



Trends in botanical education research: a bibliometric study

Tendências na pesquisa em educação botânica: um estudo bibliométrico

Tendencias en la investigación en educación botánica: un estudio bibliométrico

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RESUMO

A pesquisa em educação botânica busca cultivar uma apreciação profunda e um relacionamento responsável com a vida vegetal em nosso ambiente dinâmico. Este estudo emprega análise bibliométrica das bases de dados Scopus e WoS para revelar a trajetória do campo, as principais tendências e as áreas de pesquisa em desenvolvimento. Ele oferece insights valiosos para pesquisadores, educadores e formuladores de políticas, destacando ações promissoras para o avanço. Estas incluem o aumento da colaboração internacional, a integração de tecnologias digitais (por exemplo, experiências imersivas, aprendizagem gamificada) e o aproveitamento de espaços de aprendizagem informal como jardins botânicos, museus e herbários. Essas abordagens são promissoras para cultivar um futuro onde as plantas não sejam apenas valorizadas, mas protegidas ativamente.



Palavras-chave: consciência botânica, cegueira botânica, espaços de aprendizagem informal.

ABSTRACT

Botanical education research seeks to nurture a profound appreciation and responsible relationship with plant life in our dynamic environment. This study employs bibliometric analysis of Scopus and WoS databases to unveil the field's trajectory, key trends, and developing research areas. It offers valuable insights for researchers, educators, and policymakers, highlighting promising actions for advancement. These include enhanced international collaboration, integration of digital technologies (e.g., immersive experiences, gamified learning), and leveraging informal learning spaces like botanical gardens, museums, and herbariums. Such approaches hold promise in cultivating a future where plants are not merely treasured, but actively protected.

Keywords: plant awareness, plant blindness, informal learning spaces.

RESUMEN

La investigación en educación botánica busca cultivar una profunda apreciación y relación responsable con la vida vegetal en nuestro dinámico entorno. El presente estudio utiliza el análisis bibliométrico de las bases de datos Scopus y WoS para revelar la trayectoria del campo, las principales tendencias y las áreas de investigación en desarrollo. Ofrece valiosas ideas a investigadores, educadores y legisladores, destacando acciones prometedoras para el progreso. Entre ellas se incluyen el aumento de la colaboración internacional, la integración de las tecnologías digitales (por ejemplo, experiencias inmersivas, aprendizaje gamificado) y el aprovechamiento de espacios informales de aprendizaje como jardines botánicos, museos y herbarios. Estos enfoques son prometedores para cultivar un futuro en el que las plantas no solo se valoren, sino que se protejan activamente.

Palabras clave: conciencia botánica, ceguera botánica, espacios informales de aprendizaje.

1 INTRODUCTION

Accelerating biodiversity loss, characterized by the escalating rate of species extinction and habitat degradation, presents a monumental challenge to global environmental sustainability (Sellmann; Bogner, 2012; Uralovich *et al.*, 2023; Wudu *et al.*, 2023). The importance of plants for sustainability is increasingly recognized in the scientific literature, but this recognition is not yet



reflected in the public consciousness (Stagg; Dillon, 2023). Addressing this challenge necessitates multifaceted conservation strategies that foster environmental awareness and action (Balding; Williams, 2016). Botanical education plays a crucial role in this endeavor by cultivating an understanding and appreciation for plants, equipping individuals to make informed decisions about their conservation and management (Jose; Wu; Kamoun, 2019).

A striking imbalance exists in the research and educational emphasis placed on plants versus animals, despite the critical role played by plants in sustaining Earth's ecosystems (Balas; Momsen, 2014). This bias toward animal-centric perspectives overlooks the complex cognitive and ecological aspects of plant life (Allen, 2003). Educational systems emphasizing animals over plants contribute to this imbalance (Burke *et al.*, 2022; Sellmann; Bogner, 2012), leading to a decline in botanical education and plant awareness (Stroud *et al.*, 2022).

This oversight manifests in the concept of "plant blindness", a phenomenon highlighting the tendency to neglect the significance of plants in our environment (Balas; Momsen, 2014; Fančovičová; Prokop, 2011). Originally coined in 1998 (Wandersee; Schussler, 1998), plant blindness stems from educational biases and limitations of human visual information about plants (Allen, 2003; Balas; Momsen, 2014; Balding; Williams, 2016). This lack of appreciation for plants raises concerns about its consequences on sustainability and achieving Sustainable Development Goals (Amprazis; Papadopoulou, 2020).

Addressing plant blindness requires a multifaceted approach. Educational reforms and fostering personal connections with plants are crucial starting points (Jose; Wu; Kamoun, 2019; Nyberg; Sanders, 2013). The encouragement of plant mentorship programs alongside the adoption of innovative teaching methodologies shows considerable potential (Allen, 2003; Balding; Williams, 2016). Additionally, fostering empathy towards plants and utilizing settings like botanical gardens for hands-on learning can further reshape our relationship with them and the environment (Balding; Williams, 2016; Zelenika *et al.*, 2018). Interdisciplinary collaboration among botanists, educators, and policymakers is crucial to achieve this goal. This holistic approach is essential to cultivate a



society that comprehends and values the crucial role of plants in sustaining life on Earth.

It is important to note that nuanced discourse surrounding terminology has emerged, with suggestions like "plant awareness disparity" (PAD) offered to refine our understanding of plant significance (Parsley, 2020). This underscores the importance of precise language in framing discussions on plant perception and appreciation.

Botanical education can take place in various settings, including schools, museums, and especially botanical gardens. Exploration into educational methodologies highlights the efficacy of interactive settings like botanical gardens in reshaping perceptions and engaging people with plants (DiEnno; Hilton, 2010; Nyberg; Sanders, 2013; Zelenika *et al.*, 2018). Outdoor programs can also play a significant role in challenging the perception of plants and leading to positive shifts in attitudes toward them (Fančovičová; Prokop, 2011; Sellmann; Bogner, 2012).

This study examines the trends in botanical education through a bibliometric evaluation of articles in Scopus and Web of Science (WoS) databases. Analyzing research output aims to reveal the field's strengths, limitations, and future directions. Specifically, the study seeks to answer the following questions: How have document types, keywords, and authorship patterns evolved over the period from 1830 to 2023, and more specifically from 2020 to 2023? Are there differences in the citation rates or influence of single-authored versus co-authored papers? What are the key themes and emerging areas of interest? Who are the leading researchers and what are the most influential publications? What are the most common research themes and clusters?



