

Research Pattern and Keyword Evolution in Skills-Based Workforce Scheduling: A Bibliometric Analysis

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ABSTRACT

This bibliometric analysis examines research trends and keyword evolution, highlighting its significance in the field of skills-based scheduling. The primary aim of this study is to assess citation, publication and international collaboration trends, identify key authors, most cited papers, productive journal and keyword co-occurrence trends and evolution. In order to achieve this, a bibliometric analysis was conducted using the Web of Science database, focusing on English articles that contain keywords of “skills-based scheduling” within the years 1978 to 2023. The analysis was performed utilizing bibliometric tools such as Publish or Perish, Microsoft Excel and VOSviewer. The results reveal that out of the 2,426 articles initially retrieved from the period 1978 and 2023, only 1666 met the study’s inclusion criteria. The findings indicate that the United States leads in publication output, contributing 20.57% of all articles, with Nicola J. Hodges identified as the most influential author in the field. The BMC Medical Education journal emerged as the most productive journal, publishing 18 articles with a total of 207 citations. Furthermore, keyword co-occurrence analysis shows a significant evolution, growing from 40 keywords to 6,061 over 45 years. These insights provide a valuable roadmap for future researchers, highlighting existing gaps in the literature and offering guidance for developing research strategies and collaborations.

Keywords: Skills-based scheduling, Bibliometric analysis, Research trends, Keyword co-occurrence, VOSviewer analysis

INTRODUCTION

Skills-based scheduling is a workforce management strategy that assigns tasks based on employees’ specific skills rather than traditional shift or seniority systems. This approach optimizes productivity and customer satisfaction by aligning the right expertise with tasks, ensuring that skilled employees are available when needed. Employee skills are key drivers of competitive advantage, and effective skill management, particularly in learning, retention, and training, plays a crucial role in improving workforce efficiency [1]. This method minimizes downtime and ensures that skilled employees are available when needed, enhancing overall business performance.

In recent years, skills-based scheduling has gained traction as organizations aim to improve resource allocation in an increasingly competitive and fast-paced environment. The increasing globalization and overcrowded job market, particularly following recent economic crises, have further emphasized the importance of investing in human capital to achieve organizational success [2]. Implementing training and development programs that align workforce capabilities with organizational goals, especially in sectors like banking, can improve performance and adapt to remote work demands through dynamic, skills-based scheduling systems [2], [3].

Several studies have highlighted the benefits and challenges of implementing skills-based scheduling in various sectors. One consistent finding is the positive impact on operational efficiency. For example, [4] demonstrates that cross-training employees can significantly enhance performance in handling customer requests. At the same time, [5] shows that skills-based training significantly improves employees’ ability to recognize and report malicious elicitation. However, challenges in implementation include the complexity of workforce management

in terms of tracking and updating employee skill sets in real-time. Managing schedules, maintaining accurate skill databases, and ensuring employees are adequately trained in multiple competencies can be resource-intensive and challenging [4]. Without advanced scheduling software that integrates real-time data, organizations struggle to deploy this method effectively. In response to these challenges, researchers such as [6] have advocated for the integration of artificial intelligence (AI) and machine learning (ML) technologies, which can analyze employee performance and suggest optimal scheduling based on skill development trends, helping organizations improve efficiency and effectiveness while benefiting managers, HR professionals, and employees [6].

Despite the growing body of literature on skills-based scheduling, there is limited understanding of the collaborative networks, citation impacts, and keyword evolution that shape this field. Moreover, many studies focus on specific sectors without providing a comprehensive view across various industries. This knowledge gap highlights the need for a thorough analysis that maps the overall research landscape. Therefore, to address these gaps, a bibliometric analysis can provide an in-depth examination of the specific field in articles indexed in major databases such as Google Scholar, Scopus and Web of Science [7], [8]. Bibliometric analysis is one of the review methods that offers a structured and quantitative assessment of the growth and influence of specific research fields by examining publication trends, citation patterns, authorship, keyword usage, and collaborative networks [7], [9]. This approach systematically gathers and analyses bibliographic data to identify patterns, relationships, and gaps within the existing body of literature [8], [10], [11]. For example, a bibliometric analysis by [7], which focuses on the developments in scheduling algorithms research, reveals that the publication trend since the early 2010s, with significant activity particularly noted in sectors like healthcare, logistics, and information technology. This trend highlights the growing importance of scheduling algorithms as an essential approach for enhancing workforce management and improving operational efficiency across a range of industries.

Hence, this study will conduct a bibliometric analysis specifically on skills-based scheduling researchs, aiming to provide valuable insights for future researchers by identifying current research trends and influential literature in the field. The analysis in this study will utilize tools such as Publish or Perish, VOSviewer, and Microsoft Excel, to map and visualize the research landscape of skills-based scheduling. The study seeks to answer the following research questions: (RQ1) What are the primary trends in skills-based scheduling research? (RQ2) Which notable publications, authors, and journals have contributed most to the field? (RQ3) What are the most common themes in skills-based scheduling research? and (RQ4) How have these themes evolved?

METHODOLOGY

In this study, a systematic approach was followed to conduct a bibliometric analysis using data from the Web of Science (WOS) database. First, the research question was defined, and relevant keywords were selected to perform a comprehensive search in the WoS database, which is known for its extensive coverage of scientific literature across various disciplines [12]. A search query used in this study, shown in Figure 1, was constructed to retrieve relevant data while minimizing irrelevant results. The initial search will include a variety of publication types, such as articles, conference papers, and books. Afterwards, the results should be filtered based on specific criteria such as publication years, document types and subject areas to ensure the dataset is relevant. This approach ensures that the most appropriate and high-quality studies are used in the subsequent bibliometric analysis [13]. Once the search results are obtained for the initial and refinement stage, the metadata, including key bibliographic elements like titles, authors, publication years, abstracts and citations, will be exported into CSV and text files. This exported dataset will serve as the foundation for the bibliometric analysis.

