: A Bibliometric and Science Mapping Analysis

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## Abstract

Smart attendance systems have evolved from routine administrative tools into data-driven mechanisms that support monitoring, prediction, and institutional decision-making in educational environments. Recent technological developments have accelerated the adoption of artificial intelligence, facial recognition, deep learning, computer vision, and predictive analytics within attendance management systems. Despite these advancements, limited attention has been given to understanding how the transformation of attendance systems is interpreted from educational, ethical, and socio-technical perspectives. This study aims to examine the development, thematic evolution, and conceptual orientation of smart attendance system research through a bibliometric and science mapping approach. A total of 108 Scopus-indexed journal articles published between 2016 and 2025 were analyzed using VOSviewer and Biblioshiny to identify publication trends, dominant themes, influential authors, collaborative networks, and emerging research directions. The findings reveal a significant transition from RFID-based and manual attendance verification systems to AI-driven, automated attendance technologies. Research trends increasingly emphasize system efficiency, authentication accuracy, real-time monitoring, and automation. However, the literature remains predominantly technocentric, with limited discussion of privacy protection, informed consent, algorithmic fairness, student autonomy, and the implications of surveillance. This study identifies an “ethical silence” within the field, in which attendance is increasingly framed as a machine-verifiable construct rather than a pedagogical indicator of participation and engagement. The findings suggest that current research tends to prioritize technical optimization over human-centered educational values. Therefore, future studies should integrate educational technology, learning analytics, data ethics, and policy perspectives to ensure that smart attendance systems are designed as accountable, inclusive, and pedagogically meaningful tools. This study contributes theoretically by extending the discussion on educational datafication and, practically, by providing a comprehensive overview of the evolution and challenges of smart attendance technologies in contemporary education.

*Keywords:* bibliometric analysis; data ethics; educational datafication; learning analytics; smart attendance systems.

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## 1. Introduction

Student attendance has long been recognized as an important indicator of learning engagement and institutional compliance in formal education settings (Hancock et al., 2013; Lu & Cutumisu, 2022). In conventional practice, attendance recording primarily served administrative purposes, such as maintaining order, supporting accountability, and ensuring institutional efficiency (George & Wooden, 2023; Hasan, 2025; Khairullah et al., 2025; Lee & Ospina, 2022). With the rapid development of digital technologies, this function has evolved through the introduction of smart attendance systems (SAS), which integrate tools such as RFID, biometric identification, facial recognition, and learning management platforms (Khairullah et al., 2025; Lateef & Kamil, 2023; Mahato & Neethirajan, 2024; Qinjun et al.,

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2023). This evolution reflects a broader transition from manual recording to automated, data-driven monitoring practices (Ahsan et al., 2023).

Early research on SAS in educational contexts largely focused on technical performance and managerial efficiency. Studies commonly emphasized system accuracy, processing speed, and workload reduction as primary indicators of effectiveness (Kalita et al., 2025; Prasad et al., 2023). Within this perspective, attendance is often treated as a measurable, verifiable variable that can be optimized through technological interventions (Balalle, 2024; Emezue et al., 2022; A. Islam et al., 2024; Nguyen-Tat et al., 2024; Zhang et al., 2022). As a result, evaluation of SAS has been predominantly oriented toward operational reliability and system functionality (M. M. Islam et al., 2024).

More recently, the growing emphasis on data-driven education has extended the role of attendance systems beyond administrative recording. Attendance data are increasingly analyzed and integrated with learning analytics and artificial intelligence to identify behavioral patterns, predict academic risks, and inform institutional decision-making (Ali et al., 2022; Hartono et al., 2024; Lu & Cutumisu, 2022). In online and hybrid learning environments, attendance has also been reinterpreted as a form of digital presence, representing participation beyond physical classrooms (Iskandar et al., 2022; Raes, 2022; Xu et al., 2023). This development indicates not only a technological shift but also a change in how attendance is conceptualized within educational processes.

Despite these advancements, the implementation of SAS raises concerns about ethics, privacy, and power relations (Marshall et al., 2022; Ncube & Ngulube, 2024; Prinsloo et al., 2022). The use of biometric and surveillance-based technologies may contribute to continuous monitoring practices that reshape institutional control and influence student autonomy. From this perspective, SAS should not be viewed solely as a neutral technological solution, but as part of a broader socio-technical system involving data collection, algorithmic processing, and decision-making structures (Gerdon et al., 2022; Grimmelikhuisen & Meijer, 2022; Zuboff, 2022). In contexts where regulatory frameworks remain limited, these developments may intensify asymmetries between institutions and learners (Kong & Yang, 2024). However, existing literature remains largely dominated by technocentric perspectives that prioritize system performance over critical reflection (Carayannis et al., 2022). Discussions related to data ethics, privacy, fairness, and pedagogical implications are often limited or treated as secondary concerns (Bhuttah et al., 2024; Jia & Tu, 2024; Sadeghi et al., 2023). This imbalance reflects a condition that can be described as an “ethical silence,” in which the normative and educational dimensions are insufficiently explored.

In addition, variations in research orientation can be observed across different geographical contexts. Studies conducted in the Global South tend to emphasize practical implementation, scalability, and cost-efficiency, whereas research from the Global North more frequently addresses governance, regulation, and ethical considerations (Aamir, 2025; Djatmiko et al., 2025; S. Islam, 2025). These differences influence not only research priorities but also the way attendance is interpreted within educational systems. Given these conditions, a comprehensive examination of the development of SAS research is necessary, particularly to understand its thematic structure and conceptual direction. Previous studies have largely focused on specific technological implementations, with limited efforts to systematically map dominant and underrepresented themes. Moreover, the implications of attendance datafication for educational meaning and student agency remain insufficiently addressed.

Therefore, this study aims to analyze the evolution of research on smart attendance systems in education using bibliometric and science mapping approaches. The study focuses on identifying shifts in research themes, examining dominant and marginalized topics, analyzing the presence of ethical and privacy-related issues, and interpreting how smart attendance systems reshape the concept of attendance in contemporary education.

## **2. Materials and Methods**

### *2.1. Research Design*

This study employs a bibliometric analysis combined with science mapping to systematically examine research trends, dominant themes, and the intellectual structure of smart attendance systems (SAS) in education. Bibliometric analysis enables a quantitative and systematic exploration of publication patterns, citation performance, and collaborative relationships among authors, institutions, and countries (Agustiyar et al., 2026; K. C. Li & Wong, 2022; Riazi & Farsani, 2024). This approach is particularly well-suited to identifying longitudinal developments in scientific knowledge and to uncovering both dominant and underexplored areas within a research field.

The bibliometric approach was selected because it enables the study to examine the structure of a research field beyond individual empirical findings. In this context, bibliometric indicators are not only used to describe publication growth

but also to identify how smart attendance systems have been conceptually framed over time. Science mapping is further applied to visualize thematic relationships, detect dominant knowledge clusters, and reveal peripheral or underrepresented issues within the literature. This combination allows for a more comprehensive interpretation of the field, linking quantitative patterns with conceptual developments.

