MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2026, 22(12), em2974
ISSN:1305-8223 (online)
OPEN ACCESS Literature Review https://doi.org/10.29333/ejmste/20019

Analysis of research trends in 'plant awareness disparity' using bibliometric analysis

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Received 07 September 2026 ▪ Accepted 17 November 2026

Abstract

This study presents a systematic bibliometric analysis of 90 publications from the Web of Science core collection (2011-2026) to map the intellectual structure of plant awareness disparity (PAD) in science education. Using R Bibliometrix and VOSviewer, we synthesized quantitative publication trends, journal distributions, and researcher impact indexes. Keyword co-occurrence analysis identified five knowledge clusters: (1) affective and evolutionary approaches to overcoming zoocentrism in ecological and conservation contexts, (2) diagnosis of PAD, conceptual constructs, and curriculum critique in school biology education, (3) place-based outdoor inquiry, technology integration, and teacher professional development, (4) relationship between plant knowledge and attitudes toward sustainability values, and (5) multisensory direct experiences based in specialized informal educational institutions. In addition, temporal overlay visualization indicated increasing attention toward botanical literacy, teacher training, and education for sustainability. Addressing PAD may benefit from curriculum reform, technology-supported place-based pedagogies, and teacher preparation that strengthens plant-related pedagogical content knowledge and supports ecological citizenship.

Keywords: plant awareness disparity, science education, bibliometric analysis, VOSviewer, botanical literacy, education for sustainability

INTRODUCTION

In general, people know more about animals than about plants, leading visual attention to focus primarily on animals (Wandersee & Schussler, 1999). When processing visual information, humans tend to group static and densely clustered objects into a single background; as a result, individuals often perceive vegetation as a homogeneous green mass without recognizing distinct plant species (Wandersee & Schussler, 2001). This perceptual tendency partly explains why humans show an innate affinity for animals over plants (Schussler & Olzak, 2008).

Wandersee and Schussler (1999) originally introduced the term 'plant blindness' to describe this visual and cognitive neglect, reflecting a historical tradition in which plants were routinely undervalued and taken for granted (Hoekstra, 2000). In 2020, the term was redefined as 'plant awareness disparity (PAD)' to overcome the ableist metaphor of visual impairment (Parsley, 2020). This revised construct more objectively describes the perceptual gap where less attention and value are directed toward plants compared to animals. Along with this conceptual shift, more than 25 years of empirical research demonstrate that PAD is more than an individual cognitive deficit. Rather, it represents a substantial barrier to global sustainability goals, such as biodiversity conservation and climate change mitigation (Amprazis & Papadopoulou, 2020; Fail, 2004).

In science education, PAD poses a serious obstacle to preparing students for contemporary ecological challenges. Understanding issues like the climate crisis requires a firm grasp of botanical concepts and ecological processes, such as the carbon cycle. However, PAD directly impedes biology learning. This problem becomes evident when students fail to recognize plants as active living organisms or hold persistent misconceptions regarding plant metabolism (Amprazis

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Contribution to the literature

- This study provides a full structural overview of PAD research within science education by conducting a systematic bibliometric analysis of 90 articles indexed in the Web of Science (WoS) core collection.
- By combining R-based analysis using the Bibliometrix package with VOSviewer, the study systematically identifies productivity trends, impact metrics of core journals and researchers, and the foundational knowledge base of PAD research.
- A keyword co-occurrence network analysis clarifies five core knowledge clusters shaping PAD research, while an overlay visualization demonstrates how recent research themes have developed over time.

& Papadopoulou, 2020; Pany et al., 2024). Therefore, mitigating PAD can support the development of fundamental biological knowledge and may contribute to sustainability education by helping students recognize the ecological roles and social relevance of plants (Pany et al., 2024).

In response, science education researchers have investigated PAD across three primary areas. First, theoretical studies have refined the conceptual definitions and evolutionary bases of PAD (e.g., Albuquerque et al., 2025; Dünser et al., 2025; Parsley, 2020). Second, researchers have developed diagnostic scales to assess students' and teachers' botanical conceptions and attitudes (e.g., Bobo-Pinilla et al., 2024; Pany et al., 2024; Parsley et al., 2022). Third, empirical studies have designed and tested targeted instructional interventions to reduce PAD across varied educational settings (e.g., Kissi & Dreesmann, 2022; Park & Kim, 2026).