This bibliometric analysis uses data retrieved on September 24, 2024, and employs three primary tools: Publish or Perish (PoP), Microsoft Excel and VOSviewer. The objective of this study is to explore research trends, citation patterns, and theme evolution in the field of skills-based workforce scheduling research. The methodology for this study was adapted and modified from [8], [14], [15], [16], incorporating an additional step to enhance the analysis. This extra step involved comparing citation metrics between the initial and refined results of skills-based workforce scheduling using Publish or Perish (PoP) software. This modification provides deeper insights into the impact of the filtered publication, offering a more comprehensive understanding of citation patterns and research influence.

Once the citation analysis is complete, Microsoft Excel will be used for data cleaning and descriptive analysis.

The raw data from the Web of Science often contains inconsistencies, such as duplicate records or variations in author names. Afterwards, Microsoft Excel will be employed to generate descriptive statistics and visualizations. These will include the distribution of publications by year, a breakdown of contributions from the top authors and institutions, and a journal analysis to identify the most common sources for publishing on the skills-based scheduling topic.

The third tool, VOSviewer, will be used for an in-depth network analysis, mapping the relationships between authors, citations, and keywords through co-authorship, co-citation, and keyword co-occurrence analyses. Co-authorship analysis will reveal the collaborative network among researchers and institutions, providing insight into knowledge sharing across geographical and institutional boundaries [16], [17]. Co-citation analysis will help identify influential papers and reveal intellectual structures within the field, while keyword co-occurrence analysis will demonstrate how various research themes are interconnected.

In this study, keyword co-occurrence will be examined in two analyses: an overall analysis of all keywords spanning 45 years (1978-2023) and a phase-specific analysis that tracks keyword evolution across four chronological phases (Foundation Phase: 1978-1993; Development Phase: 1994-2003; Innovation Phase: 2004-2013; Exploration Phase: 2014-2023). The link strength in these network visualizations reflects the correlation strength between nodes, with higher values indicating stronger relationships [17]. As mentioned by [18], VOSviewer creates these networks using two counting methods: full counting and fractional counting. This study employs full counting, which assigns an integer value to the connection strength based on the co-authored documents. As a result of these connections, visual maps such as co-authorship and keyword co-occurrence maps will show the thematic clusters that have developed in the literature, which identify both core topics and emerging research areas.

In the final stage, the data gathered from these analyses will then be interpreted to uncover significant findings. The analysis will highlight key research areas, as well as collaboration patterns between authors, institutions and countries. The study will also examine temporal trends, revealing how the volume of research and citation patterns have evolved. Moreover, the keyword co-occurrence analysis will offer insights into the thematic development of the research related to skills-based scheduling by showing how research themes evolved across the decades. The detailed methodology of this study is illustrated in Figure 1 below.

While the analysis will provide valuable insights, this study also has certain limitations that need to be highlighted. This study will only use a dataset retrieved from the Web of Science, which may not cover all relevant articles, particularly from less established or regional journals. Besides that, the inconsistencies in the dataset, such as errors in author names or incomplete records, may affect the results. These limitations are not only in the Web of Science. Each of the search tools, such as the Scopus database and Publish or Perish software. However, despite these challenges, the combined use of Web of Science, Publish or Perish, Microsoft Excel, and VOSviewer will provide a comprehensive understanding of the research trends in skills-based scheduling.

In conclusion, this methodology will offer a detailed bibliometric analysis of the field, revealing key patterns and thematic developments in the literature. By combining citation analysis, descriptive statistics and network visualizations, this study will contribute valuable insights into the evolution of research in skills-based workforce scheduling and lay the groundwork for future investigations.

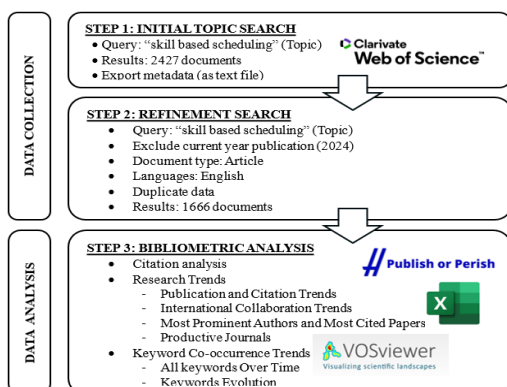


Figure 1. Bibliometric analysis flowchart

RESULTS AND DISCUSSION

The results of this bibliometric analysis on the term “skills-based scheduling” from the Web of Science database are presented in three main sub-sections: Citation Analysis using Publish or Perish, Descriptive Analysis using Microsoft Excel, and Network Analysis using VOSviewer.

A. Citation Analysis

This section will reveal and interpret the main findings from the evaluation of citation metrics using Publish or Perish software between initial and refined papers. The citation metrics analysis provides valuable insights into the scholarly impact and research output regarding the term “skill-based scheduling”. The comparison between the initial search and the refinement search is presented in Table 1 below, revealing significant trends in citation and publication patterns.

Table 1: Citation metrics comparison between initial and refinement search

Metric Data	Initial Search	Refinement Search
Source	Web of Science	Web of Science
Query	“Skill based scheduling”	“Skill based scheduling”
Query date	24/09/2024	24/09/2024
Year	1978 – 2024 (46 years)	1978 – 2024 (46 years)
Papers	2427	1666
Citations	40,217	33,766
Cites/year	874.28	734.04
Cites/paper	16.57	20.27
Cites/author	12,541.25	10,391.06
Papers/author	843.11	544.93
Author/paper	4.11	4.29
h-index	85	79
g-index	134	119
hi-norm	43	38
hi-annual	0.93	0.83
hA-index	20	17

The initial search yielded 2,427 papers, while the refinement search resulted in 1,666 papers. This data indicates a substantial reduction of 761 publications after applying specific criteria, which exclude the current year, 2024 and English articles only. Notably, the total citations decreased from 40,217 in the initial search to 33,766 in the refined search. This drop reflects the elimination of less-cited or potentially less-relevant works, suggesting that the refinement process enhances the quality of the selected literature.