## 2.2. Data Source and Search Strategy

The dataset was obtained from the Scopus database, selected for its extensive coverage of peer-reviewed publications and reliable citation indexing (Gerasimov et al., 2024; Maddi et al., 2025). Scopus also offers a relatively broad geographical coverage, including research from developing regions, which is relevant to this study (Chankseliani, 2023). Data collection was conducted on 27 October 2025, covering publications from 2016 to 2025 (Inglis et al., 2022; Umana et al., 2022). The search query was formulated using Boolean operators (AND, OR) to capture studies related to attendance systems, artificial intelligence, and educational contexts. To ensure relevance, filters were applied to include only English-language journal articles. This strategy was designed to balance comprehensiveness and precision, ensuring that the dataset includes studies that specifically address technology-driven attendance systems in educational environments.

## 2.3. Inclusion and Exclusion Criteria

To ensure the dataset's relevance and quality, inclusion and exclusion criteria were defined. Studies were included if they focused on smart or automated attendance systems in educational settings, were published as peer-reviewed journal articles, and were written in English. Studies were excluded if they addressed attendance systems outside educational contexts, were published in formats such as books or conference proceedings, were not written in English, or did not demonstrate clear relevance after screening. The detailed criteria used in this study are summarized in Table 1.

**Table 1.** Inclusion and exclusion criteria for article selection

Criteria Type	Code	Description
Inclusion Criteria	IC1	Studies addressing smart or automated attendance systems in educational contexts
	IC2	Peer-reviewed journal articles
	IC3	Publication written in English
Exclusion Criteria	EC1	Discusses non-educational attendance systems
	EC2	Publications other than articles, such as books, book chapters, conference proceedings, reviews, editorials, or gray literature
	EC3	Not written in English
	EC4	Articles that are not substantively relevant to the topic of smart attendance in education after the screening process.

These criteria were applied to ensure that the final dataset consisted only of peer-reviewed journal articles that substantively addressed smart, automated, or data-driven attendance systems within educational settings. Studies outside educational contexts, or those focusing solely on general attendance behavior without technological components, were excluded.

## 2.4. Data Selection Procedure

The document selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to ensure transparency and reproducibility (Agrawal et al., 2024; Basenach et al., 2023; Cacciamani et al., 2023; Sewell et al., 2023). The procedure was carried out in three main stages. First, all records retrieved from the Scopus database were filtered by document type, source type, language, and publication year, yielding 575 articles. Second, titles and abstracts were screened to exclude studies not directly related to smart attendance systems in educational contexts. Third, a full-text assessment was conducted to confirm the substantive relevance of each article to automated, biometric, or data-driven attendance systems. Through this process, the dataset was refined from an initial 1,371 records to 108 articles included in the final analysis. The overall selection process is presented in Figure 1, which illustrates the systematic reduction of records and ensures that only relevant and high-quality studies are retained for further analysis.

During the initial screening stage, titles and abstracts were examined to assess their substantive relevance to the research objectives. Articles were retained when they explicitly addressed technology-mediated attendance systems in educational settings, including systems based on RFID, biometrics, facial recognition, artificial intelligence, learning

analytics, or related digital monitoring approaches. Studies were excluded at this stage when they focused on attendance systems in non-educational sectors, discussed general educational technologies without a specific connection to attendance monitoring, or lacked sufficient conceptual relevance to automated and data-driven attendance practices.

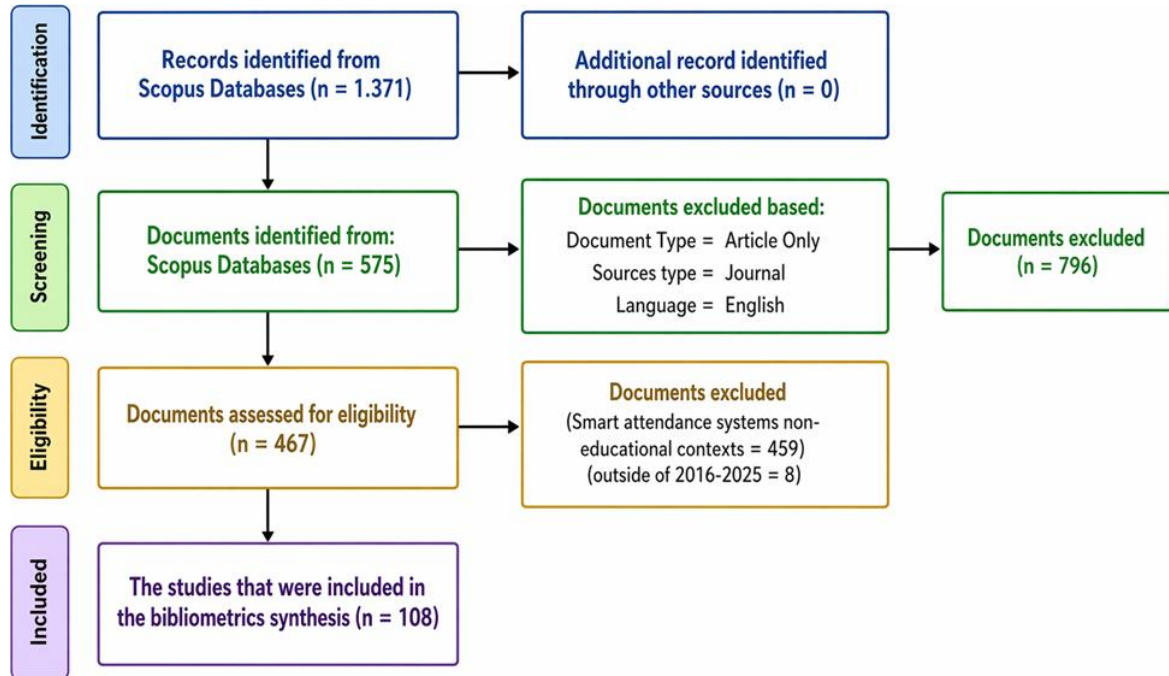


Figure 1. PRISMA flow diagram of the article selection process.

### 2.5. Data Analysis Techniques

Bibliographic data were exported in CSV format and processed using Biblioshiny, VOSviewer, and Microsoft Excel. A descriptive bibliometric analysis was first conducted to examine publication trends, authorship patterns, institutional productivity, journal distribution, and citation performance across the dataset. To investigate the intellectual structure of the field, a co-occurrence analysis of author keywords was conducted using VOSviewer. A minimum occurrence threshold was applied to identify the most relevant keywords and construct network visualizations. These visualizations illustrate thematic clusters, conceptual linkages, and the relative positions of dominant and peripheral research topics. In addition, thematic evolution analysis was performed using Biblioshiny to track changes in research focus over time. The findings are presented through tables, graphs, and network maps, enabling a structured interpretation of the development of research on smart attendance systems (SAS) in education.

The interpretation of results was based on both keyword frequency and keyword positions within the network structure. Frequently occurring and centrally located keywords were interpreted as dominant themes, whereas less frequent and peripheral terms were considered emerging or underexplored topics. This analytical approach enables the study to go beyond descriptive reporting and to provide a more nuanced understanding of the conceptual structure and thematic imbalance within the field.