Alongside these empirical investigations, several review studies have synthesized the development of plant blindness and PAD from qualitative and pedagogical perspectives (e.g., Amprazis & Papadopoulou, 2020; Stagg & Donkin, 2013). These studies have provided valuable conceptual foundations by examining the historical origins of the phenomenon, clarifying definitions, and evaluating classroom practices based on the literature available up to their time of publication.

To complement these qualitative syntheses, a quantitative bibliometric approach can offer an expanded, macro-level overview of the field. A bibliometric analysis of publication trends, citation networks, and keyword co-occurrence patterns across an extended timeframe maps how scholarly communication is organized, identifies central thematic areas, and traces the temporal progression of research interest in science education. Such an analysis provides a structural baseline that clarifies the broader educational research context surrounding PAD.

Therefore, this study aims to map the intellectual structure of PAD research within science education, categorize its core research themes, identify existing gaps, and provide actionable implications for future practice. The specific research questions guiding this study are as follows:

1. What are the publication trends of PAD research in science education regarding annual productivity and the impact of sources, authors, and documents?
2. What are the intellectual structure and temporal developmental stages of PAD research in science education, as identified through keyword co-occurrence network analysis and overlay visualization?

METHODOLOGY AND PROCEDURE

To provide a clear and systematic roadmap of the investigation, the research workflow was organized into a four-phase methodological pipeline combining literature refinement, dual-track bibliometric analysis, and pedagogical synthesis (**Figure 1**). In phase 1, literature retrieval from the WoS core collection and a two-stage screening protocol based on PRISMA 2020 guidelines established a focused corpus of 90 peer-reviewed articles. In phase 2 and phase 3, this focused dataset was subjected to two complementary analytical lanes: in phase 2, a quantitative performance evaluation conducted via the R 'bibliometrix' package examined annual scientific production, source distributions, author productivity, and foundational cited documents; and in phase 3, structural knowledge mapping executed via VOSviewer software visualized the keyword co-occurrence network, identified five primary knowledge clusters, and traced the temporal evolution of research themes. Finally, in phase 4, the empirical findings from both analytical streams converged to inform a thematic discussion and derive actionable educational implications for science curricula, instructional design, and teacher preparation.

Methodology

Bibliometric analysis is an effective method for systematically structuring vast bodies of academic literature. It enables researchers to capture the overall structure of a discipline, identify knowledge gaps, and establish directions for future inquiry (Donthu et al., 2021). Historically, bibliometric research faced practical barriers because it relied on multiple specialized software programs that often required commercial licenses (Guler et al., 2016).