In terms of citations per year, it shows a decrease from an average of 874.28 in the initial search to 734.04 in the refined search. This decline aligns with the reduction in overall citations and may indicate that the refined set of papers, while more relevant, received fewer citations in the same timeframe. However, the metric for citations per paper increased from 16.57 to 20.27. This suggests that the documents retained in the refined search are cited more frequently on average, highlighting their higher scholarly impact.

Meanwhile, the citations per author seem to have dropped from 12,541.25 to 10,391.06 as a result of refinement. This decrease could reveal that while fewer authors contributed to the refined set of papers, their collective impact remained significant. On the other hand, the number of papers per author decreased from 843.11 to 544.93, suggesting that authors in the refined dataset may be more specialized or focused on fewer works, potentially leading to more profound research contributions in skills-based scheduling. In terms of author-to-paper ratio, the results slightly increased from 4.11 to 4.29 in the refined search. This change indicates a trend towards collaborative research efforts, with more authors contributing to each paper in the refined set. This scenario often leads to higher quality outputs due to diverse expertise and perspectives.

Furthermore, there are other metrics given by Publish or Perish, including h-index, g-index, hi-norm, hi-annual and hA-index. The h-index and g-index metrics revealed notable changes, with the h-index decreasing from 85 in the initial search to 79 in the refined search and the g-index dropping from 134 to 119. These declines suggest that while the overall impact of the literature in the refined search remains significant, some highly cited works may have been filtered out. The h-index measures the number of papers with citations equal to or greater than a certain threshold, while the g-index places greater emphasis on highly cited articles; thus, the reductions in these indices imply a shift towards more recently published works with strong citation potential. Similarly, the hi-norm and hi-annual values also declined, from 43 to 38 and from 0.93 to 0.83, respectively, reflecting the average annual citations of the most cited papers. This indicates that the refinement process has led to a selection of documents with fewer average annual citations, although the chosen works still maintain significant visibility within the research community. Additionally, the hA-index fell from 20 to 17, signifying a reduction in the number of articles that have received a substantial number of citations over the years, further supporting the notion that the refinement search prioritized quality over quantity.

In summary, the citation metrics between initial and refined searches reveal a clear picture of the research landscape surrounding skills-based scheduling. The refinement process not only reduced the total number of papers but also highlighted a collection of works with higher average citations per paper, suggesting that the selected literature possesses more outstanding quality and scholarly impact.

B. Research Trends

This section aims to provide a comprehensive overview of the evolving landscape of research in the selected field. In this study, the trends and impacts of skills-based scheduling will be examined by analyzing publication patterns across leading countries and academic institutions, identifying prominent authors with the highest number of publications in this area, and exploring productive journals that have published influential works that show their contributions to the academic discourse. These elements will illustrate the dynamic nature of research trends and the key players that shape the topic's development.

Publication and Citation Trends

The publication and citation trends for skills-based scheduling are based on the retrieved data from the Web of Science database from 1978 to 2023, as shown in Figure 2 below. It shows a clear evolution in academic interest. Initially, from 1978 to the late 1990s, the number of publications was limited, with years like 1979 to 1981 seeing no publications at all. There were only a few publications during the early 1980s, peaking at just two in 1985. The early 1990s witnessed some growth, with a total of six publications in 1992 and four in 1993. This data reflects the limited recognition of the topic's importance.

Meanwhile, the early 2000s marked the beginning of a significant upward trend, likely driven by technological advances and growing awareness of the need for skill optimization in various industries, particularly after 2005, when publications surged to 26. By 2010, the number had risen to 47, indicating increasing interest in the topic. This growth continued, with notable peaks in subsequent years: 2014 saw 75 publications, followed by 86 in 2015, and a remarkable jump to 141 publications in 2019, which remained consistent into 2020. The trend has continued upward in recent years, with 161 publications in 2021, 175 in 2022, and 154 in 2023, demonstrating that the subject of skills-based scheduling continues to attract significant scholarly attention and research output.

In terms of citation trends, as can be seen from Figure 2 below, the citations align with the publications, showing a significant peak in 2020. This pattern supports the idea that the academic community widely recognizes and is

engaged in research on skills-based scheduling. The slight decline post in 2020 in both publications and citations could signal a natural levelling off or indicate that the field is stabilizing as foundational theories and models become established. Alternatively, it may point to emerging subfields or new directions within the broader scope of workforce optimization. The overall upward trend and sustained high levels of publications and citations in recent years confirm that skills-based scheduling remains an essential and relevant area of study, with ongoing implications for industries and workforce management strategies.

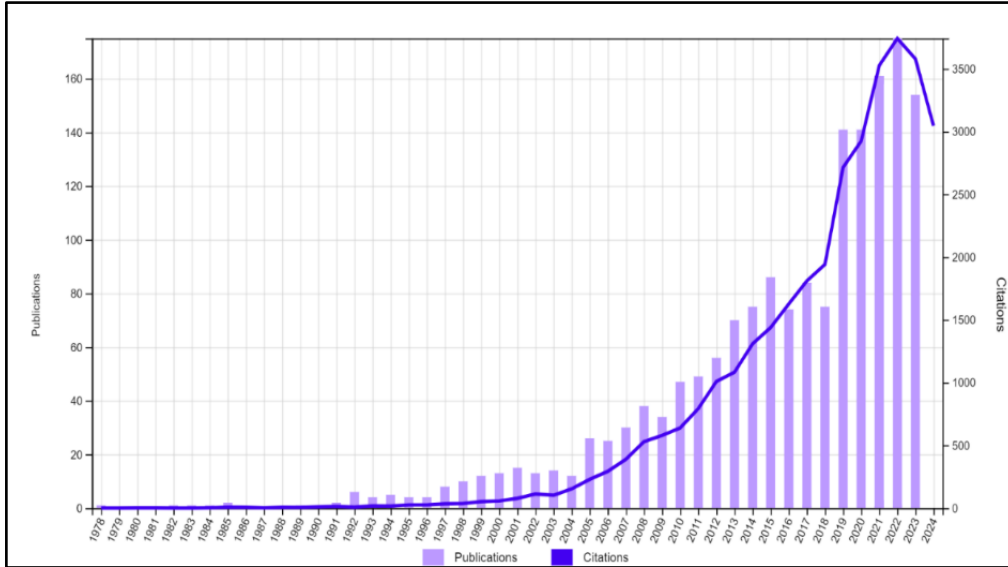


Figure 2. Publications versus citations over time for skills-based scheduling research (Source: Web of Science)

International Collaboration Trends

In order to develop a better understanding of international collaboration in publication trends, a co-authorship analysis was performed using VOSviewer, with the results of the network visualization shown in Figure 3. This analysis focused on articles involving a maximum of 25 countries per document. Among the selected articles, only those from countries with at least five publications were included in the analysis. Consequently, 50 out of 96 countries met the threshold. However, of these 50 countries, only 49 are connected, indicating instances of collaboration among them.