## 3. Results and Discussion

### 3.1. Descriptive Bibliometric Analysis

The bibliometric analysis indicates that research on smart attendance systems (SAS) in education has developed progressively over the 2016–2025 period. A total of 108 articles published in 89 academic journals were identified, suggesting that the topic is distributed across a wide range of outlets rather than concentrated in a limited number of specialized journals. This pattern reflects the interdisciplinary nature of SAS research, which intersects educational technology, information systems, and data-driven analytics. The annual growth rate of publications reached 11.2%, indicating a consistent increase in scholarly attention to the topic. The average document age of 3.16 years indicates that most contributions are relatively recent, underscoring the field's emerging and evolving nature. In terms of citation

performance, the average number of citations per document was 12.7, with a total of 1,030 references across the dataset, suggesting a moderate level of academic engagement and knowledge accumulation.

From an authorship perspective, 405 researchers contributed to the dataset, with 15 single-authored articles, indicating a strong tendency toward collaborative research. The average number of co-authors per document was 3.75, while the international collaboration rate reached 20.37%, reflecting a growing level of cross-country academic interaction. Furthermore, 564 Keywords Plus and 416 Author Keywords were identified, demonstrating a diverse and expanding range of research topics and terminologies within the field.

**Table 2.** General bibliometric characteristics of the dataset

No	Description	Results
1	Timespan	2016:2025
2	Journals	89
3	Article	108
4	Annual Growth Rate %	11.2
5	Document Average Age	3.16
6	Average citations per doc	12.7
7	References	1030
8	Keywords Plus (ID)	564
9	Author's Keywords (DE)	416
10	Authors	405
11	Authors of single-authored docs	15
12	Single-authored docs	15
13	Co-Authors per Doc	3.75
14	International co-authorships %	20.37

Table 2 presents an overview of the dataset's main bibliometric characteristics, including publication output, citation patterns, authorship structure, and keyword diversity. These indicators provide a general picture of how research on smart attendance systems in education has developed, both in terms of academic productivity and collaborative dynamics.

### 3.2. Publication Trends

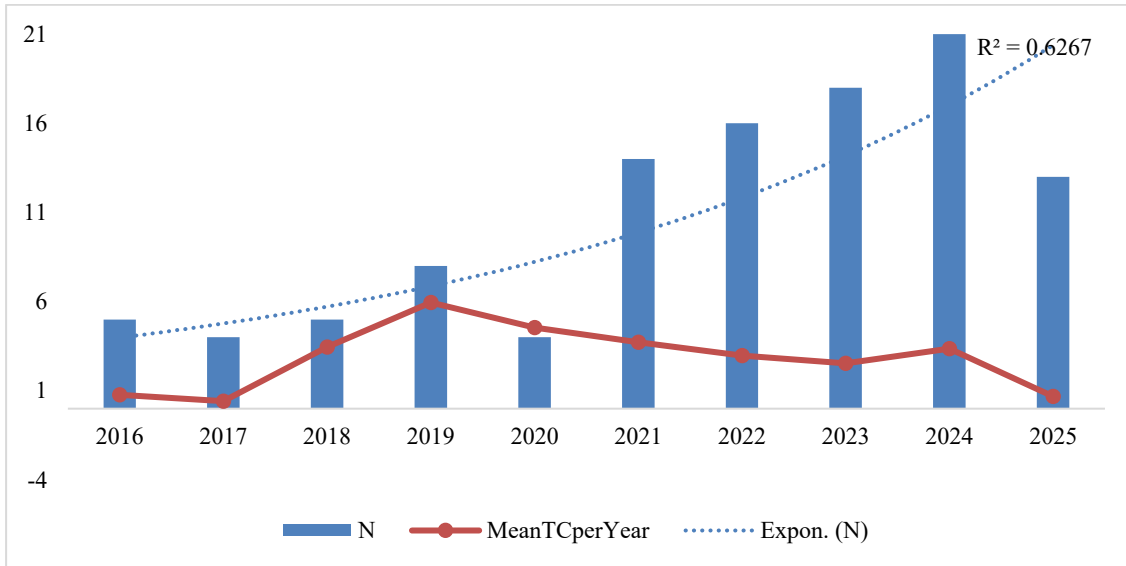
The annual distribution of publications and citation patterns is presented in Figure 2. The results show a relatively moderate level of research productivity during the 2016–2020 period, followed by a noticeable increase from 2021 onwards. This shift reflects a growing academic interest in smart attendance systems, particularly in relation to the expanding use of digital and data-driven technologies in educational environments. The increase after 2020 can be interpreted in connection with the broader acceleration of digital transformation in education. During and after the COVID-19 pandemic, educational institutions adopted various digital tools to monitor student participation, manage hybrid and online learning, and support institutional accountability. Within this context, smart attendance systems gained greater relevance as part of a wider ecosystem of educational data and monitoring practices.

The number of publications peaked in 2024, indicating heightened research activity and increased technological adoption in this area. The slight decline observed in 2025 is more likely attributable to incomplete indexing of recent publications than to a reduction in research interest. Furthermore, the trendline ( $R^2 = 0.6267$ ) suggests a consistent positive growth pattern over time. This indicates that research on smart attendance systems continues to develop steadily and is becoming increasingly relevant within the broader domain of educational technology and digital transformation.

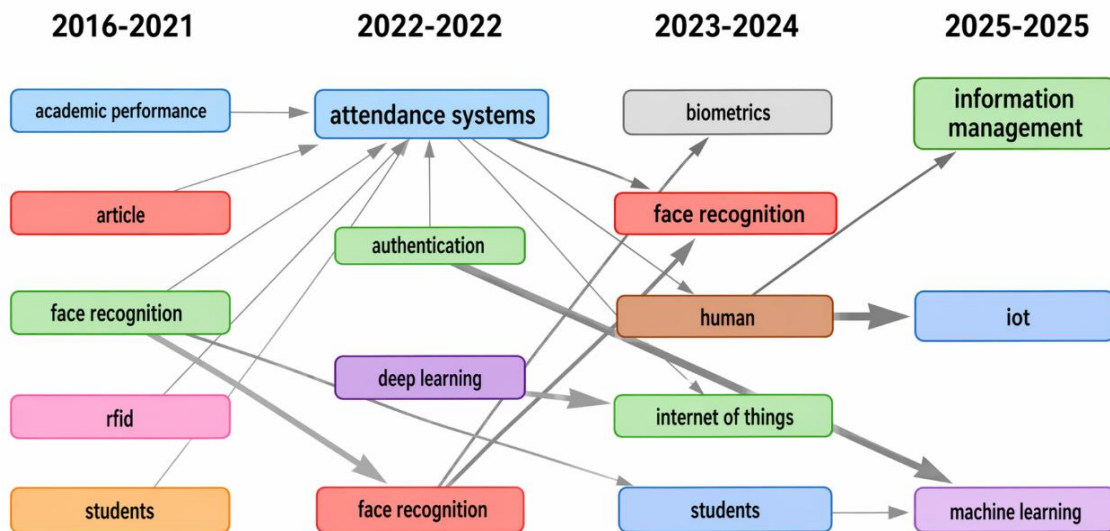
### 3.3. Thematic Evolution

The thematic evolution of smart attendance systems research is presented in Figure 3, illustrating the progression of dominant research themes over time. During the early period (2016–2021), research was primarily focused on foundational topics such as student attendance, RFID-based systems, and academic performance, reflecting an emphasis on basic system implementation and monitoring. In 2022, the research focus began to shift toward more advanced system architectures, particularly attendance systems and authentication mechanisms, supported by emerging technologies such as facial recognition and deep learning. This transition indicates the growing integration of artificial intelligence in attendance monitoring processes. In the subsequent period (2023–2024), research themes expanded to include the Internet of Things (IoT), image processing, and machine learning, highlighting the growing complexity and