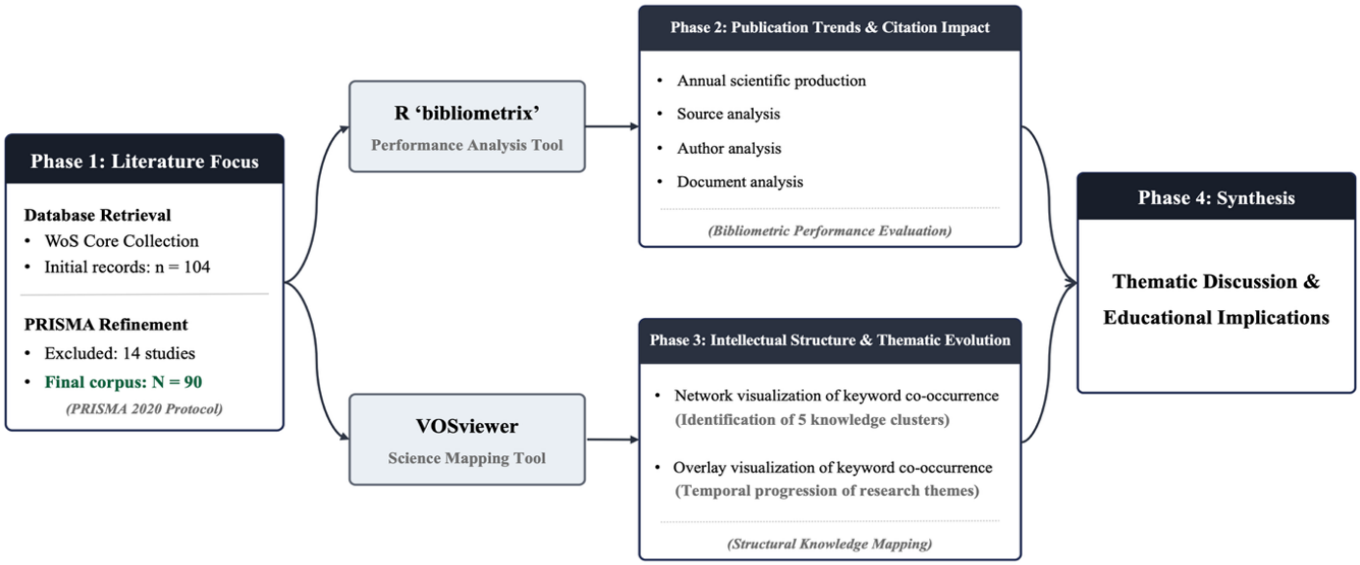

Figure 1. Overall methodological workflow of the study (the authors' own elaboration)

To address these limitations, recent educational research has actively adopted the open-source, R-based Bibliometrix package (Aria & Cuccurullo, 2017; Bae & Son, 2024; Wardat et al., 2025). As an R package, it is freely accessible, integrates easily with diverse statistical workflows, and adapts well to developing fields of study. Bibliometrix generates both fundamental bibliographic metrics, such as annual publication counts, core journals, and author productivity, and advanced citation impact indicators (Aria & Cuccurullo, 2017). Accordingly, this study used Bibliometrix in R to investigate the productivity trends and citation impact of PAD literature.

In addition, we used VOSviewer to visualize the intellectual structure and chronological evolution of the field (Perianes-Rodriguez et al., 2016; van Eck & Waltman, 2007, 2010). VOSviewer is widely used for science mapping and network visualization (Ha et al., 2020; Y. W. Lim et al., 2023). It allows researchers to set minimum occurrence thresholds to filter out low-frequency, idiosyncratic terms. This thresholding feature simplifies dense networks and produces clear visualizations of co-occurrence relationships among core concepts (van Eck & Waltman, 2010).

In this study, we conducted a keyword co-occurrence analysis using all keywords available in the WoS records, including author keywords and keywords plus. This approach was selected to capture both the concepts explicitly designated by authors and the additional index terms derived from cited-reference titles providing a broader representation of the thematic structure of PAD research. Keyword co-occurrence analysis identifies core research themes and subfields by examining how frequently pairs of keywords appear together in the same publications (Zupic & Čater, 2015). In the VOSviewer network map, each node represents a keyword, and the node size reflects its occurrence frequency. The edges connecting nodes indicate co-occurrence relationships, with line thickness representing link strength (van Eck & Waltman, 2026). Finally, an overlay visualization applied a color gradient based on the average publication year of each keyword. This map contrasts early foundational topics with recent themes to indicate the thematic shifts and temporal progress of PAD research. To reduce indexing redundancy and resolve semantic variations resulting from combining author keywords with keywords plus, a customized VOSviewer thesaurus file was applied before generating the network. Singular and plural variants were unified into consistent canonical forms (e.g., merging 'plant' and 'plants' into 'plant', and 'attitude' and 'attitudes' into 'attitudes'), and synonymous historical phrases such as 'plant blindness' and 'lack of plant awareness' were merged into 'plant awareness disparity'. Non-topical terms were removed, including generic methodology labels ('research design', 'responses') and broad descriptors ('education', 'students') that do not differentiate specific themes.

Procedure

Data source and search strategy

The primary dataset for this bibliometric analysis was retrieved from Clarivate Analytics' WoS core collection. The WoS core collection was selected because it provides broad coverage of high-impact, peer-reviewed journals and maintains data consistency (Afaneh et al., 2026). To maintain high academic standards, the citation indexes were strictly limited to the science citation index expanded (SCI-E), social sciences citation index (SSCI), arts & humanities citation index (A&HCI), and emerging sources citation index (ESCI). In addition, document types were restricted to peer-reviewed 'articles' and 'review articles' to ensure the reliability of the literature corpus.