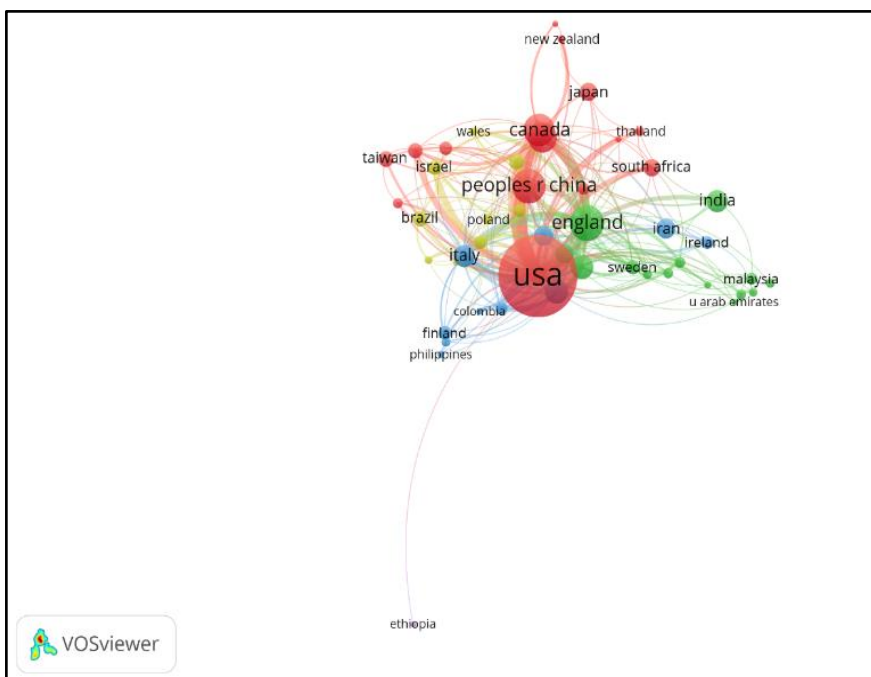


Figure 3. Network visualization of the international collaboration for skills-based scheduling research from 1978 to 2023 (Online map: <https://tinyurl.com/yn82rtq2>)

According to Figure 3, all 49 countries have been clustered into 5 clusters, which were grouped based on collaboration intensity and had 274 collaborations, producing a total link strength of 566. Cluster 1 (Red) contained 15 items, Cluster 2 (Green) included 14 items, Cluster 3 (Blue) comprised ten items, Cluster 4 (Yellow) had nine items and Cluster 5 (Purple) only had one item. The details for countries in each cluster are listed in Table 2 below. As can be seen in Figure 3, some nodes and links are connected. The node sizes represent the influence of each item (country) within the network based on specific metrics, such as the number of documents, citations, or collaborations associated with that country. Countries with larger nodes mean they contribute more documents or have more citations [14]. Based on Figure 3, the United States (USA) had the largest node in the map, indicating its dominant role in global research collaborations with the highest number of documents (677), citations (16,255) and a total link strength of 181. These data show the USA’s significant contribution to the global academic ecosystem, making it a focal point for international co-authorship.

Following closely, England has published 127 documents and retrieved 2,965 citations, showcasing a strong presence and an active network of partnerships (link strength of 125), particularly with countries like India and Iran. China is another major contributor, with 123 documents and 2,054 citations, reflecting its impactful collaborative efforts (link strength of 55), especially in collaboration with the USA. Canada also plays an essential role, with 107 documents and 2,793 citations, maintaining a strong network (link strength of 45), mainly through its collaborations with the USA. Additionally, Australia contributes significantly, with 92 documents and 2,123 citations, and actively participates in international partnerships (link strength of 69). Other key countries include Germany (60 documents, 963 citations, link strength 40), Italy (51 documents, 1,333 citations, link strength 53), and the Netherlands (56 documents, 959 citations, link strength 50), each showing strong engagement and cooperation within this research area. These findings illustrate the international scope and collaborative nature of research on skills-based scheduling, with meaningful contributions from both developed and developing nations, highlighting a strong trend towards global cooperation to advance the field.

Table 2: International collaboration for skills-based scheduling research

Cluster	Countries (Number of documents; Number of collaborations)
Cluster 1 (Red): 13 countries	USA (677; 42), Canada (107; 15), China (123; 24), Australia (92; 27), South Africa (31; 10), Turkey (20; 6), South Korea (24; 12), Taiwan (27; 5), Thailand (9; 8), Belgium (15; 11), Portugal (12; 7), New Zealand (7; 4), Tanzania (5; 6), and Vietnam (5; 3).
Cluster 2 (Green): 9 countries	England (127; 36), Netherlands (56; 19), India (52; 6), Spain (38; 19), Sweden (21; 11), Malaysia (15; 8), Saudi Arabia (12; 6), Singapore (11; 7), Greece (10; 11), Nigeria (9; 2), Egypt (8; 6), Bangladesh (6; 7), Pakistan (13; 13), and United Arab Emirates (5; 6).
Cluster 3 (Blue): 10 countries	Germany (60; 18), France (39; 19), Italy (51; 23), Iran (41; 6), Finland (19; 7), Ireland (17; 6), Switzerland (17; 15), Austria (9; 8), Philippines (6; 4), and Colombia (6; 5).
Cluster 4 (Yellow): 9 countries	Brazil (25; 12), Scotland (25; 11), Norway (20; 20), Denmark (17; 14), Israel (22; 11), Poland (12; 2), Argentina (7; 7), Wales (7; 7), and Chile (5; 8).
Cluster 5 (Purple): 1 country	Euthopia (5; 1)