2 METHODS

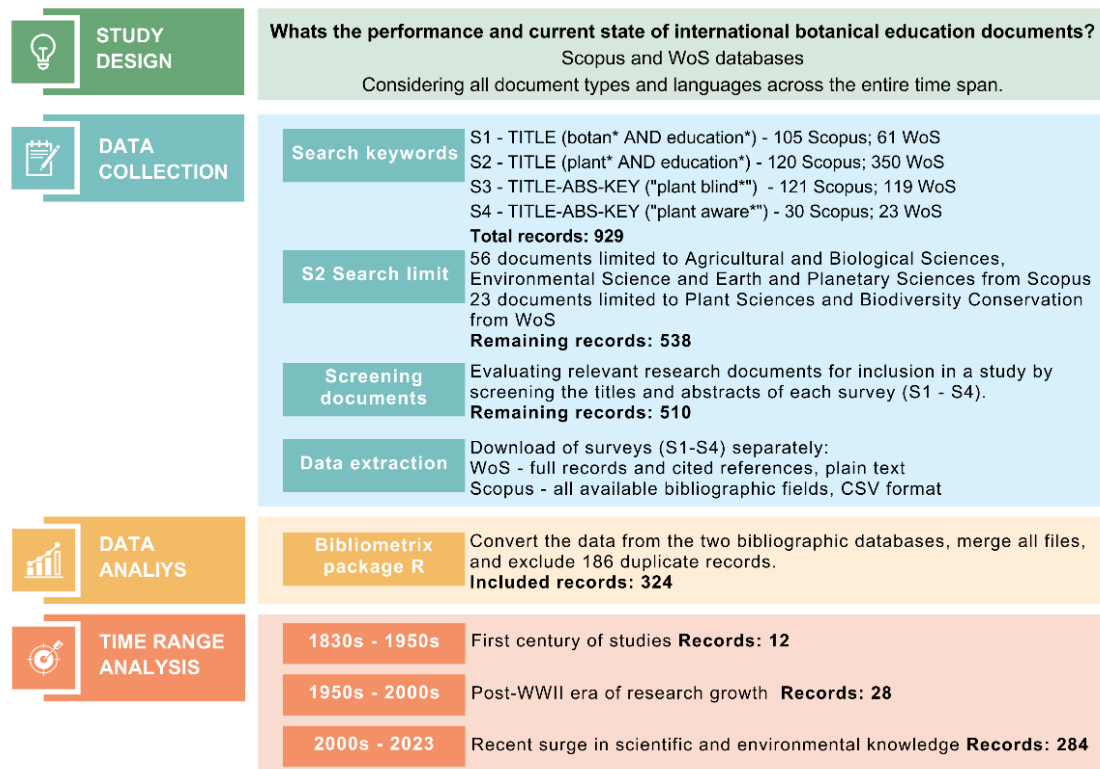
2.1 STUDY DESIGN

This study employs bibliometric analysis, a powerful statistical method for investigating research trends, to assess the performance and current state of international botanical education documents. The increasing popularity of bibliometrics aligns with the expansive scientific landscape, making it a critical tool for discerning its complexities and extracting valuable insights into research topics and their evolution (Zupic; Čater, 2015). To uphold transparency and methodological rigor, the present study adopted a five-step workflow (Aria; Cuccurullo, 2017). This approach resulted in the extraction and synthesis of relevant data, as depicted in Figure 1.

This study utilized Scopus and WoS, leading scientific databases, to conduct four surveys (Pranckutė, 2021). All document types, regardless of language or publication date, were considered, excluding duplicates and those outside the scope of the research. To investigate temporal trends in document types, keywords, and authorship patterns across the entire time (1830–2023), the analysis was divided into three distinct periods: (1) 1830–1950, (2) 1950–2000, and (3) 2000–2023. While the initial periods are summarized, the specific focus of this study is on the most recent timeframe (2000–2023). This allows for a more detailed examination of contemporary trends and facilitates a deeper understanding of recent developments in the field.



Figure 1 – Flowchart for study workflow



Source: Prepared by the Authors (2024)

2.2 DATA COLLECTION

To ensure retrieved articles aligned with the research objectives, the search process was divided into four targeted surveys using relevant keywords. This approach streamlined the process of verifying document relevance to the research goals, resulting in the retrieval of 929 articles through a targeted search using the surveys' keywords:

The first survey (S1) employed the focus on titles only, searching for "botan*" and "education*" resulting in 105 Scopus documents and 61 from WoS. The second survey (S2) used the keywords "plant*" and "education*", restricting the search to relevant subject areas in Scopus (Agricultural and Biological Sciences, Environmental Science, and Earth and Planetary Sciences) and WoS (Plant Sciences and Biodiversity Conservation). This approach retrieved 56 articles in Scopus and 23 in WoS. The third survey (S3) employed the keyword "plant blind*" across titles, abstracts, and keywords, yielding 121 articles from



Scopus and 119 from WoS. Finally, the fourth survey (S4) employed the keyword "plant aware*" retrieving 30 from Scopus and 23 documents from WoS.

To ensure data precision and relevance for the specific research question, S2 had its search deliberately narrowed to specific subject areas within Scopus and WoS. This avoided potential interference from broader subject areas, allowing focused analysis of articles directly focused on botany education. Surveys S3 and S4 employed contrasting search terms, "plant blind" and "plant aware", to capture the spectrum of botanical education within the context of human-plant relationships. S3 focused on articles addressing the widespread lack of basic plant knowledge and appreciation in everyday life, while S4 targeted educational approaches that cultivate critical thinking and responsible interaction with plants.

Following a meticulous screening of titles and abstracts of the initial search, a final dataset of 510 documents exhibiting a clear connection between botany and education was established. Data was extracted from both WoS (full records and cited references, plain text) and Scopus (all available bibliographic fields, CSV format).

2.3 DATA ANALYSIS

The citation patterns of the final dataset were investigated using bibliometrix 4.1.4 (Aria; Cuccurullo, 2017), a comprehensive R package (version 4.3.2) for bibliometric analysis. Four surveys (S1-S4) from the two databases were imported separately into R and merged into a single bibliographic data frame with 324 documents and 31 variables after removing duplicate entries (186 documents). Analysis was facilitated by biblioshiny, a user-friendly web browser interface built within the bibliometrix package (Ab Rashid, 2023).



2.4 DATA VISUALIZATION

This study employed a multifaceted bibliometric approach combining performance analysis and science mapping to gain a holistic understanding of botanical education research (Aria; Cuccurullo, 2017).

Performance analysis focused on quantifying the contributions of research actors, including institutions, authors, and sources. Descriptive statistics were calculated for annual and total publication counts, citations, and top-cited studies. Additionally, the most productive authors, sources, institutions, and countries were identified.

Science mapping, on the other hand, aimed to uncover the relationships between these actors, offering a powerful tool for knowledge synthesis by statistically analyzing scientific literature. It uncovers the conceptual structure (key themes and trends), intellectual structure (influences of an author's work), and social structure (interactions between authors, institutions, and countries) within a specific field (Zupic; Čater, 2015).

Cluster analysis based on document coupling and author keywords was conducted to identify thematic clusters within the field. Co-occurrence networks, co-citation networks, and country participation networks were also constructed to visualize the relationships between research areas, authors, and countries. Finally, thematic maps were constructed to unveil the spatial distribution of these thematic clusters and relationships. This allows each scientific community to gain a comprehensive understanding of their field's progress, track the evolution of theories and techniques, and identify promising avenues for future research.

3 RESULTS AND DISCUSSION

3.1 PUBLICATION OUTPUT

The analysis reveals a nuanced picture of botanical education research evolution of 324 botanical education studies (Table 1), spanning nearly two



centuries (1830-2023) and sourced from 172 diverse publications, offering a detailed snapshot of this evolving research landscape. The predominance of journal articles (64%) compared to other document types (conference papers, book chapters, book reviews, editorials, erratum, letters, meeting abstracts, news items, notes, proceedings papers, reviews, and short surveys) aligns with established scientific research trends (Mashroofa; Jusoh; Chinna, 2020). While publication output serves as a valuable indicator of research activity, it's important to note that it doesn't necessarily reflect the quality or impact of individual studies (Durieux; Gevenois, 2010).