interconnectedness of SAS. These developments suggest a move toward intelligent and context-aware systems capable of real-time data processing and analysis. By 2025, the research landscape showed a stronger focus on information management and data-driven monitoring systems. This shift reflects a broader transformation in which attendance is no longer treated merely as a recording mechanism but as part of a comprehensive data ecosystem supporting decision-making and institutional analytics.



**Figure 2.** Annual distribution of publications (N) and mean citations per year, including exponential trendline ( $R^2 = 0.6267$ ) for smart attendance systems research (2016–2025)



**Figure 3.** Thematic evolution of research on smart attendance systems, showing the transition from foundational attendance technologies to data-driven, intelligent monitoring systems (2016–2025).

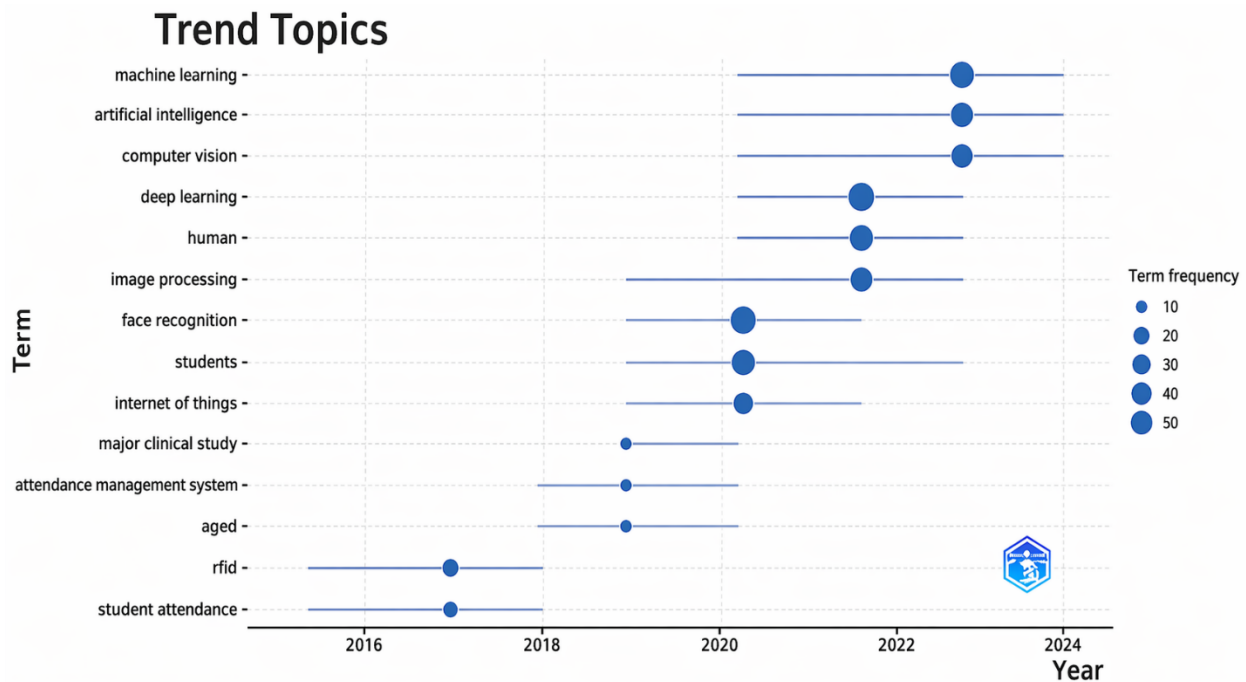
### 3.4. Trending Topic Analysis

The evolution of research topics in smart attendance systems is presented in Figure 4. The figure illustrates a clear temporal progression in dominant research themes across the study period. In the early phase, particularly between 2016 and 2018, the research focus was on foundational topics such as RFID and student attendance. These themes reflect an emphasis on basic identification technologies and administrative monitoring functions, where attendance was treated mainly as a procedural requirement within educational institutions. As the field developed, the thematic focus gradually shifted toward more advanced and technology-driven approaches. During the 2019–2021 period, terms such as face recognition, image processing, and the Internet of Things began to emerge, indicating the integration of automated,

interconnected systems in attendance monitoring. This phase marks a transition from simple recording mechanisms to systems capable of real-time identification and data processing.

In recent years, particularly since 2022, research trends have increasingly been dominated by artificial intelligence-related topics, including machine learning, deep learning, and computer vision. The prominence of these terms suggests a strong movement toward intelligent and predictive systems, in which attendance data are not only captured but also analyzed to support decision-making. These developments reflect a broader shift toward data-driven educational environments in which attendance becomes part of a larger analytical framework. In addition to technology-oriented themes, several general descriptors, such as “students” and “human,” also appear in the dataset, indicating that attendance research remains situated within broader educational and behavioral contexts. However, these terms are less dominant compared to technology-focused keywords, suggesting that the research emphasis remains largely centered on system capabilities rather than on pedagogical interpretation.

The temporal distribution of topics also reveals differences in the duration of research attention. Early themes such as RFID tend to appear over shorter time spans, while more recent topics related to artificial intelligence show longer and more sustained prominence. This pattern indicates that contemporary research is increasingly concentrated on advanced analytical technologies, reinforcing the transition from administrative attendance recording toward intelligent, data-driven monitoring systems in education.



**Figure 4.** Temporal distribution of trending topics in smart attendance systems research, highlighting the shift from RFID-based approaches to artificial intelligence and IoT-driven systems.

