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Bibliometric Analysis of Internet of Things (IoT) Applications in Vocational Education

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ABSTRACT

The rapid integration of Industry 4.0 technologies has necessitated a transformation in vocational education, with the Internet of Things (IoT) emerging as a critical competency. However, a comprehensive mapping of the research landscape in this niche is still limited. This study aims to conduct a bibliometric analysis to identify trends, dominant contributors, and thematic evolutions of IoT applications in vocational education. Data were retrieved from the Scopus database, yielding 121 relevant documents. The analysis focused on four main dimensions: publication year, geographical distribution, subject areas, and source titles, processed through bibliometric mapping techniques. The findings indicate a significant upward trend in publications, reaching its peak in 2024, signaling an urgent global interest in digitalizing vocational training. China and the United States emerged as the most productive countries, reflecting their strategic focus on smart manufacturing and educational innovation. Subject-wise, Engineering and Computer Science dominate the literature, suggesting that research is currently centered on technical infrastructure and system implementation. Furthermore, IEEE was identified as the leading source of publications, reinforcing the technical and standardized nature of current IoT research in the vocational sector. This study highlights a shift from theoretical exploration to practical implementation. The dominance of technical subjects suggests a research gap in the pedagogical and social impacts of IoT, providing a clear direction for future studies to explore the human-centric aspects of IoT-enabled vocational learning.

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1. INTRODUCTION

The global industrial landscape has undergone a seismic shift due to the Fourth Industrial Revolution, where the Internet of Things (IoT) serves as the primary backbone for smart manufacturing and digital ecosystems [1]. This transformation necessitates a workforce that is not only digitally literate but also technically proficient in managing interconnected devices [2]. Consequently, Vocational Education and Training (VET) has been identified as a critical sector for fostering these competencies, as it directly supplies the technical talent required to maintain and innovate within Industry 4.0 frameworks [3].

The rapid evolution of Industry 4.0 mandates that technical training frameworks integrate smart automation technologies to maintain market relevance [14]. Consequently, fostering hands-on competencies in hardware programming and embedded systems has become an essential prerequisite for modern electronics engineering students [15]

However, despite the clear demand for IoT skills, vocational institutions face significant challenges in systematically integrating these technologies into their curricula. There is a lack of standardized frameworks for IoT pedagogy, leading to fragmented implementation where some institutions focus solely on hardware while others prioritize software, often without a clear understanding of global industrial trends [4]. This problem is compounded by the rapid pace of technological change, which often outstrips the ability of vocational educators to update their training modules, resulting in a mismatch between graduate skills and industry requirements [5].

Existing literature on IoT in education has predominantly focused on theoretical frameworks for higher education or specific technical case studies involving sensor deployment in laboratory settings [6]. While these studies provide valuable technical insights, they often overlook the broader strategic mapping of how IoT is being institutionalized across the diverse landscape of vocational training globally. Furthermore, systematic reviews in this niche are scarce, leaving researchers and policymakers without a clear data-driven overview of which geographical regions, institutions, and thematic clusters are leading the current discourse [7].

To address this gap, this study proposes a bibliometric analysis as a comprehensive solution to map the intellectual structure of IoT applications in vocational education. By retrieving and analyzing 121 curated documents from the Scopus database, this research employs quantitative mapping techniques to evaluate publication trends, geographical contributions, and subject distributions [8]. This approach allows for the transformation of vast metadata into actionable insights, identifying the peak in publication activity in 2024 and the dominant roles of countries such as China and the United States, alongside the technical leadership of sources like IEEE [9].

The innovation and new value of this research lie in its role as a "research compass" for the vocational sector. Unlike previous qualitative reviews, this study provides the first

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large-scale quantitative evidence of the shift toward "Engineering" and "Computer Science" dominance in vocational IoT research, highlighting a critical need for more "Social Science" integration to address pedagogical effectiveness [10]. By revealing these specific gaps and trends, this research offers a novel strategic roadmap that enables vocational stakeholders to align their investments and curriculum development with the actual trajectory of global scientific innovation.