Table 1 – Evolution of botanical education research: descriptive statistics of publications within distinct timeframes (1830-2023: full historical spectrum, 1830-1950: first century of studies, 1950-2000: post-WWII era of research growth, 2000-2023: recent surge in environmental focus)

Description/Timespan	1830:2023	1830:1950	1950:2000	2000:2023
MAIN INFORMATION ABOUT DATA				
Sources (Journals, Books, etc)	172	4	19	159
Documents	324	12	28	284
Annual Growth Rate %	1.84	0	2.93	11.13
Average citations per doc	7.601	0.4615	12.38	7.363
Author's Keywords (DE)	808	2	40	775
AUTHORS				
Authors	747	9	57	689
Authors of single-authored docs	88	9	17	66
AUTHORS COLLABORATION				
Single-authored docs	104	12	19	75
Co-Authors per Doc	2.59	0.923	1.74	2.76
International co-authorships %	1.524	0	0	1.761
DOCUMENT TYPES				
Article	211	7	19	187
Others (book chapter and review, letter, review, etc)	103	6	15	83

Source: Scopus and WoS / Biblioshiny

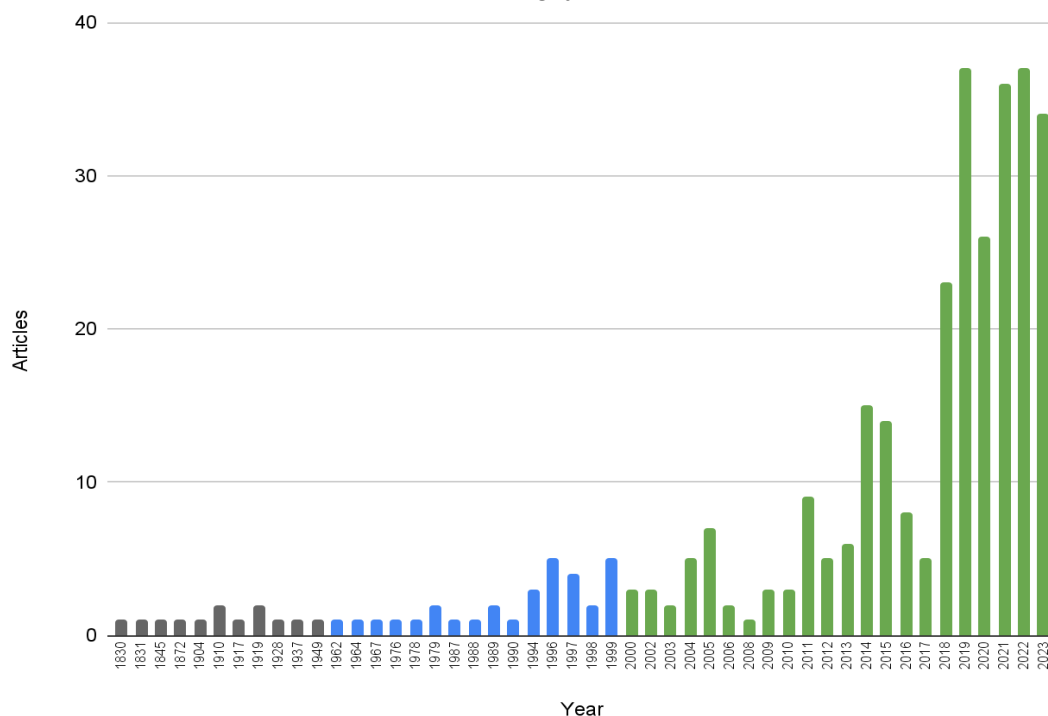


3.1.1 Annual Trends

A historical analysis of botanical education research reveals a consistent increase in publication activity from 1830 to 2023, with an overall annual growth rate of 1.84%. However, a closer examination of specific periods reveals further insights into this general trend.

The early years (1830-1950) saw the field in its embryonic stage, characterized by minimal research activity with an annual growth rate near zero (Figure 2, gray). In contrast, the post-World War II era (1950-2000) witnessed a flourishing of environmental research (Praskievicz, 2021), with a significantly steeper annual growth rate of 2.93% (Figure 2, blue). This pattern intensifies further when narrowing the scope to the last two decades (2000-2023), a period marked by a surge in environmental consciousness (Saric; Murthada; Jusatria, 2023). During this time, the annual growth rate jumps to 11.13% (Figure 2, green).

Figure 2 – Temporal trends in Botanical Education Publications from 1830 to 2023, with an average annual growth rate of 1.84%. Color coding indicates different periods: gray bars (1830–1950) represent an average annual growth rate of 0%; blue bars (1950–2000) exhibit a moderate growth rate of 2.93%; and green bars (2000–2023) with an average annual rate of 11.13%.



Source: Scopus and WoS / Biblioshiny



Despite a temporary dip in publications during the COVID-19 pandemic (2019-2021), botanical education research continues to see an accelerated growth trend since 2000. This reflects the increasing awareness of plants' importance in sustainability and the field's dedication to expanding botanical education knowledge.

3.1.2 From Medical Roots To Broader Horizons – 1830s to 1950s

The first century of botanical education witnessed a humble beginning, with only 12 publications. Early publications emphasized the link between botany and medical education, as evident in titles like "Botany as a Part of Medical Education" (Howison, 1830). Later publications addressed the broader value of botanical education in general, as evident in titles such as "Botany as a Factor in Education" (Bessey, 1904) and "A Basis for Reconstructing Botanical Education" (Gager, 1919), highlighting the potential of botany to cultivate critical thinking, nurture a reverence for nature, and reveal the intricate interdependence of plants and human life. Botanic gardens further emerged as educational tools, as highlighted in publications like "The Social Educational and Scientific Value of Botanic Gardens" (Coulter, 1917) and "Botanic Gardens in Science and Education" (Gager, 1937). These works advocated for their immersive potential, allowing students to forge deeper connections with the natural world. This evolution from medicine-centric botany to a broader educational recognition emphasizes the importance of botany in scientific inquiry and interdisciplinary studies, culminating in a more holistic understanding of its significance across diverse realms.

3.1.3 Blossom Of Botanical Education – 1950s to 2000s

This period had a minimum growth in the number of publications from 28 documents. Botanical gardens remained central to fostering plant awareness and education, with ten dedicated articles highlighting their role.



An increasing utilization emerged towards practical applications and environmental consciousness, exemplified by studies on plant problem diagnosis (Kells; Vitosh; Hesterman, 1987), and restoration projects (McLoughlin, 1997). This reflected the utilization of botanical knowledge to address real-world challenges.

The 1990s witnessed a shift towards student-centered learning with programs like "Garden Explorations" (Wagner; Fones, 1999) and "A Botanical Treasure Hunt" (Fox; Gaynor; Cribben, 1998) emphasizing inquiry and hands-on activities. Researchers explored diverse areas, including computer simulations enhancing ecological understanding (Golluscio; Paruelo; Aguiar, 1990), studies on pre-college environmental awareness promoting early engagement (Uno, 1994), and an examination of the intersection of plant conservation, horticulture, and education through Puerto Rican expeditions (Sastre-D.J.; Santiago-Valentín, 1996). Furthermore, the concept of "plant blindness" (Wandersee; Schussler, 1998) gained traction, emphasizing the public's lack of awareness about plants' crucial role, a theme that would resonate even stronger in the following period.

Overall, botanical education diversified beyond academia, embracing environmental concerns, public engagement, and practical applications, demonstrating a growing understanding of the vital role botanical knowledge plays in both individual understanding and societal well-being.

3.1.4 Botanical Education's Rise In A World Awakening To Nature – 2000s to Nowadays

This study focuses on a delineated timeframe encompassing research published between 2000 and 2023 (284 documents). This specific period was chosen for further analysis due to several compelling reasons.

Comprehensiveness of Recent Trends: It aligns with the most recent decades in botanical education research, offering valuable insights into the cutting-edge trends and developments shaping the field (Stagg; Dillon, 2023; Stroud *et al.*, 2022).