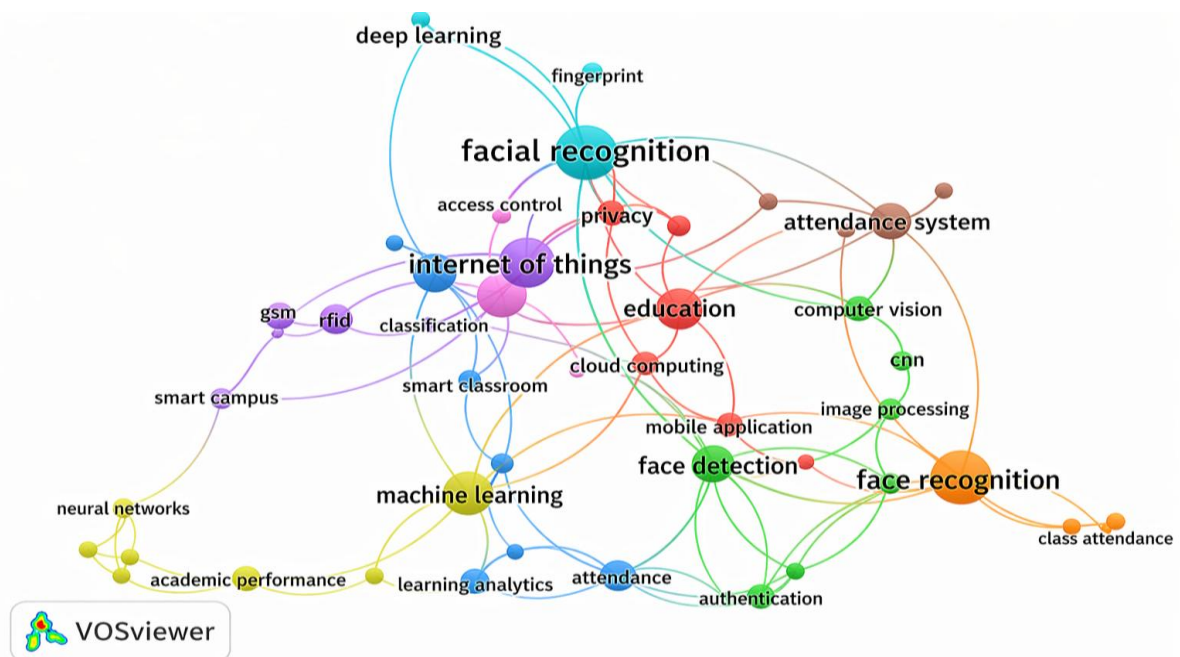
### 3.5. Co-Occurrence Network and Thematic Clusters

The co-occurrence analysis of author keywords identified 52 significant keywords grouped into nine thematic clusters, as illustrated in Figure 5. These clusters represent the intellectual structure of research on smart attendance systems and highlight both dominant and emerging areas within the field. The most prominent clusters center on biometric authentication and computer vision technologies, including face recognition, image processing, convolutional neural networks (CNNs), and OpenCV. This pattern indicates that SAS research is strongly influenced by advances in artificial intelligence and visual recognition technologies. In addition to these dominant themes, several clusters reflect system integration and application-oriented research, such as RFID-based attendance systems, the Internet of Things, and smart campus environments. Other clusters highlight educational and analytical dimensions, including learning analytics, educational data mining, and academic performance prediction. These findings suggest that the field is gradually expanding beyond technical implementation toward data-driven educational applications.

**Table 3.** Main keyword clusters identified through co-occurrence analysis

Cluster	Color	Keywords
1	Green	Face detection, image processing, authentication, biometrics, CNN, computer vision, OpenCV, Viola–Jones.
2	Light blue	Facial recognition, fingerprint, distance learning, deep learning, and BP neural network.
3	Orange	Face recognition, distance education, class attendance, and a convolutional neural network.
4	Brown	Attendance system, RFID technology, smart attendance system, web application.
5	Red	Education, biometrics, cloud computing, database, e-learning, Internet of Things (IoT), mobile application, and privacy.
6	Purple	Internet of Things, RFID, GSM, classification, smart campus, smart school.
7	Pink	IoT, access control, and attendance monitoring.
8	Blue	Artificial intelligence, attendance, data visualization, educational technology, gamification, learning analytics, smart classrooms.
9	Yellow	Machine learning, academic performance, educational data mining, neural networks, prediction.

The clustering pattern further shows that technology-oriented themes occupy a more central position in the network than educational and socio-ethical themes. While concepts such as learning analytics, educational technology, and academic performance appear across several clusters, their relative positioning suggests a supporting rather than dominant role. In contrast, keywords related to biometric authentication, face recognition, RFID, and the Internet of Things are more strongly connected and frequently co-occur, indicating greater structural importance within the research landscape. This distribution suggests that research on smart attendance systems is still largely driven by technological capabilities and system performance, with comparatively less emphasis on pedagogical interpretation and ethical considerations.

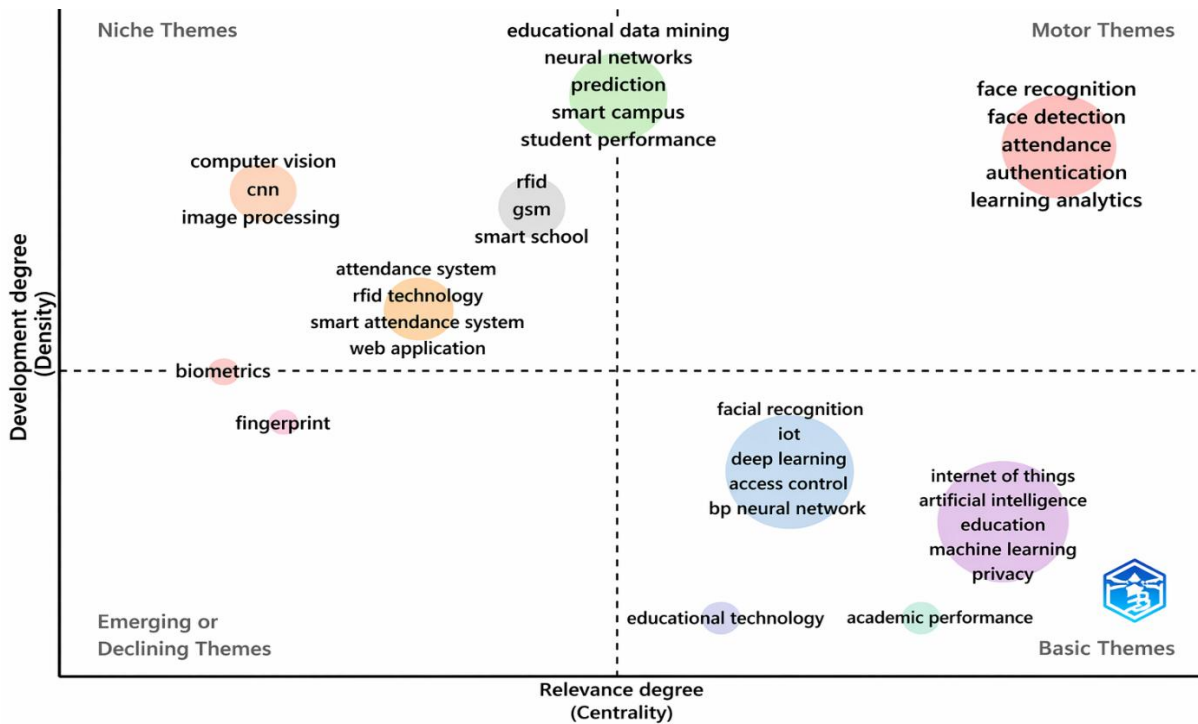


**Figure 5.** Co-occurrence network of author keywords illustrating thematic clusters in smart attendance systems research.