Most Prominent Authors and Most Cited Papers

This sub-section will present the top 5 authors with the highest number of publications (Table 3) and the top 10 most cited papers (Table 4) in skills-based scheduling research, revealing both their contributions and the collaborative dynamics. As in Table 3, Hodges Nicola J. stands out as the most prolific author, with an h-index of 33, indicating a substantial impact within the literature. With seven total articles and 82 total citations, Hodges

contributes significantly to the discourse on practice design in sports coaching. The author’s highly cited work, “An Extended Challenge-based Framework for Practice Design in Sports Coaching” [19], suggests a focused research agenda that resonates with the academic community, reinforcing the importance of practice design in this field. Affiliated with the University of British Columbia, Canada, Hodges exemplifies how targeted research can lead to impactful contributions.

Following Nicola J Hodges is Narayana Manjunatha, with six total articles and 93 total citations, resulting in a contribution rate of 36%. His notable article, “Designing and implementing an innovative digitally driven primary care psychiatry program in India” [20], emphasizes the increasing importance of digital solutions in healthcare, with his affiliation to the National Institute of Mental Health and Neurosciences in India highlighting the relevance of his research in a critical global health context. Meanwhile, Kenneth Silverman, sharing an h-index of 36, also has six articles and 141 citations. His highly cited work, “A Web-based Therapeutic Workplace for the Treatment of Drug Addiction and Chronic Unemployment” [21], addresses pressing social issues, illustrating the author’s commitment to applying research for societal benefit. As a member of Johns Hopkins University, Silverman’s contributions reflect an interdisciplinary approach to complex challenges, enhancing the visibility and applicability of his findings.

Meanwhile, Channaveerachari Naveen Kumar, with an h-index of 42, demonstrates robust research impact despite having only five articles. His 71 total citations and 0.30% contribution rate highlight his work in the same innovative digital psychiatry program as Manjunatha, suggesting potential collaborative efforts between the two authors. Kumar’s association with Chitkara University in Punjab emphasizes the growing focus on digital innovations in mental health care. Lastly, Suresh Bada Math, also affiliated with the National Institute of Mental Health and Neurosciences in India, has an h-index of 27, with five articles and 71 citations. Similar to Kumar, Math’s contributions to the digitally driven psychiatry program further illustrate a concerted effort in this emerging research area. The overlap in their highly cited work suggests a collaborative framework that may enhance the visibility and impact of their research outputs.

Following the discussion on the top authors with the highest number of publications, the most cited papers in skills-based scheduling research demonstrate a diverse range of influential studies across various disciplines, particularly in medical training, psychology, and manufacturing. The leading paper, titled “Virtual Reality Simulation for the Operating Room - Proficiency-based Training as a Paradigm Shift in Surgical Skills Training” [22], published in 2005 in the *Annals of Surgery* journal, has accumulated 735 citations, contributing 2.17% of the total citations, emphasizes a paradigm shift in surgical skills training through proficiency-based models. Following this paper, the paper [23] discusses the effectiveness and cost efficiency of bench models over traditional operating room experience.

Another highly cited paper, [24] and [25] published in 2006 in the *Journal of Child Psychology and Psychiatry* and *Annals of Surgery*, respectively, received 481 citations (1.42%) and 476 citations (1.41%). Additionally, a paper [26] published in 2001 in the *Journal of Applied Sport Psychology* accumulated 359 citations (1.06%), presenting a functional equivalence model for motor imagery in sport psychology. In conclusion, these top-cited papers highlight the interdisciplinary impact of skills-based scheduling research, underscoring its applications in enhancing training protocols, developmental studies, and sports psychology, with medical training emerging as a particularly dominant focus area.

Table 3: Top 5 most prominent authors with the highest number of publications

No	Author Name	H-index	Total articles	Total citations	Contribution Rate (%)	Highly Cited Article (Title)	Current Affiliation	Country
1	Hodges, Nicola J.	33	7	82	0.42	An extended challenge-based Framework for practice design in Sports	University of British Columbia	Canada

						Coaching [19]		
2	Manjunatha, Narayana	10	6	93	0.36	Designing and implementing an innovative digitally driven primary care psychiatry program in India [20]	National Institute of Mental Health and Neurosciences	India
3	Silverman, Kenneth	36	6	141	0.36	A Web-based therapeutic workplace for the treatment of drug addiction and chronic unemployment [21]	Johns Hopkins University	USA
4	Kumar, Channa veerachari Naveen	42	5	71	0.30	Designing and implementing an innovative digitally driven primary care psychiatry program in India [20]	Chitkara University	Punjab
5	Math, Suresh Bada	27	5	71	0.30	Designing and implementing an innovative digitally driven primary care psychiatry program in India [20]	National Institute of Mental Health and Neurosciences	India

Table 4: Most cited papers related to skills-based scheduling research

No	Article Title	Year	Source Title	Total citations	Contribution Rate (%)	Publisher
1	Virtual reality simulation for the operating room - Proficiency-based training as a paradigm shift in surgical skills training [22]	2005	Annals Of Surgery	735	2.17	Lippincott Williams & Wilkins
2	Laparoscopic training on bench models: Better and more cost effective than operating room experience? [23]	2000	Journal Of The American College Of Surgeons	547	1.62	Elsevier Science Inc
3	Development in infants with autism spectrum disorders: a prospective study [24]	2006	Journal Of Child Psychology And Psychiatry	481	1.42	Wiley