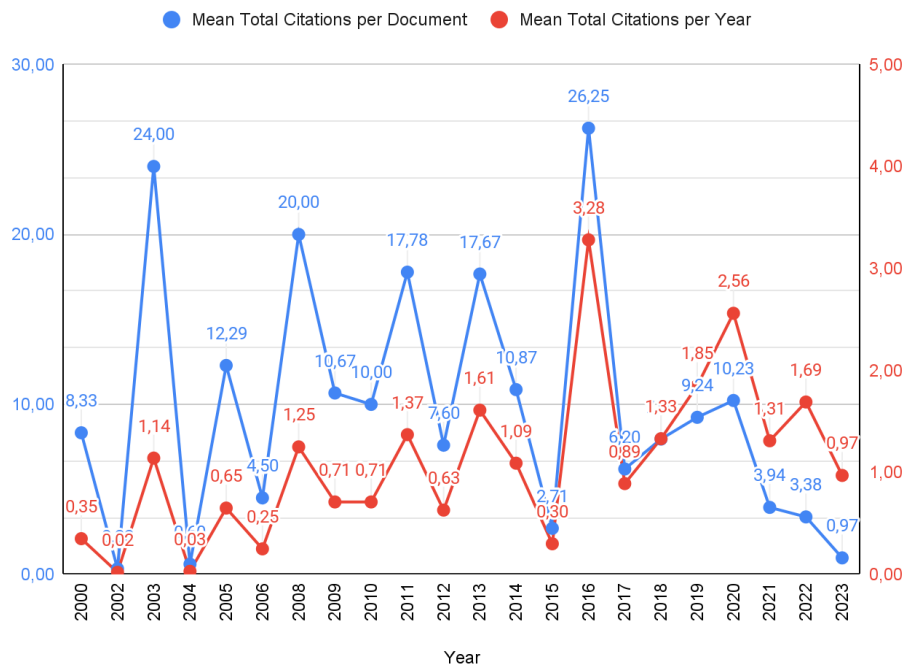


Era of Transformation: This period witnessed significant transformative shifts in botanical education. The emergence of novel technologies, evolving pedagogical approaches, and shifting societal priorities have significantly reshaped the landscape (Jose; Wu; Kamoun, 2019).

Surging Interest: This timeframe coincides with a marked increase in the volume of published research and the diversification of target audiences within botanical education.

While the number of publications reflects the productivity of a research area (Figure 2), the total average citations per document and the average over the years are two important metrics that provide an indicator of the degree of utilization and can thus measure the impact of articles (Figure 3) (Mattedi; Spiess, 2017).

Figure 3 – Annual citation per document over the years: the variation of the average total citations per document (blue) and the comparison of the average citation over the years (red).



Source: Scopus and WoS / Biblioshiny

The average total citations per document exhibit remarkable year-to-year variability, closely mirroring the average citations per document. Notably, peaks in 2003 and 2016 likely reflect the emergence of highly influential papers or



significant field-specific events. However, a recent decline in per-document citations was anticipated due to natural publication time lags, the data unexpectedly reveal a sustained downward trend extending into 2021, consistently falling below the overall average of 9.8 citations per document.

Conversely, the average annual citations per year, though lower than the overall period, remain above the overall average (1.09) from 2021 onwards. This suggests that while the impact of individual publications might be decreasing over time, the field itself maintains a steady level of interest and engagement, as evidenced by the consistent annual citation rate.

3.2 SOURCES ANALYSIS

3.2.1 Most Relevant Sources/Journals

Among the 284 document publications, 159 distinct sources were identified. Table 2 presents the top ten most relevant journals that contributed a notable number of articles on botanical education from 2000 to 2023.

Table 2 – Most relevant and productive journals from 2000 to 2023

Sources	Articles	Percentage (%)	H-Index
Plants People Planet	24	12,8	21
Journal Of Biological Education	16	8,6	44
Environmental Education Research	13	7,0	87
American Biology Teacher	10	5,3	34
Sustainability	10	5,3	136
Thaiszia Journal Of Botany	8	4,3	9
Education Sciences	5	2,7	40
Biological Conservation	4	2,1	224
Journal Of Environmental Education	3	1,6	66
Natural Sciences Education	3	1,6	11

Source: Scopus and WoS / Biblioshiny

Sources like "Plants, People, Planet" and "Environmental Education Research" encourage interdisciplinary approaches to botanical education, linking



plant science with fields like social sciences, humanities, and sustainability studies. The presence of "Education Sciences" reflects the increasing role of technology in botanical education. Articles in this journal explore the potential of various educational technologies to enhance learning and engagement in plant science topics. Sustainability journals like "Sustainability" and "Biological Conservation" emphasize the need for sustainable practices in managing plant resources. Journals such as "Journal of Biological Education", "American Biology Teacher" and "Education Sciences" emphasize the crucial connection between academic research and effective teaching methodologies that touch upon the importance of effective science communication between academic research and public understanding.

3.3 AUTHOR ANALYSIS

3.3.1 Impact of single-authored vs. co-authored works

Examining the publication landscape from 2000 to 2023, a dataset of 284 documents by 689 authors reveals an interplay between single-authored and co-authored works. While 26% of the documents were authored by a single researcher (75), the majority involved collaboration (209). This is further evidenced by a moderate average collaboration rate of 2.76 co-authors per document. However, this collaborative spirit does not extend significantly beyond national borders. Only 1.76% of co-authorships involve international partnerships. This is corroborated by the collaboration index (1.8), which suggests a tendency towards smaller research teams and a focus on internal collaborations within the field.

3.3.2 Co-authorship Collaboration Network

Co-authorship networks offer a powerful lens to analyze the social structure of research communities (Peters; Raan, 2005). Through this analysis,



we gain a deeper understanding of the collaborative fabric that forms the foundation of scientific progress.

Authors' relationships reveal the presence of many clusters (14), suggesting that the field is fragmented (Figure 4). This division into numerous clusters with limited inter-cluster connections can lead to isolated pockets of collaboration. Such a scenario might imply restricted knowledge diffusion across the entire network. While authors within clusters appear well-connected internally, the sparse connections between clusters could limit the diversity of ideas and collaborations across the network.

3.3.3 Most relevant authors' and Authors' Production over Time

A bibliometric analysis of 689 authors publishing in botanical education research from 2000 to 2023 reveals Sanders, D., as the most productive and impactful researcher in this field (Figure 5). Sanders stands out with a substantial publication record of nine articles, garnering a total of 140 citations. Dreesmann, D., follows closely with seven publications and 55 citations, while Pany, P., contributes with five publications and 40 citations. Identifying these leading authors offers valuable insights into the research landscape and informs potential collaboration networks.