2. RESEARCH METHOD

This study employs a descriptive design with a bibliometric approach to systematically map the scientific landscape of Internet of Things (IoT) applications in vocational education. The entire document identification and selection process was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol to ensure that the research procedures are transparent and replicable [11]. The research was conducted chronologically through four main stages: identification, screening, eligibility, and inclusion.

In the identification stage, data acquisition was performed through the Scopus database using the search query: TITLE-ABS-KEY ("Internet of Things" OR "IoT") AND ("Vocational Education"), which initially yielded 2,913 records. From this total, 141 records were removed, leaving 2,772 records to proceed to the screening stage [1]. The screening process was conducted by applying strict inclusion criteria: articles published between 2010 and 2025, categorized under the subject areas of Engineering and Computer Science, consisting of original research articles, and written in English [3].

Following the screening process, the documents were evaluated during the eligibility stage, resulting in 121 articles that met the requirements for full-text analysis. Ultimately, 121 articles were finalized for inclusion in this bibliometric analysis [5]. The final dataset was then cleaned using OpenRefine software to ensure metadata accuracy before visualization. The descriptive analysis focused on temporal trends, showing a peak in 2024; geographical distribution, with a focus on China and the United States; and source analysis centered on IEEE publications [6]. All data were visualized using VOSviewer to provide an objective descriptive overview of the interconnections between research variables [7].

2.1. Data Source

The Scopus database was selected as the primary data source for this study due to its reputation for providing extensive literature coverage, encompassing internationally reputable journals and proceedings within the domains of engineering, information technology, and education. Scopus's advantage in providing structured and standardized bibliographic metadata makes it a highly appropriate instrument for supporting the depth of bibliometric analysis

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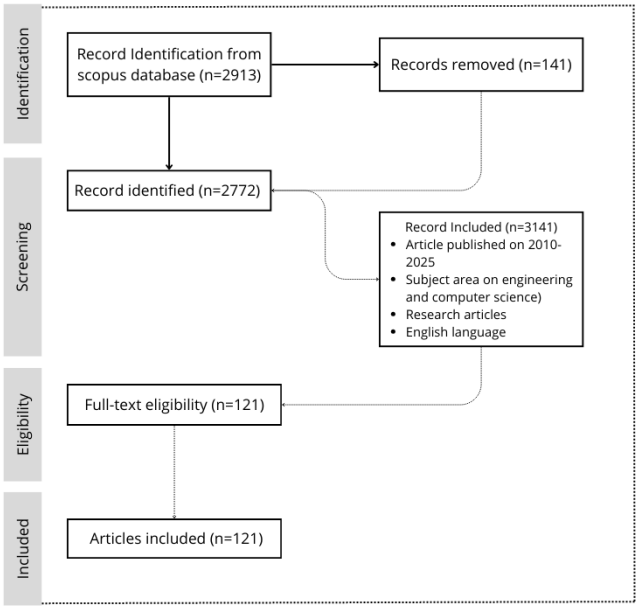

Figure 1. PRISMA Flow Diagram

2.2. Inclusion and Exclusion Criteria

The literature screening process was conducted by establishing strict inclusion and exclusion criteria. Inclusion criteria were utilized to identify articles with comprehensive data relevant to the research objectives, while exclusion criteria were applied to eliminate documents that did not meet the technical parameters or substantive requirements established in this study

Table 1. Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Technology	Internet Of Things (IoT)	Other technologies (e.g., virtual reality, robotics, e-learning, LMS, etc.)
Publication Year	2015-2025	Prior to 2015
Subject Scope	Students in Computer Science and Engineering education	Students in primary, junior high, senior high schools, and general higher education
Research Design	Quasi-experimental research incorporating control and experimental groups with pre-test and post-test measures	Correlational, regression, case study, R&D, 4D, and qualitative research designs
Language	Bahasa Inggris	Non-English

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To ensure the sharpness of the descriptive analysis, this study implemented strict inclusion and exclusion criteria, as detailed in Table 1. The primary focus on the technological aspect was specifically limited to Internet of Things (IoT) applications to avoid bias from other digital technologies, such as robotics or pure e-learning platforms [11]. Document selection was conducted within a publication timeframe of the last ten years (2015–2025) to capture the most current trends in the Industry 4.0 era [1]. Furthermore, this study only included research conducted on students in the fields of Computer Science and Engineering.