### 3.6. Representation of Ethical and Privacy Issues

The representation of ethical, privacy, and surveillance-related themes in research on smart attendance systems is summarized in Table 4. The analysis shows that these dimensions appear far less frequently than dominant technological themes, indicating an imbalance in the current research landscape. Keywords related to privacy, such as privacy and data privacy, are present but occur in relatively low frequencies and tend to occupy peripheral positions within the network. Similarly, surveillance-related terms appear only sporadically and do not form a coherent or stable thematic cluster. More notably, keywords directly associated with ethical considerations, such as fairness, consent, and bias, are absent from the dataset. This absence suggests that ethical concerns are not yet systematically integrated into the core

discourse of SAS research. In contrast, terms related to technical control, including authentication, access control, and security systems, appear more frequently and occupy structurally stronger positions within the network. This contrast indicates that the research focus remains largely centered on system functionality, performance, and technical reliability, rather than on broader educational or socio-ethical implications. Taken together, these findings point to a structural gap in the literature. While smart attendance systems are increasingly embedded within data-driven educational environments, critical dimensions such as ethics, privacy, and power relations remain underexplored. This imbalance suggests that current research tends to frame SAS primarily as a technological solution, without fully addressing its implications for student agency, data governance, and institutional responsibility



**Figure 6.** Thematic map showing the distribution of research themes based on centrality and development in smart attendance systems research.

**Table 4.** Representation of Ethical Issues, Privacy, and Power Relations

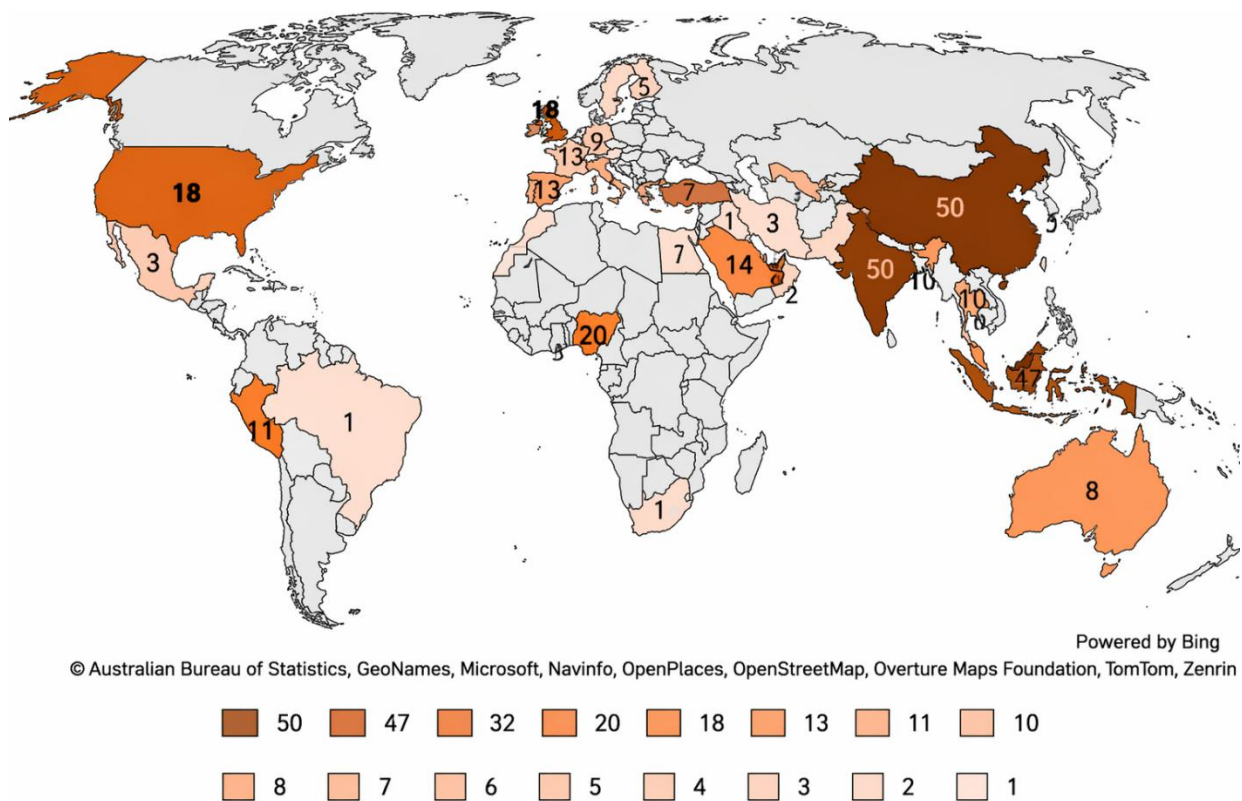
Dimension	Representative Keywords	Frequency	Thematic Position
Privacy	privacy; data privacy	5; 2	Very peripheral
Surveillance	surveillance; surveillance cameras	1; 1	Sporadic, not clustered
Ethics	ethics; fairness; consent; bias	0	Not present
Power relations	power relations; control (explicit)	0	Not present
Technical control	authentication; access control; security systems	6; 5; 4	Relatively prominent

### 3.7. Geographical Distribution and Collaboration

The geographical distribution of publications on smart attendance systems is illustrated in Figure 7. The results show that a substantial proportion of research output originates from countries in Asia and other developing regions, with China, India, and Indonesia emerging as the most active contributors. This pattern may be associated with the growing demand for scalable, cost-effective, and practical attendance solutions in educational contexts with large student populations and limited administrative resources. At the same time, the distribution reflects the broader expansion of SAS research across regions, although contributions from Europe and North America appear less prominent in publication volume. Rather than indicating a disparity in research capacity, this pattern may suggest differences in research priorities, with some regions focusing more on system implementation and operational efficiency, while others engage more extensively with regulatory, theoretical, or policy-related aspects of educational technology.

The co-authorship network analysis, presented in Figure 8, identifies 24 countries that meet the minimum collaboration threshold. The network structure reveals several interconnected clusters, indicating active cross-country collaboration among researchers. Countries such as China, India, and Indonesia occupy relatively central positions within the network, suggesting their influential role in shaping current research directions and facilitating knowledge exchange across regions. Overall, these findings indicate that SAS research is not only geographically widespread but also increasingly collaborative. The combination of growing publication output and expanding international partnerships suggests a field that is gradually consolidating and maturing. This collaborative dynamic supports the ongoing transition of SAS research from basic administrative applications to more advanced, integrated systems that incorporate artificial intelligence, biometric identification, and data-driven analytics.

However, this interpretation should be read carefully, since geographical publication patterns can be shaped by database coverage, indexing practices, and the search strategy used in this study. Even so, the findings indicate that emerging economies have become important contributors to practical innovation in educational technology, particularly in the design and implementation of smart attendance systems.



**Figure 7.** Geographical distribution of scientific publications in smart attendance systems research across countries.

The co-authorship network analysis (Figure 8) further illustrates the structure of international collaboration, highlighting clusters of countries actively engaged in joint research.