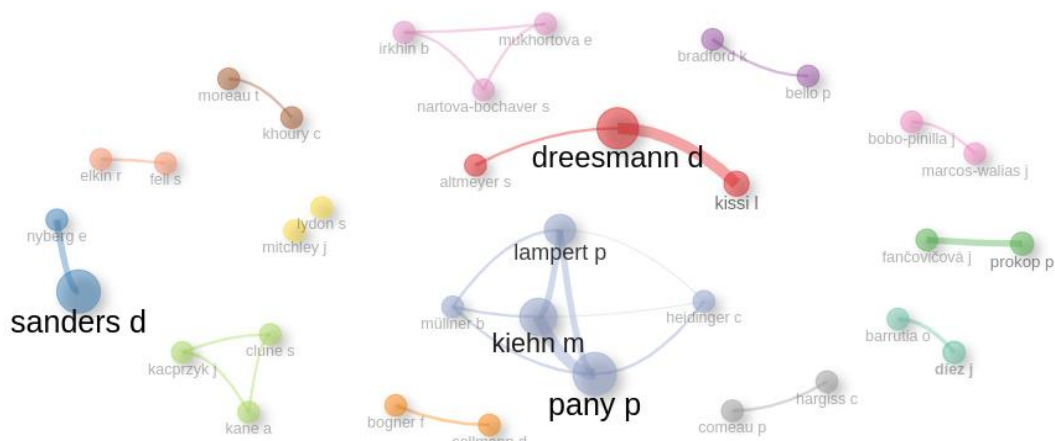
3.3.4 Most Relevant Affiliations

Among the 310 institutions identified in this study, some stand out for their contributions to the field of botanical education. This information can be used to identify institutions that are leading the field and to promote collaboration between institutions from different parts of the world. The University of Vienna (Austria) leads the pack with 20 publications, followed by the University of Gothenburg (Sweden) (13 publications) and the University College Dublin (Ireland) (11 publications). Comenius University (Slovakia), Florida International University



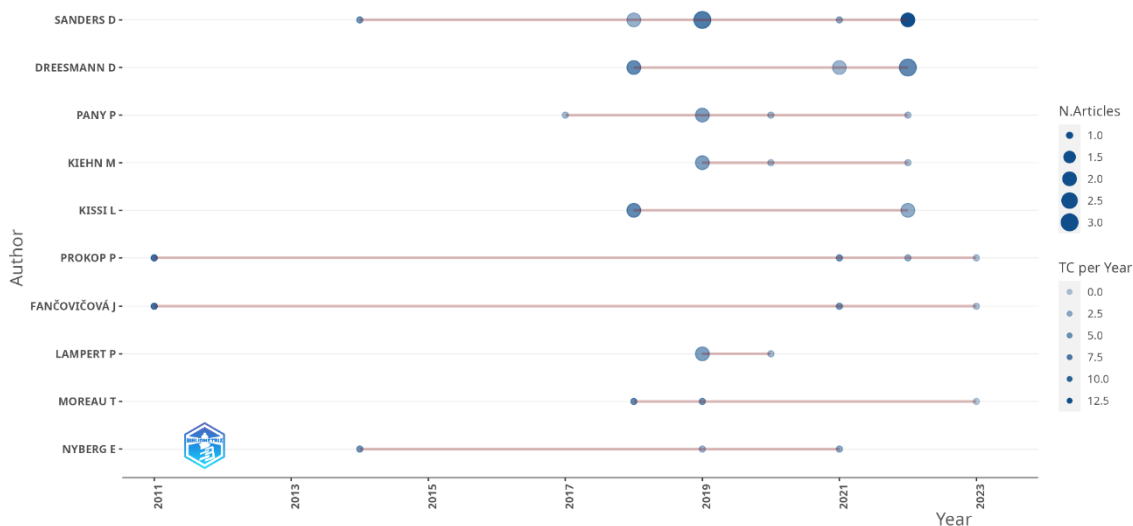
(United States), and the University of the Basque Country (Spain) each have 8 publications.

Figure 4 – Co-authorship Collaboration Network: map between authors on botanical education research (Standard method parameters; Number of nodes = 50)



Source: Scopus and WoS / Biblioshiny

Figure 5 – Top authors' production over time: red lines indicate continued citation; the circle size represents the number of documents published per year by each author, while the intensity of the blue color indicates the total number of citations received per year.



Source: Scopus and WoS / Biblioshiny

3.3.5 Corresponding Author's Countries

Figure 6 highlights the top ten countries of origin for corresponding authors among the 47 nationalities represented in this search. A significant portion of



publications in this field originate from single-country authors (SCPs). Only three countries, the United States, Brazil, and Australia, exhibit a presence of multiple-country authors (MCPs). This finding suggests that botanical education research currently exhibits a compartmentalized structure, characterized by limited international collaboration. Fostering international collaborative efforts presents a strategic opportunity for knowledge exchange and the pooling of diverse expertise. Such collaborative endeavors hold the potential to propel advancements within the field of botanical education research.

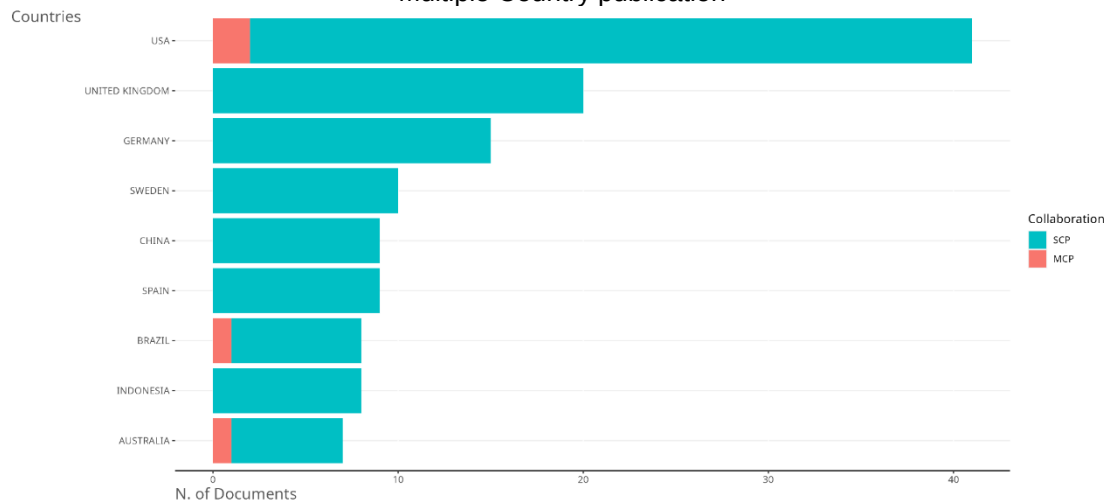
3.3.6 Country Scientific Production

A global analysis of scientific output on this topic ranks the top 10 countries worldwide contributing the most published articles between 2000 and 2023 (Table 5), in a diverse landscape with 49 contributing countries (Figure 7). The United States emerges as the undisputed leader, having the highest publication count (63) and a median average citation (9.90), implying both prolific research and impactful contributions.

Europe displays its robust research environment with several countries, including the United Kingdom, Germany, Spain, and Italy, ranking within the top 10. Notably, Australia stands out with an exceptional average citation rate (28.60) despite having fewer publications (9), suggesting highly influential research, possibly due to niche focus or strong international collaborations.