3. RESULTS AND DISCUSSION

3.1. Annual Publication Trend Analysis (2015-2025)

Based on the data obtained from Scopus, the development of research concerning Internet of Things (IoT) applications in vocational education demonstrates highly dynamic growth. Although the search period spans from 2015 to 2025, a significant surge became evident in the post-pandemic era, with the publication peak occurring in 2024. This indicates that the adoption of IoT technology has shifted from mere theoretical discourse to an implementational necessity within vocational curricula to address the challenges of Industry 4.0 [6], [8]. This upward trend also aligns with educational digitalization efforts in various countries striving to synchronize graduate competencies with the smart factory ecosystem

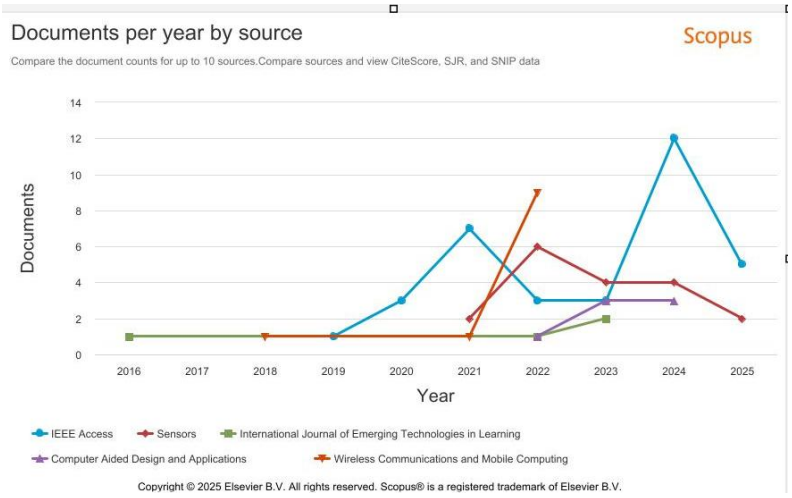

Figure 2. Publication distribution by year

3.2. Geographic Distribution and Productivity of Countries

Descriptive analysis of the authors' countries of origin reveals that China and the United States are the primary contributors to this discourse. China's dominance is closely

linked to their national policies regarding industry-education integration, whereas the United States focuses more on instructional innovation and IoT system security within school environments [7]. On the other hand, the emergence of research from developing countries indicates that the IoT is starting to be viewed as a crucial instrument for enhancing the quality of practical learning in vocational workshops, making it more efficient and digitally measurable [9].