Table 1. Parametric specifications and modular search syntax of the bibliometric retrieval strategy

Step/parameter	Field tag	Verbatim query/specification	Logic & methodological purpose
Database source	N/A	WoS core collection	To access curated international peer-reviewed journals with structured citation tracking
Citation indexes	N/A	SCI-E, SSCI, A&HCI, ESCI	To ensure high scholarly standards and metadata consistency
Timespan & language	PY/LA	All indexed years through August 25, 2026 (earliest retrieved: 2011); English	To capture the full publication history without arbitrary date restrictions
Disciplinary scope	ALL	Science education OR biology education OR life science education OR geoscience education OR chemistry education OR earth science education OR physics education OR STEAM OR STEM	OR logic; broadly captures traditional science disciplines and integrated STEM/STEAM contexts
Target phenomenon	ALL	"Plant blindness" OR "plant awareness disparity"	OR logic; exact-phrase matching capturing both foundational and contemporary terminology
Document types	DT	Article OR review article	OR logic; restricts records to peer-reviewed original empirical research and review articles
Combined query execution	Boolean AND	(Disciplinary scope) AND (target phenomenon) AND (document types)	Intersects educational discipline, target phenomenon, and document type filters
Retrieval yield	N/A	104 publications (retrieved on August 25, 2026)	Complete initial corpus exported for PRISMA 2020 eligibility screening (**Figure 2**)

Our primary objective was to examine the intellectual structure and citation patterns of peer-reviewed journal articles within international science education. As scientometric evaluations have demonstrated, the WoS core collection represents an established, selective corpus of scholarly journals, with over 96% of its indexed journals overlapping with Scopus (Martín-Martín et al., 2021; Visser et al., 2021). Merging records across disparate databases introduces substantial preprocessing challenges, including duplicate resolution, author and institutional disambiguation, and reconciliation of divergent citation tracking algorithms (Caputo & Kargina, 2022; Mongeon & Paul-Hus, 2016). Relying on a unified WoS dataset avoided these potential artifacts and supported the reproducibility of our citation calculations. In addition, specialized educational databases such as ERIC do not provide structured cited reference metadata (the 'CR' field) required for algorithmic citation analysis in R 'bibliometrix', and recent evaluations have noted their coverage limitations in large-scale evidence synthesis (Fitzgerald et al., 2025; Gusenbauer & Haddaway, 2020). Using a unified corpus was therefore considered advantageous for maintaining internal validity across both our performance metrics and keyword network mapping. Literature indexed outside WoS is addressed as a study limitation.

To capture pertinent literature across diverse educational contexts, the retrieval strategy targeted the 'all fields' (ALL) scope by combining three core parameters: disciplinary descriptors encompassing traditional science disciplines and integrated STEM/STEAM frameworks, the target phenomenon constructs ('plant blindness' and 'plant awareness disparity'), and document type filters. The exact Boolean syntax, field tags, and modular parameter specifications are detailed in **Table 1**.

Data retrieval was executed on August 25, 2026. We did not preset the search period to 2011-2026; instead, the search was conducted without any timespan restriction, yielding an initial corpus of 104 publications. In the retrieved results, the earliest peer-reviewed publication meeting the search criteria appeared in 2011 (Fančovičová & Prokop, 2011), which resulted in a 15-year analytical timeframe (2011-2026). Earlier works introducing 'plant blindness' (Wandersee & Schussler, 1999, 2001) appeared in society newsletters (e.g., *Plant Science Bulletin*), commentaries, or conference proceedings, and thus fell outside our criteria of peer-reviewed journal articles indexed in the WoS core collection.