Figure 6 – Corresponding Author's Countries. SCP: Single country publication and MCP: Multiple Country publication



Source: Scopus and WoS / Biblioshiny

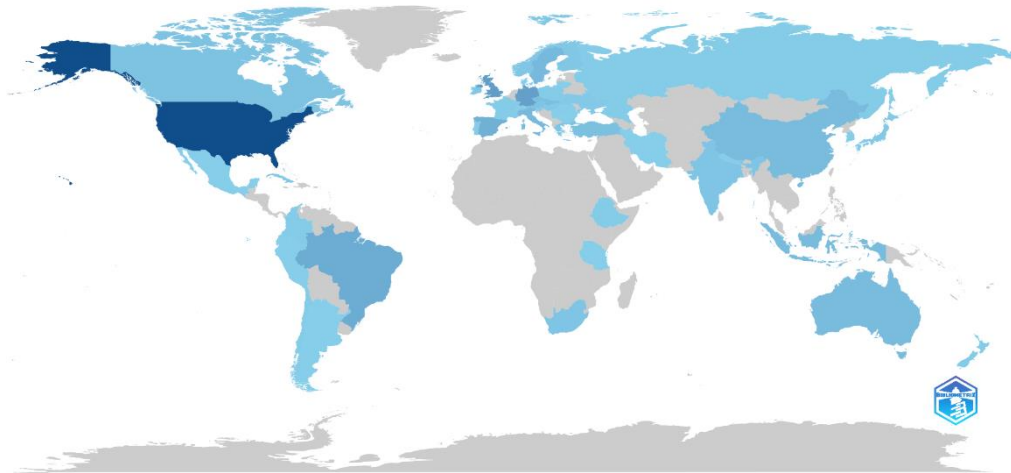
Table 5 – Top 10 Countries in Scientific Production

	Frequency	Total Citations	Average Article Citations
USA	63	406	9.90
UNITED KINGDOM	23	225	11.20
GERMANY	22	139	9.30
BRAZIL	16	8	1.00
SPAIN	14	48	5.30
ITALY	10	9	3.00
SWEDEN	10	127	12.70
AUSTRALIA	9	200	28.60
CHINA	9	58	6.40
INDONESIA	9	15	1.90

Source: Scopus and WoS / Biblioshiny



Figure 7 – Country Scientific Production map: the intensity of the blue color in the map indicates the number of publications/frequencies for each country (see Table 5).



Source: Scopus and WoS / Biblioshiny

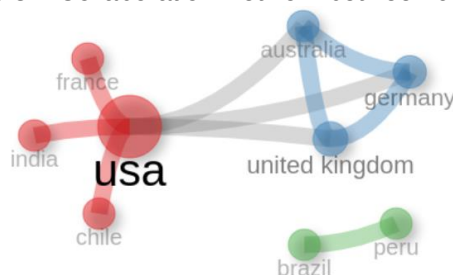
The inclusion of Brazil and Indonesia highlights the increasing participation of developing nations in global scientific dialogue, even with lower citation rates. Investigating the evolving dynamics of scientific production, particularly the rise of non-Western countries and novel collaborations, holds significant promise for understanding the future trajectory of this field.

3.3.7 Countries Collaboration Network

Analysis of the collaboration network between countries exposes a fragmented landscape, characterized by a scarcity of robust connections between clusters (Figure 8). This observation aligns with the notion that international collaboration remains limited, potentially obstructed by cultural or linguistic barriers. The United States emerges as a central hub within the network, facilitating connections with other countries. However, most individual countries exhibit restricted collaborative efforts, primarily engaging in internal research or with a select few partners.



Figure 8 – Collaboration Network between counties



Source: Scopus and WoS / Biblioshiny

3.4 DOCUMENT ANALYSIS

3.4.1 Citation

Table 6 presents the most influential articles in botanical education research based on their citation counts. While traditional citation counts (TC) identify highly cited works, normalized total citations (NTC) offer a more refined analysis by accounting for publication dates and the number of authors involved.

The most cited articles delve into various aspects of botanical education, including its influence on conservation efforts (Balding; Williams, 2016; Jose; Wu; Kamoun, 2019), they explore educational interventions aimed at raising awareness and altering attitudes (Fančovičová; Prokop, 2011; Parsley, 2020; Sellmann; Bogner, 2012), and investigate the potential of botanical gardens as informal learning environments for fostering environmental knowledge and action (DiEnno; Hilton, 2010; Nyberg; Sanders, 2013; Zelenika *et al.*, 2018). These findings reveal how botanical education sets the direction for environmental awareness, conservation, and sustainability actions.

3.4.2 Papers' Co-citation Network

Analysis of prominent papers within the field reveals the thematic organization of the research community into distinct clusters (Figure 9). The central red cluster, anchored by highly cited works such as (Strgar, 2007) and (Sanders, 2007), represents the core paradigm or dominant research area.



These central works solidify their position through their focus on student interest and informal learning environments.

Smaller, yet influential clusters, such as the blue and green ones, highlight related but distinct research domains. Furthermore, the positioning of studies on teacher dispositions (Schussler; Stooksberry; Bercaw, 2010) and seminal "plant blindness" theory (Wandersee; Schussler, 2001) within their respective clusters reinforces thematic coherence within each grouping.

The remaining, smaller clusters potentially represent emerging research areas or novel perspectives. This analysis, therefore, provides a valuable roadmap of the field, highlighting established themes and potential avenues for future research endeavors.

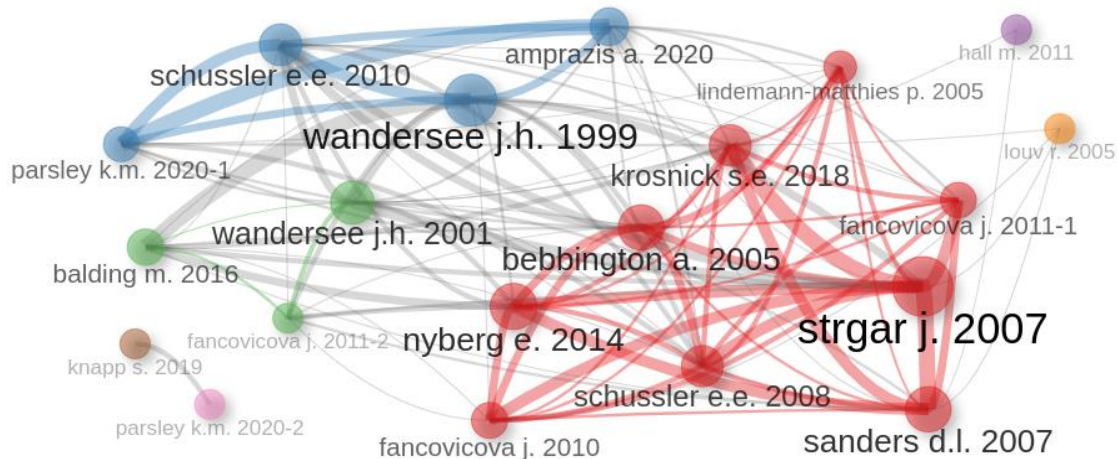
Table 6 – Most Global Cited Documents.

Paper	Title	Total Citations	TC per Year	Normal. TC
Balding; Williams, 2016	Plant Blindness And The Implications For Plant Conservation	161	20.13	6.13
Fančovičová; Prokop, 2011	Plants Have A Chance: Outdoor Educational Programmes Alter Students' Knowledge And Attitudes Towards Plants	118	9.08	6.64
Sellmann; Bogner, 2012	Climate Change Education: Quantitatively Assessing The Impact Of A Botanical Garden As An Informal Learning Environment	73	6.64	4.13
Balas; Momsen, 2014	Attention "Blinks" Differently For Plants And Animals	70	7.00	6.44
Parsley, 2020	Plant Awareness Disparity: A Case For Renaming Plant Blindness	62	15.50	6.06
Dienno; Hilton, 2010	High School Students' Knowledge, Attitudes, And Levels Of Enjoyment Of An Environmental Education Unit On Non-Native Plants	56	2.95	4.56
Nyberg; Sanders, 2013	Drawing Attention To The 'Green Side Of Life'	52	5.20	4.79
Jose; Wu; Kamoun, 2019	Overcoming plant blindness in science, education, and society	44	8.80	4.76
Allen, 2003	Plant Blindness	44	8.80	4.76
Zelenika et al., 2018	Sustainability education in a botanical garden promotes environmental knowledge, attitudes, and willingness to act	38	6.33	4.78

Source: Scopus and WoS / Biblioshiny



Figure 9 – Papers' Co-citation Network: authors are grouped into distinct clusters, reflecting shared research themes and intellectual connections (Biblioshiny standard method parameters; number of nodes = 20)