4	Teaching surgical skills: What kind of practice makes perfect? A randomized, controlled trial [25]	2006	Annals Of Surgery	476	1.41	Lippincott Williams & Wilkins
5	The PETTLEP approach to motor imagery: A functional equivalence model for sport psychologists [26]	2001	Journal Of Applied Sport Psychology	359	1.06	Taylor & Francis Ltd
6	Brain-computer communication: Self-regulation of slow cortical potentials for verbal communication [27]	2001	Archives Of Physical Medicine And Rehabilitation	254	0.75	W B Saunders Co-Elsevier Inc
7	LAPS CARE -: an operational system for staff planning of home care [28]	2006	European Journal Of Operational Research	252	0.75	Elsevier Science Bv
8	The new ACS/APDS skills curriculum: Moving the learning curve out of the operating room [29]	2008	Journal Of Gastrointestinal Surgery	250	0.74	Springer
9	Intervention targeting the development of socially synchronous engagement in toddlers with autism spectrum disorder: a randomized controlled trial [30]	2011	Journal Of Child Psychology And Psychiatry	222	0.66	Wiley
10	Knowledge-driven digital twin manufacturing cell towards intelligent manufacturing [31]	2020	International Journal Of Production Research	214	0.63	Taylor & Francis Ltd

Productive Journals

The analysis of publication and citation metrics across key journals in skills-based scheduling indicates a vibrant and interdisciplinary landscape. The list of the top 10 most popular journals that productively published research articles is listed in Table 5 below. The BMC Medical Education journal leads with 18 publications and a total of 207 citations, highlighting its focus on educational methodologies in healthcare. Its most cited article discusses physiotherapy students' perspectives on online e-learning for interdisciplinary management, underscoring the importance of adapting educational practices in response to contemporary challenges. The Journal of Autism and Developmental Disorders is closely followed by the Journal of Autism and Developmental Disorders, which has 16 publications and an impressive 671 citations. Its highly cited study on teaching behaviours to high-functioning children with autism illustrates the journal's significant impact on understanding effective interventions for developmental disorders.

In addition, the European Journal of Operational Research stands out with 13 publications and 549 citations, reflecting its emphasis on practical applications in healthcare settings, mainly through its highly cited article on the LAPS CARE operational system for staff planning in-home care [28]. Journals like Computers and Industrial Engineering and Computers and Operations Research further contribute to the field with their focus on optimization techniques; the former's simulated annealing algorithm and the latter's goal programming model for nurse scheduling demonstrate the critical role of mathematical programming in workforce management. Overall, these findings highlight the substantial scholarly engagement in skills-based scheduling, with various disciplines converging to enhance training, operational efficiency, and educational practices in healthcare and related fields.

Table 5: The most productive journals that actively published skills-based scheduling articles

No	Publication Title	Total Publications	Total Citations	Highly Cited Article (Title)	Times Cited	Publisher
1	Bmc Medical Education	18	207	Physiotherapy students' perspectives of online e-learning for interdisciplinary management of chronic health conditions: a qualitative study [32]	35	BMC
2	Journal Of Autism And Developmental Disorders	16	671	Teaching on-task and on-schedule behaviors to high-functioning children with autism via picture activity schedules [33]	202	Springer
3	Plos One	14	117	Factors influencing antiretroviral treatment suboptimal adherence among perinatally HIV-infected adolescents in Thailand [34]	38	Public Library Science
4	European Journal Of Operational Research	13	549	LAPS CARE -: an operational system for staff planning of home care [28]	252	Elsevier
5	Computers Industrial Engineering	12	246	A Simulated Annealing algorithm for a mixed model assembly U-line balancing type-I problem considering human efficiency and Just-In-Time approach [35]	67	Elsevier
6	Computers Operations Research	11	399	A 0-1 goal programming model for nurse scheduling [36]	153	Elsevier
7	International Journal Of Production Research	11	503	Knowledge-driven digital twin manufacturing cell towards intelligent manufacturing [31]	214	Taylor & Francis
8	Frontiers In Psychology	10	135	Self-controlled feedback is effective if it is based on the learner's performance: a replication and extension of Chiviacowsky and Wulf (2005) [37]	44	Frontiers
9	Medical Teacher	10	140	High-fidelity simulation is superior to case-based discussion in teaching the management of shock [38]	35	Taylor & Francis
10	Perceptual And Motor Skills	10	273	Subject-Controlled Performance Feedback And Learning Of A Closed Motor Skill [39]	105	Sage Publications

C. Keywords Co-occurrence Trends and Evolution

This sub-section will employ VOSviewer to perform two different analyses: ALL keyword (author and index keywords) co-occurrences and keyword evolution across four chronological phases. The dataset, sourced from the Web of Science, consists of 1,666 English articles that were published till the year 2023. This dataset will be systematically divided into four phases: Foundation Phase (1978-1993), Development Phase (1994-2003), Innovation Phase (2004-2013), Exploration Phase (2014-2023). This segmentation allows for a detailed analysis and discussion of how keyword usage has evolved.

The keyword co-occurrence analysis using VOSviewer provides critical insights into dominant themes and emerging trends within the research field. The software is set to include all keywords, whether assigned by the author or extracted from the database. However, only articles that contain a keyword with at least five occurrences will be chosen for further analysis so that it ensures the relevance and significance of the findings. Consequently, among 7,581 identified keywords, only 475 met this setting and were grouped into five clusters. These clusters consisted of 6,304 occurrences, 10,579 links, and an overall link strength of 15,396, as shown in Figure 4.

As the result of the keywords co-occurrences analysis, “skills” was identified as the most frequently mentioned keyword, appearing 123 times with a total link strength of 547, underscoring its central importance in the body of literature. This keyword was combined with 225 other terms, highlighting its broad relevance across various studies. Similarly, the keyword “education” appeared 122 times, linked with 215 different keywords, and had a total link strength of 464, emphasizing its role as a core theme. Another prominent keyword, “performance,” was observed 118 times with a link strength of 541 and connected to 227 other keywords. These findings suggest that the research focuses heavily on skill development, educational strategies, and performance evaluation, indicating a strong emphasis on improving outcomes through structured training and knowledge dissemination.

By clustering keywords and tracking their co-occurrences, the analysis not only reveals central themes but also provides a comprehensive understanding of the interconnectedness of different concepts over time. This method allows for the identification of shifts in research focus, such as the increasing emphasis on skill development in recent years or the growing integration of educational frameworks into workforce scheduling and optimization studies. These patterns are valuable for recognizing current and emerging research trends, guiding future studies to address gaps and expand on existing knowledge areas.