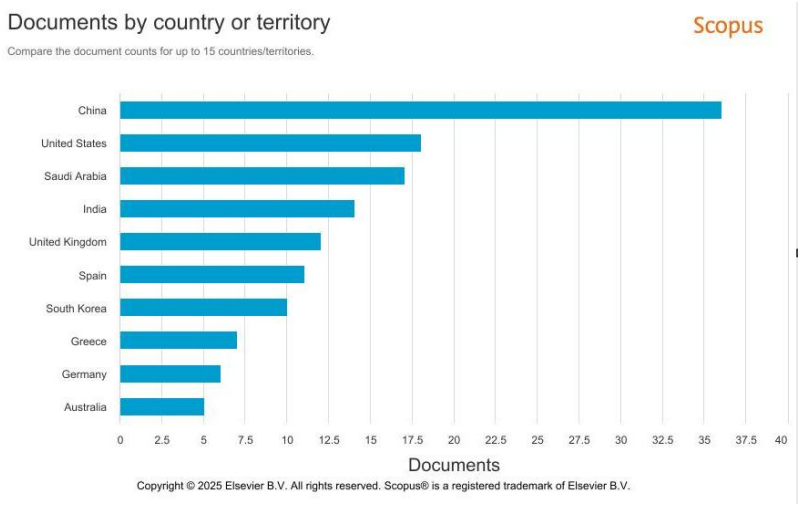

Figure 3. Publication distribution by country

3.3. Analysis of Subjects and Publication Sources

The data indicates that the fields of Engineering and Computer Science lead as the dominant subjects, confirming that current research remains heavily focused on technical infrastructure development, sensor connectivity, and IoT system architecture [9]. IEEE emerged as the primary publication source (journals/proceedings) for this research, suggesting that technical standards and system reliability are the main parameters discussed by researchers(fig.2). However, there is a research gap regarding pedagogical aspects and the socio-psychological impact on students, which requires further attention in future studies [10].

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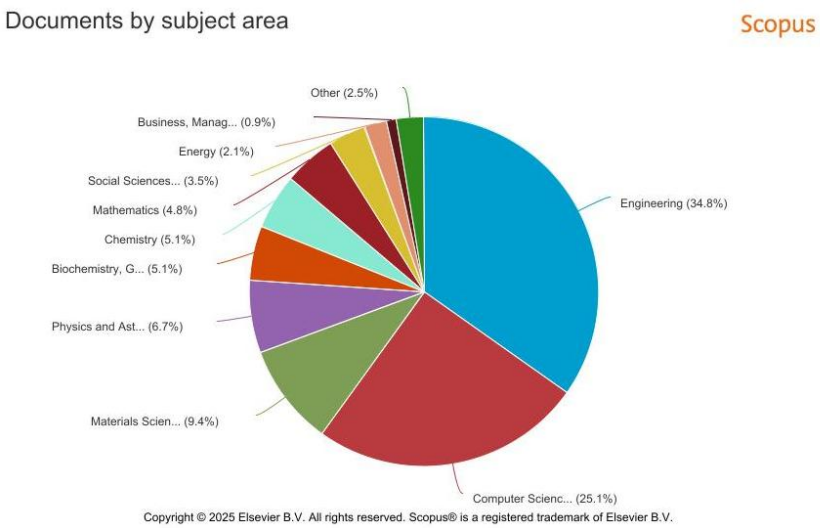

Figure 4. Distribution of Observed research fields

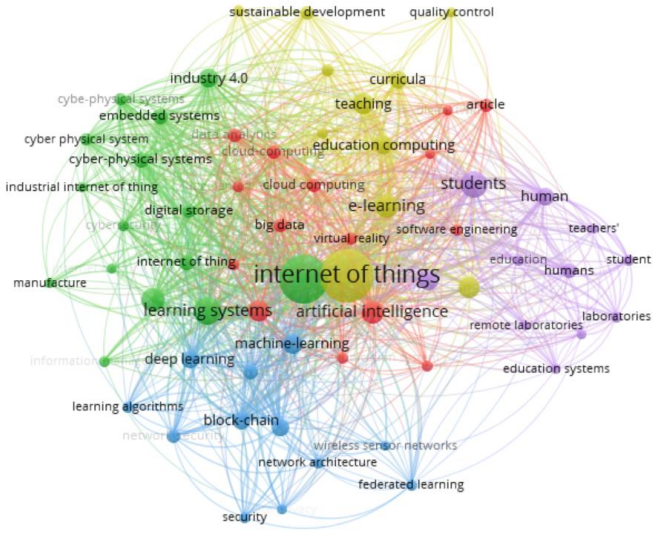

Figure 5. Distribution of observed research fields based on Scopus data

The network visualization illustrates the emergence of several interconnected thematic clusters, representing the intellectual structure of the field. Clusters positioned near the center of the network are dominated by keywords such as artificial intelligence, learning systems, machine learning, e-learning, and students. This central positioning suggests that Internet of Things (IoT) research in technical education is fundamentally anchored in the development of intelligent systems and the integration of smart technologies to facilitate complex engineering instruction. This trend is consistent with

previous studies [1], which highlight that connected IoT ecosystems are increasingly utilized to deepen conceptual understanding and modernize learning experiences in higher education.