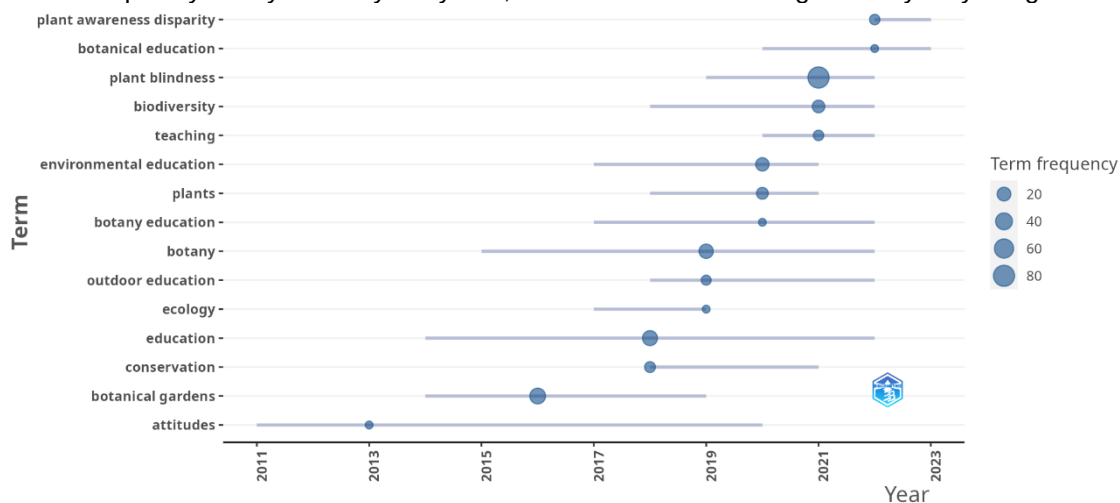


Source: Scopus and WoS / Biblioshiny

3.4.3 Identification of Key Research Areas

Examining keywords within a research dataset can reveal valuable insights into dominant themes and emerging areas of interest within a particular field. This study analyzed a dataset of 775 unique author keywords, revealing the evolving research trajectory across time (Figure 10).

Figure 10 – Trend topics author's Keywords frequencies over time: blue lines trace the evolving frequency of keywords by the years, with circle size indicating overall yearly usage



Source: Scopus and WoS / Biblioshiny



The keyword "plant blindness" appears with a frequency of 81 and exhibits a sustained peak from 2019 onwards, clearly establishing itself as the author's most prominent research emphasis in recent years. This suggests a growing interest in exploring the phenomenon and the growing importance of valuing plants in their environment.

Notably, the recently coined term "plant awareness disparity" (Parsley, 2020) appears alongside "botanical education" among the most frequently used terms in 2022-2023. It marks a potential shift from simply studying the negative phenomenon of plant blindness towards active intervention through education.

Compared to the early dominance of "attitudes" (2011-2020), keywords related to botanical knowledge ("botanical gardens", "botany") and education ("education", "environmental education", "outdoor education") now take center stage. This indicates a potential transition from studying public perceptions of plants to investigating potential solutions, such as botanical garden experiences and various educational approaches, to address plant blindness.

3.4.4 Factorial Approaches of the Author's Keywords

A factor analysis condensed the data into four key thematic clusters, each represented by a distinct color in Figure 12.

Cluster red centers around the themes of education and plant knowledge, suggesting prioritizing public understanding and combating "plant blindness" through education about plants and general knowledge about the plant kingdom.

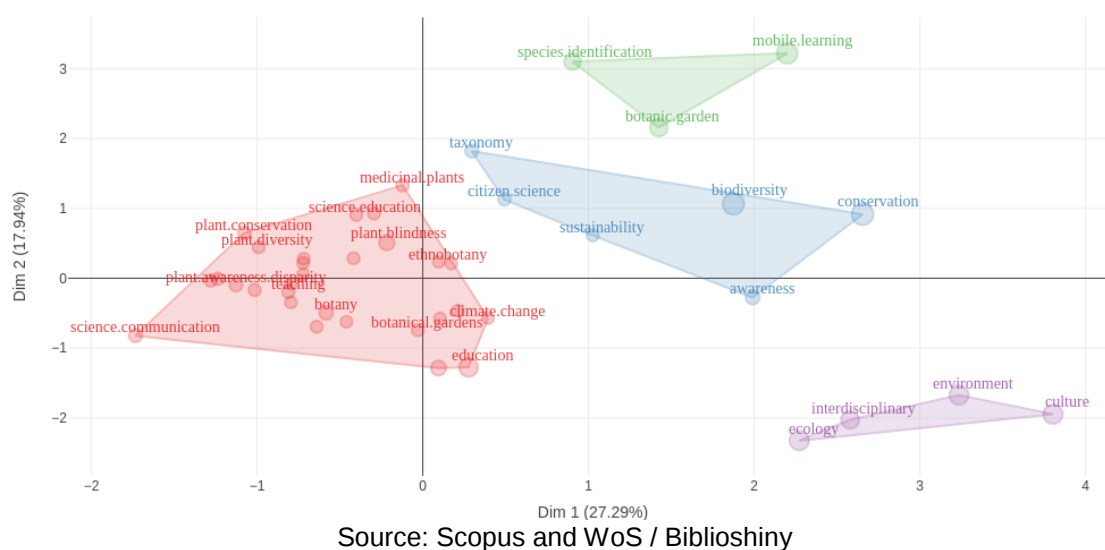
Cluster Blue focuses on conservation and awareness, advocating for appreciating biodiversity and raising awareness about the importance of plants, emphasizing both biodiversity conservation and addressing plant awareness.

Cluster green revolves around botanical gardens and active learning, underscoring the role of botanical gardens as learning spaces and the importance of active methods, such as species identification, in engaging the public and enriching education.



Finally, cluster purple centers around ecology and interdisciplinarity, highlighting the connections between plants and the ecosystem, as well as the need for interdisciplinary approaches to understanding socio-environmental issues, emphasizing a holistic perspective and integrated knowledge for plant appreciation and conservation.

Figure 12 – Author's Keywords clusters: hierarchical clustering (Multiple Correspondence Analysis) identified thematically distinct groups represented by color



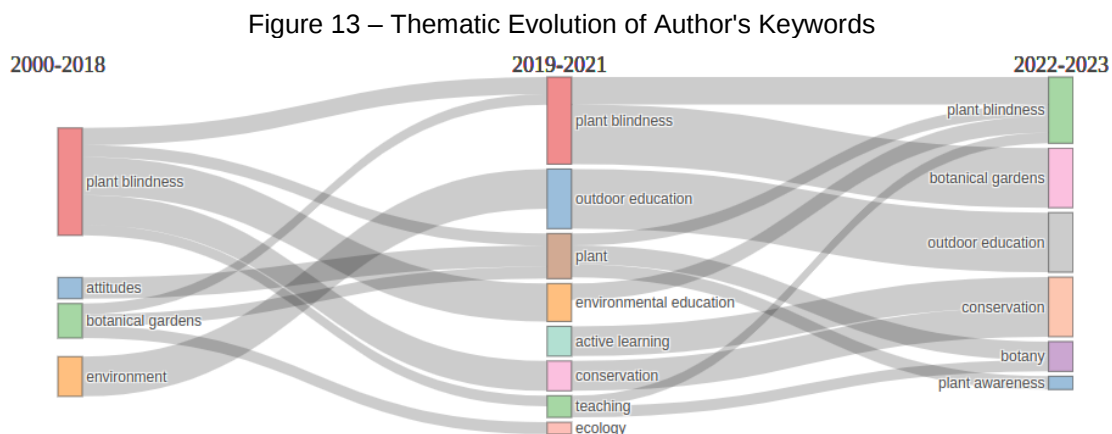
3.4.5 Thematic Evolution of Author's Keywords

A closer look at the temporal distribution of publications (Figure 1) revealed distinct breakpoints in 2018 and 2021. This allowed for the data to be partitioned into three time slices for a thematic analysis of author keywords (Figure 13). This analysis unveiled a dynamic landscape within botanical education research, characterized by both thematic continuity and the emergence of novel trends.