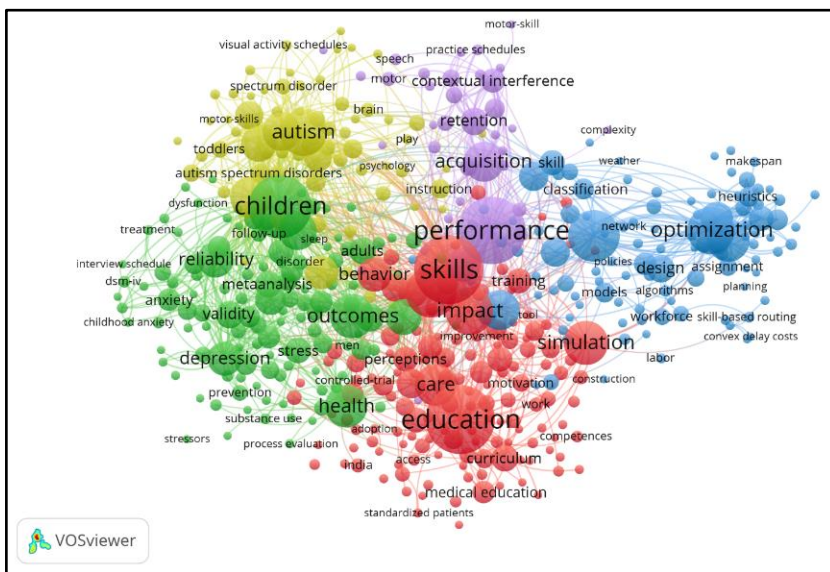


Figure 4. Network visualization of all keywords co-occurrences from 1978 to 2023 (Online map: <https://tinyurl.com/ywvynwq4>)

In addition to examining the overall keywords in skills-based scheduling research, this paper will also delve into the evolution of these keywords across four distinct phases: the Foundation Phase (1978-1993), the Development Phase (1994-2003), the Innovation Phase (2004-2013), and the Exploration Phase (2014-2023). For each phase,

a comprehensive counting analysis will focus on keywords with a minimum of five occurrences (if possible) to create the network visualization in VOSviewer. However, during the Foundation Phase, the threshold was adjusted to include keywords with at least one occurrence due to the limited number of keywords in this period. Over these 15 years, only 40 keywords were identified, with 10 forming a connected cluster. This cluster, consisting of 45 links and a total link strength of 312, is shown in Figure 5a. The connected keywords include “acquisition”, “adults”, “autistic children”, “behavior”, “increase language use”, “instruction”, “reinforcement” “retarded deaf girl”, “skills”, and “time-delay”. Each of these keywords appears once, with nine links and a total link strength of nine, illustrating the foundational themes and early focus areas of the research.

Meanwhile, during the Development Phase (1994-2003), the keyword analysis initially applied a threshold of a minimum of five occurrences. Yet, only four out of 508 keywords (“autism”, “children”, “skills”, and “performance”) met this setting. Since only three of these keywords (“skills”, “autism”, and “children”) were interconnected, the threshold was reduced to a minimum of four occurrences to enhance the network visualization. This adjustment allowed for the connection of 11 keywords, resulting in 19 links and a total link strength of 24. These keywords were grouped into three distinct clusters: Cluster 1 comprised “autism”, “children”, “communication” and “students”; Cluster 2 included “clinical competence”, “performance”, “reliability”, and “skills”; and Cluster 3 consists “acquisition”, “knowledge” and “retention”.

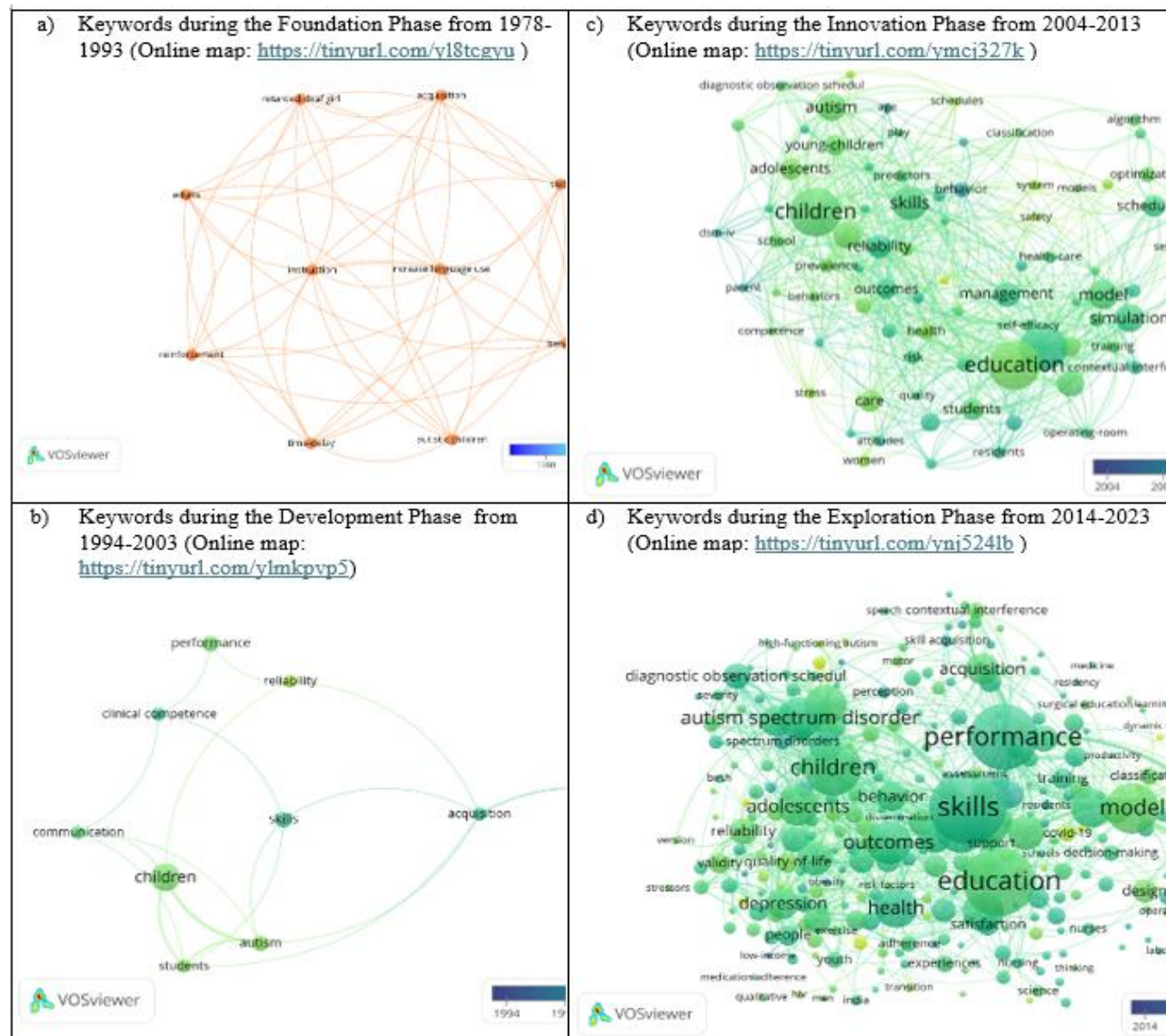
The most frequently occurring keyword during this period was “children”, appearing ten times and linking to 4 other terms, with a total link strength of 7. It was followed by “autism”, which appeared five times, connected to 5 different keywords and had a total link strength of 8. Other notable keywords included “skills”, which also appeared five times, forming four links with a total link strength of 4. Meanwhile, the term “performance” appeared five times but only had two connections, resulting in a total link strength of 2. Additionally, “students” appeared four times and linked to five other terms, achieving a link strength of 7. This phase demonstrates a growing focus on skill development and competency evaluation, particularly within the context of children and autism, indicating a shift in research priorities.