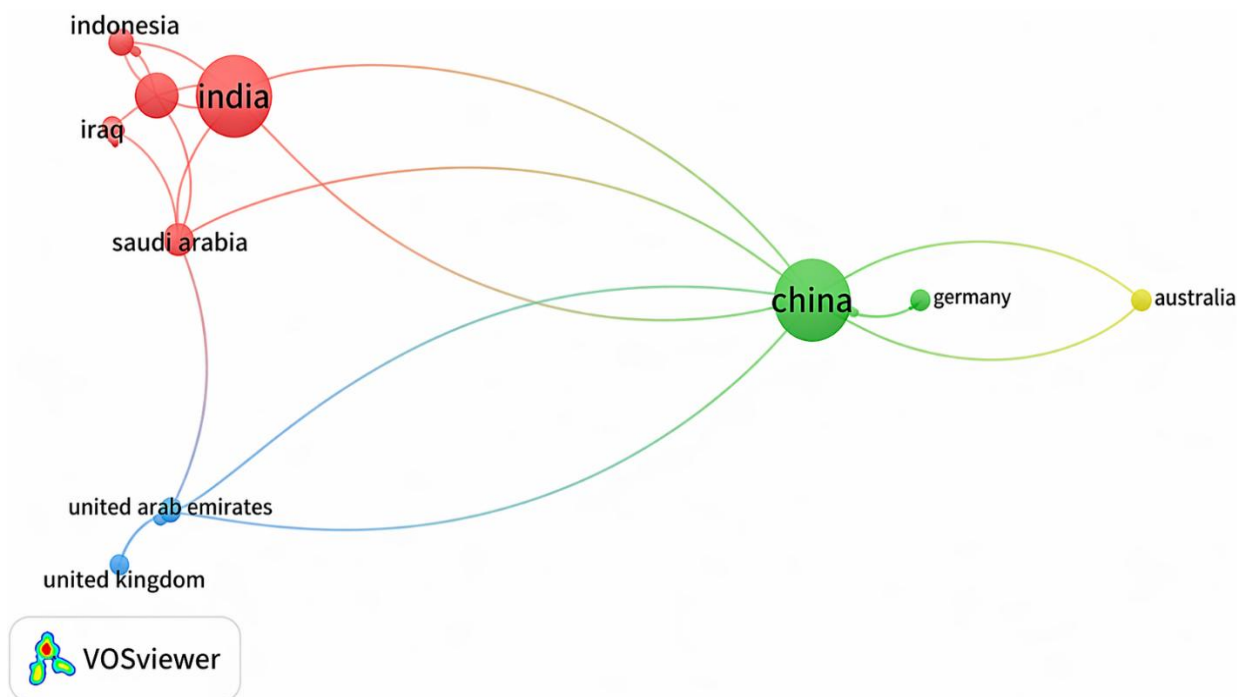
### 3.8. Interpretation of Findings

The results of this study demonstrate a substantial expansion of research on smart attendance systems in education over the past decade, with a particularly notable increase after 2020. This acceleration is closely associated with the broader digital transformation of educational systems, especially during and following the COVID-19 pandemic, when institutions were required to rapidly adopt online and hybrid learning modalities. In this context, automated monitoring tools, including smart attendance systems, became increasingly important as mechanisms for tracking student participation, maintaining accountability, and supporting institutional management (Badshah et al., 2023; Lien & Vhaduri, 2023; Pahuja & Goel, 2024; Zainuddin et al., 2024).

While the growth in publication output indicates a rising level of scholarly attention, the field's thematic composition reveals a strong concentration on technological aspects. A significant proportion of the studies examined in this analysis

focus on improving system performance, particularly in identification accuracy, processing speed, and preventing fraudulent attendance practices such as proxy attendance. These priorities reflect a technical problem-solving orientation, where attendance is treated primarily as a measurable and optimizable variable within system architectures.

This pattern suggests that SAS research continues to be largely framed within a systems engineering paradigm. Although such a perspective is valuable for advancing technological capabilities, it tends to limit engagement with the broader educational implications of attendance. As a result, attendance is often conceptualized in operational terms rather than as an indicator of meaningful participation or engagement. This imbalance highlights a key limitation in the current research landscape, where the expansion of technological solutions has not been matched by a corresponding development in pedagogical or theoretical understanding.



**Figure 8.** Co-authorship network by country showing international collaboration patterns in smart attendance systems research.

A central finding of this study is the transformation of attendance from a simple administrative record into a computational object embedded within data-driven systems. Traditionally, attendance has been used as a procedural tool to document student presence and ensure compliance with institutional requirements. However, the integration of technologies such as machine learning, facial recognition, and data analytics has fundamentally altered this function. In contemporary research, attendance is increasingly treated as structured data that can be processed, analyzed, and used to generate predictive insights. This shift reflects a broader trend toward the datafication of educational processes, where various aspects of student behavior are translated into quantifiable data points for analysis and decision-making. Within this framework, attendance is no longer a passive record but an active component of analytical systems that aim to identify patterns, predict outcomes, and inform institutional strategies.

Despite the presence of themes such as learning analytics and academic performance in the literature, these elements often play a secondary role. Attendance is frequently incorporated into predictive models as a variable, rather than being examined as a complex educational phenomenon in its own right (Almalawi et al., 2024; Sastro & Syafiih, 2024; Shafiq et al., 2022). This reductionist approach may limit researchers' and practitioners' ability to fully understand the relationship between attendance and learning outcomes. The evolution of themes identified in earlier sections reinforces this transformation. As shown in Figures 3 and 4, the progression from RFID-based systems to artificial intelligence-driven approaches illustrates not only technological advancement but also a shift in conceptual focus. Attendance is increasingly embedded within systems designed to monitor, analyze, and predict student behavior, thereby altering its meaning within educational contexts. One of the most significant contributions of this study is the identification of an “ethical silence” in SAS research. Although issues related to privacy and surveillance are occasionally mentioned, they

appear infrequently and do not form central themes in the research landscape. More explicitly normative concepts, such as fairness, consent, and bias, are largely absent.

This absence is particularly striking when compared to the broader field of educational technology, where ethical considerations have become increasingly prominent. Issues such as data governance, algorithmic transparency, and institutional accountability are widely recognized as critical concerns (Dhirani et al., 2023; Z. Li & Zhang, 2025; Marshall et al., 2022; Nguyen et al., 2023). The limited attention given to these issues within SAS research suggests a gap between technological development and ethical reflection. The concept of “ethical silence” does not imply that researchers are unaware of ethical issues. Rather, it indicates that these issues are not systematically addressed within the research agenda. Evidence from the keyword analysis and network structure supports this interpretation, showing that ethical and privacy-related terms occupy peripheral positions and lack strong connections to dominant themes. This condition raises important questions about the long-term implications of SAS implementation.