A key trend observed is a shift from a focus on human attitudes towards plants in earlier periods to a focus on the intrinsic value of plants themselves in recent times. This suggests a growing emphasis on understanding and appreciating plants beyond an anthropocentric perspective. Similarly, the prevalence of "ecology" in earlier periods reflected a broader recognition of the interconnectedness of plants within ecosystems. However, its prominence has



lessened in the most recent period, potentially due to the emergence of more specific terms like "conservation" and "botany."



Source: Scopus and WoS / Biblioshiny

Certain themes demonstrate remarkable stability across all periods. "Outdoor education" remains a cornerstone strategy, highlighting its continued relevance. "Plant blindness" persists as a concern, although its prominence has decreased in recent times. This aligns with the emergence of "plant awareness" as a focus, suggesting a shift in the approach to addressing this challenge. Additionally, the persistent association of "botanical gardens" with "plant blindness" suggests their potential role in mitigating this issue.

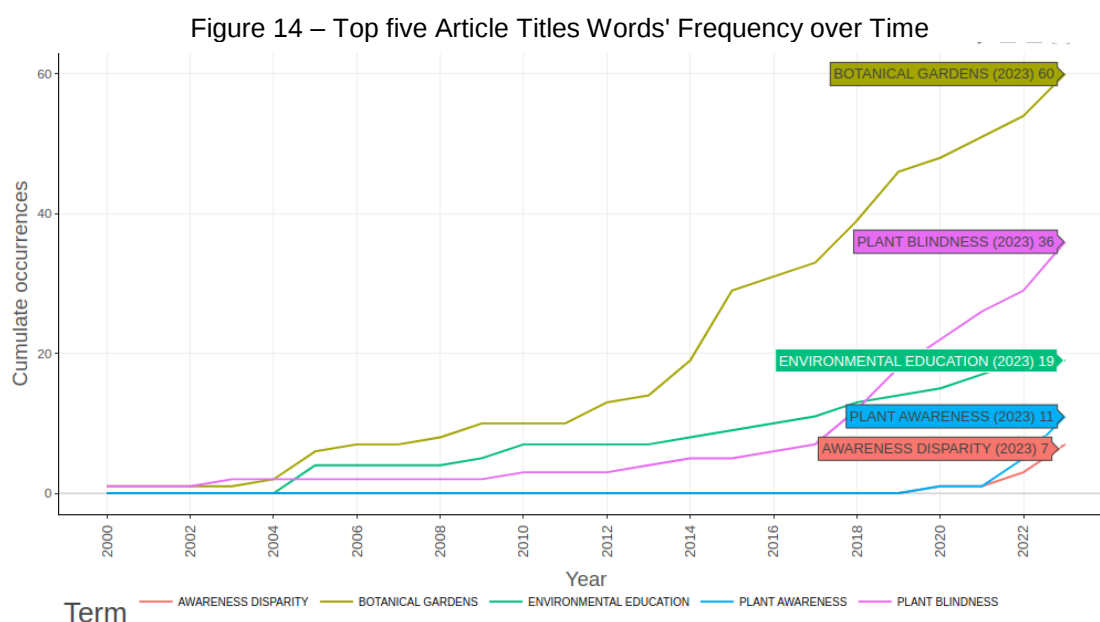
Evolving priorities are reflected in the newly formed connections. Notably, "conservation" has gained prominence recently, forging a stronger link between botanical education and environmental stewardship. This connection is further reinforced by the emergence of "active learning," indicating a move towards holistic and engaging educational experiences. Additionally, the link between "plant" to "plant awareness" and "plant blindness" emphasizes the growing focus on fostering responsible interactions with plants within the context of botanical education.

The thematic evolution analysis paints a picture of a maturing field of botanical education. The dynamic nature of the research landscape signifies a field actively adapting to foster deeper understanding and promote responsible interactions with plants in a changing world.



3.4.6 Document titles

While author-defined keywords provide valuable insights into research priorities, analyzing article titles offers a complementary perspective on the evolving landscape of botanical education research. Examining the cumulative frequency of bigrams (two-word phrases) within titles sheds light on emerging trends in the field (Figure 14).



Source: Scopus and WoS / Biblioshiny

Unsurprisingly, terms like "botanical gardens" (60 occurrences in 2023) and "environmental education" (19) remain stalwart areas of focus, highlighting their continued importance. Interestingly, the discourse surrounding "plant blindness" (36) exhibits a steady rise, particularly since 2017, indicating a concerted effort to address this critical challenge. Furthermore, the emergence of "plant awareness" (11) and "awareness disparity" (7) from 2021 onwards signifies a nuanced shift in terminology (Parsley, 2020).

This shift from "blindness" towards "awareness" acknowledges the presence of knowledge gaps. It opens doors for targeted educational interventions aimed at bridging these disparities in the future.



However, the network reveals more than just distinct clusters. The interconnectivity between these nodes, measured by their centrality scores, suggests cross-cutting themes and potential bridges. Knowledge generation and dissemination efforts interweave with plant-related research and conservation initiatives, forming a dynamic cycle of understanding and action.

4 CONCLUSION

Botanical education research has undergone a remarkable transformation in recent years, evolving from a focus on medical applications to a multifaceted field encompassing public engagement, environmental awareness, and holistic learning experiences. This study has identified several key areas driving this evolution:

Combating Plant Blindness: Recognizing the critical disconnect between scientific knowledge and public understanding of plants, researchers actively address this issue to raise awareness and appreciation for plant life. The term "plant awareness" emerges as a nuanced and actionable approach, shifting the focus from merely identifying the problem of "blindness" to actively fostering connections with plants through education.

The Power of Botanical Gardens and Active Learning: Botanical gardens are increasingly valued as invaluable informal learning environments, offering immersive experiences that cultivate a deeper understanding and appreciation for the natural world. Active learning methodologies, such as hands-on activities and outdoor education, are further emphasized as key tools for engaging students and promoting meaningful learning outcomes.

Integrating Conservation with Education: The growing recognition of the intertwined nature of botanical education and environmental stewardship has led to a stronger emphasis on integrating conservation initiatives into educational programs. This approach empowers individuals to become responsible stewards of the plant world, fostering a sense of connection and action towards protecting biodiversity.



While this study reveals significant progress in botanical education research, potential pathways for future directions. Fostering international collaboration in research would accelerate knowledge sharing and dissemination of best practices across diverse contexts. Empowering the digital frontier is essential to unlocking transformative outcomes in botanical education. Immersive virtual field trips, augmented reality plant identification, and gamified learning hold the key to enhancing accessibility, fostering engagement, and revolutionizing educational impact.

Additionally, investigating the effectiveness of various informal learning methods, such as exploiting the educational potential of museums and herbariums, offers valuable avenues for future research. By addressing these opportunities and building upon the current momentum, botanical education research can continue to play a pivotal role in cultivating a world where plants are valued, understood, and protected.



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