The analysis of the keyword co-occurrences during the Innovation Phase (2004-2013), as shown in Figure 5c, reveals an expanded and interconnected research landscape in skills-based scheduling. A significant increase in the number of nodes can be seen compared to the previous phase, reflecting a broader scope and depth of research activity. During this decade, a total of 2,102 keywords were identified, with 84 of them meeting the threshold of appearing at least five times, qualifying them for further analysis. These 84 keywords were clustered into six distinct clusters with 640 links and a total link strength of 914. The increase in the number of clusters and links, compared to previous phases, indicates a diversification and maturation of the field as new topics and methodologies emerged while existing ones became more integrated. This phase showcases the evolution of research focus, with an emphasis on both the refinement of existing concepts and the exploration of innovative approaches within skills-based scheduling.

Furthermore, Figure 5 illustrates how the network maps became increasingly dense over time, with the Exploration Phase (2014-2023) being the most densely populated. In this period, a total of 6,061 unique keywords were identified, and 317 of them appeared at least five times. These keywords were grouped into six distinct clusters, forming 6,250 connections and a total link strength of 9,158. The keyword “skills,” which has been present since the Foundation Phase (1978-1993), remained a central focus. It appeared 96 times and connected with 159 other terms, including “education,” “performance,” “algorithm,” “meta-analysis,” and “attitudes,” resulting in a total link strength of 386. Similarly, “education” emerged as the second most frequently mentioned keyword in this phase, having initially appeared during the Innovation Phase. During this phase, it was mentioned 89 times, linked to 152 other terms, and had a total link strength of 303 compared to the previous phase, which only appeared 31 times, linked to 33 other keywords and had a total link strength of 67. This data shows a significant evolution in focus on education within skills-based scheduling research, which points towards a more integrated and comprehensive approach to understanding its role and impact. This keyword was associated with several other terms, including “students” (link strength of 12), “impacts” (link strength of 7), “simulation” (link strength of 6), and “curriculum” (link strength of 7).

In summary, the analysis of keyword co-occurrences and the evolution of keywords across the chronological phases offers critical insights into the shifting landscape of skills-based scheduling research. By examining the

variations in the prevalence and interrelationships of popular keywords throughout distinct phases, this study reveals prominent themes and emerging trends in this research area. The noticeable increase in the frequency of keyword occurrences highlights the increasing complexity and significance of comprehending skills-based scheduling research, thus indicating the necessity for continued research and academic innovation in this field.



CONCLUSION

The bibliometric analysis presented in this paper offers in-depth insights into the prevailing research trends and identifies areas that require further exploration within the domain of skills-based scheduling. This study examines 1,666 articles published in the Web of Science database between 1978 and 2023, shedding light on the substantial growth in research contributions from diverse authors, countries, and journals. Additionally, the paper traces the evolution of keywords within the field, providing a comprehensive view of how research themes have developed over time. The analysis utilized Publish or Perish, Microsoft Excel and VOSviewer software, encompassing data from 96 countries, 1032 journals, 7,053 authors, and 6,061 keywords.

The findings of this study are invaluable for future researchers in planning international collaborations to enhance the exchange of ideas and knowledge globally. The analysis of keyword co-occurrences highlights potential research gaps and opportunities, particularly in underexplored sectors and emerging themes within skills-based scheduling. Therefore, this study recommends that future researchers strengthen international collaborations, especially with countries that currently have lower publication outputs, to encourage greater diversity and inclusivity in the field. Furthermore, expanding the research focus beyond healthcare to include sectors such as manufacturing, agriculture, and education will broaden the applicability and impact of skills-based scheduling. Additionally, leveraging advanced artificial intelligence (AI) and machine learning (ML)

technologies is recommended to optimize the management and tracking of workforce skills, which will improve efficiency and adaptability in dynamic work environments.

As this field continues to evolve, it is essential for future research to innovate and develop new models that effectively address the dynamic challenges of workforce scheduling. By remaining adaptive and utilizing the latest technology, future studies can ensure that solutions are both effective and sustainable.

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