As these systems become more widespread, the absence of a robust ethical framework may lead to unintended consequences, including the erosion of student autonomy, the normalization of surveillance practices, and the reinforcement of power imbalances within educational institutions. The technocentric orientation of SAS research also brings attention to issues of equity and access. Many smart attendance systems are designed with implicit assumptions about the availability of technological infrastructure, including stable internet connections, reliable devices, and consistent system performance. However, these assumptions do not hold across all educational contexts (Deng & El Hag, 2024; Golden et al., 2023), particularly in resource-limited regions (Heeks, 2022; Imran, 2023). In practice, technological limitations can have significant consequences for students. For example, unreliable connectivity or inadequate hardware may lead to failed authentication attempts or incomplete attendance records. In such cases, students may be penalized not for a lack of participation but for factors beyond their control. This situation highlights the risk of digital exclusion, where technological systems inadvertently disadvantage certain groups of learners.

Furthermore, the implementation of rigid attendance systems may exacerbate existing inequalities. Students in well-resourced environments are more likely to benefit from accurate and reliable systems, while those in under-resourced settings may face additional barriers. This dynamic underscores the importance of considering contextual factors in the design and deployment of SAS. Addressing these challenges requires a shift in focus from purely technical performance to broader considerations of inclusivity and accessibility. Future research should explore how attendance systems can be adapted to diverse educational contexts and how potential inequalities can be mitigated. The geographical distribution of SAS research provides further insight into the patterns observed in this study. A significant proportion of publications originates from countries in the Global South, including China, India, Indonesia, and Malaysia. In these contexts, research tends to focus on practical challenges such as scalability, efficiency, and fraud prevention (Raihan et al., 2025; Rosário & Raimundo, 2025).

This emphasis on applied solutions reflects the specific needs of educational systems in these regions, where large student populations and limited administrative resources create a demand for efficient monitoring tools. As a result, research is often oriented toward developing and implementing technological systems to address these challenges. In contrast, regions that are more actively engaged in discussions of data governance and ethics appear less prominent in terms of publication volume in this field. This difference does not necessarily indicate a lack of interest, but rather a divergence in research priorities. While some regions focus on technological implementation, others may prioritize theoretical, regulatory, or policy-related issues.

These geographical dynamics play a significant role in shaping the overall direction of SAS research. When most contributions emphasize practical implementation, the field tends to prioritize technical solutions, potentially at the expense of broader critical discussion. Understanding this context is essential for interpreting the observed imbalance between technological and ethical dimensions. Beyond its technological and geographical dimensions, the evolution of SAS research also reflects a deeper epistemological shift in how attendance is understood. Traditionally, attendance has been associated with presence, participation, and engagement within a learning environment. It has been seen as an indicator of student involvement and interaction.

However, in the context of smart attendance systems, attendance is increasingly defined by system-generated data. Presence is determined through mechanisms such as biometric authentication, QR code scanning, or digital activity logs. This shift transforms attendance from a relational concept into a measurable signal. This redefinition has important implications for educational practice. When attendance is reduced to a data point, its connection to meaningful engagement may be weakened. Students may be physically or digitally present, depending on the system, but this does not necessarily indicate active participation or learning. Moreover, the increasing reliance on automated monitoring systems raises questions about the role of surveillance in education. While such systems can improve efficiency and

accountability, they may also contribute to a culture of constant observation, where compliance is prioritized over engagement. This shift calls for a critical examination of how technology shapes educational practices and values.

This study contributes to the literature by providing a comprehensive mapping of the evolution of SAS research and by highlighting a persistent imbalance between technological advancement and critical reflection. By introducing the concept of “ethical silence,” the study offers a new perspective on the limitations of current research and underscores the need for a more integrated approach. Several directions for future research can be identified. First, there is a need for empirical studies examining how attendance data are interpreted and used in educational settings. Such studies can help clarify the relationship between attendance and engagement. Second, the development of ethical frameworks is essential to address issues such as privacy, consent, and fairness. Third, future research should consider the inclusivity of attendance systems, particularly in resource-limited contexts. Ultimately, the advancement of SAS research requires a shift toward a more balanced perspective that integrates technological innovation with pedagogical insight and ethical awareness. By addressing these dimensions, future studies can contribute to the development of attendance systems that are not only efficient but also meaningful and equitable.

### 3.9. Limitations

This study is limited to Scopus-indexed journal articles published in English between 2016 and 2025. As a result, relevant studies indexed in other databases, conference proceedings, books, or non-English publications may not have been included. In addition, the interpretation of thematic clusters is influenced by the selected search terms and bibliometric thresholds. Therefore, the findings should be understood as a focused mapping of technology-mediated smart attendance research rather than a complete representation of all attendance-related studies in education.

## 4. Conclusions

This study investigated the evolution of smart attendance system (SAS) research in education through a bibliometric and science mapping analysis of 108 Scopus-indexed journal articles published between 2016 and 2025. The findings demonstrate a clear shift from conventional attendance recording toward data-driven monitoring practices, supported by the integration of technologies such as RFID, facial recognition, computer vision, deep learning, Internet of Things (IoT), and predictive analytics. This transition indicates that attendance is no longer treated solely as an administrative record but has become embedded within a broader educational data ecosystem. Despite this rapid technological advancement, the analysis reveals that the research landscape remains predominantly technocentric. Most studies emphasize system performance, including authentication accuracy, automation, and operational efficiency, while critical dimensions such as ethics, privacy, surveillance, and pedagogical meaning receive comparatively limited attention. The absence or marginal presence of key concepts such as fairness, consent, bias, student agency, and power relations highlights what can be interpreted as an “ethical silence” within the current body of SAS research.

This study contributes to the literature by providing a comprehensive mapping of thematic developments and by demonstrating that smart attendance systems not only enhance administrative efficiency but also fundamentally reshape how attendance is conceptualized. Attendance is increasingly treated as a machine-verifiable data point rather than a meaningful indicator of student participation and engagement. This shift carries important implications for educational governance, the design of learning analytics systems, and the role of student autonomy in data-driven learning environments. In light of these findings, future research should move beyond purely technical optimization and adopt a more integrative perspective that combines technological innovation with pedagogical theory, ethical frameworks, and inclusive design principles. Attention should be directed toward developing transparent, accountable, and context-sensitive attendance systems that are responsive to diverse educational settings. Without such a shift, the continued expansion of SAS risks reinforcing surveillance-oriented practices without adequately addressing their broader educational and societal implications. Overall, this study underscores the need to reposition smart attendance systems not merely as technical solutions, but as socio-technical constructs that shape and are shaped by educational values, institutional practices, and data governance frameworks.

In response to the ethical silence identified in this study, future research should move beyond technical optimization and explicitly incorporate ethical and socio-technical dimensions into the design and evaluation of smart attendance systems. Researchers are encouraged to investigate issues related to informed consent, algorithmic fairness, bias detection, transparency, and student autonomy. Comparative studies across institutional and cultural contexts are also needed to examine how governance frameworks and regulatory environments shape the implementation of attendance technologies. In addition, interdisciplinary approaches that integrate educational technology, learning analytics, data

ethics, and policy studies will be essential to ensure that smart attendance systems are developed as accountable, inclusive, and pedagogically meaningful tools rather than merely as instruments of surveillance and administrative control.

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