Beyond the purely technical clusters, the analysis reveals dimensions focusing on pedagogical and evaluative frameworks. These are characterized by terms such as learning outcomes, student engagement, motivation, and usability. The presence of these nodes indicates a critical shift in the literature: the focus has expanded from the mere technical architecture of IoT devices to a rigorous evaluation of how these systems impact the overall learning process and student performance. This evolution confirms that IoT research in the technical domain is becoming increasingly multidisciplinary, successfully bridging the gap between engineering innovation and educational theory [3].

The overall network density and the high frequency of interconnections between keywords suggest that IoT in vocational and technical education has matured into a robust and well-integrated research area. However, the presence of smaller nodes with fewer connections points toward emerging "niche" topics. These include specialized IoT applications in specific engineering branches or localized learning contexts, representing fertile ground for future investigation.

In conclusion, this co-occurrence analysis demonstrates that while the field is currently dominated by technological infrastructure and system-based simulations, there is a significant rise in research dedicated to pedagogical efficacy and learner-centered experiences. The resulting network structure reaffirms that this discipline operates at the intersection of technology, engineering, and education, moving steadily toward a holistic, learning-oriented paradigm.

3.4. IoT in the Context of Vocational Education

This research clearly illustrates that the scholarly discussion surrounding IoT is highly correlated with institutional adaptability and curriculum alignment. In developing regions, this structural shift is heavily driven by industrial demand, forcing vocational institutions to systematically realign their core graduate competencies with emergent IoT job profiles [16]. However, the operational deployment of such advanced technologies often encounters bottleneck friction regarding localized digital infrastructure readiness and teacher technological literacy [17]. As a tactical response to these structural gaps, recent local initiatives have increasingly pivoted toward creating low-cost, customized microcontroller training kits integrated with IoT capabilities to maintain pedagogical continuity in technical classrooms [18]

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4. CONCLUSION

In summary, this bibliometric analysis provides a comprehensive overview of the research landscape regarding IoT integration in vocational education. The steady upward trajectory in publication volume, peaking in 2024, underscores an accelerating global recognition of IoT as a cornerstone of Industry 4.0 within vocational training frameworks. Furthermore, the prominent scholarly output from China and the United States, coupled with the dominance of technical domains such as Engineering and Computer Science, reflects a global priority on establishing robust technical infrastructures and smart manufacturing capabilities.

The study concludes that while the technical foundation for IoT in vocational education is rapidly maturing—as evidenced by the high volume of publications in venues like IEEE—a significant imbalance persists within the current literature. Research remains heavily skewed toward system implementation and architectural design, leaving the pedagogical, psychological, and socio-economic dimensions of this digital shift largely under-explored. This pattern is also observable in regional contexts, where local vocational studies often focus predominantly on the development of practical IoT learning media for specific technical subjects [12].

However, several limitations must be considered when interpreting these findings. First, the bibliographic data retrieval was strictly confined to a single database, Scopus. Although Scopus is recognized for its rigorous peer-review indexing standards, this reliance potentially omits relevant technical papers, regional vocational studies, or gray literature archived in alternative databases such as Web of Science (WoS), IEEE Xplore, or Google Scholar. Consequently, broader educational technology research trends mapped within local indexes may not be fully represented in this macro-analysis [13]. Second, the search query was limited to English-language keywords, which inherently excluded valuable non-English regional publications, particularly from emerging industrial nations where localized vocational advancements are documented in native languages. Lastly, as a bibliometric study, the evaluation primarily captures the quantitative macro-patterns of metadata rather than qualitatively assessing the instructional efficacy, curricular alignment, or internal validity of the proposed IoT frameworks.

Consequently, future research should bridge these gaps by integrating multi-database datasets and adopting mixed-method systematic approaches to investigate human-centric dimensions. Priority should be given to exploring instructor readiness, student learning experiences, and the long-term impacts of IoT-enabled vocational training on the labor market. By shifting the scholarly focus from "how the technology works" to "how the technology teaches," the academic community can ensure that the digital transformation of vocational education is both technically sound and pedagogically effective.

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