Because retrieval was conducted within a single database, no duplicate records were present before screening (n = 0). The authors independently evaluated the 104 records through a two-stage screening protocol adhering to the PRISMA 2020 guidelines (Page et al., 2021), with discrepancies resolved through mutual consensus (**Figure 2**). In the first stage (title and abstract screening), seven records were excluded because they examined non-plant biological taxa (bees, lichens, or fungi; n = 3) or focused on non-educational contexts outside science education (literary fiction criticism, culinary ethnobotany, disability philosophy, or sculpture art; n = 4). Full-text reports for the remaining 97 articles were retrieved for eligibility assessment. In the second stage (full-text eligibility assessment), an additional seven studies were excluded based on two explicit criteria: studies investigating purely laboratory cognitive mechanisms or ecological patterns without educational contexts (n = 3; e.g., Balas & Momsen, 2014), and studies addressing general environmental

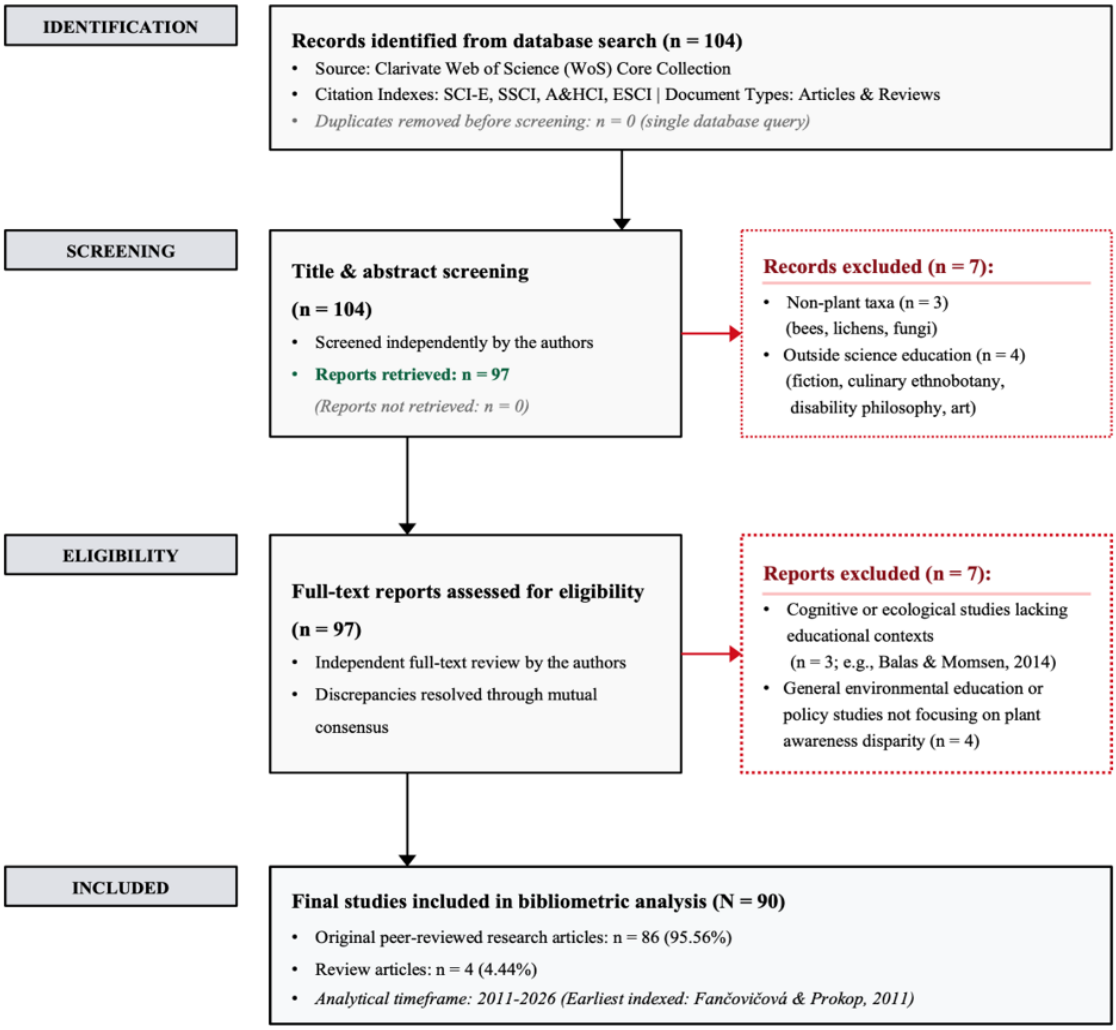

Figure 2. PRISMA 2020 flow diagram of the literature identification, screening, and inclusion process (the authors' own elaboration, adapted from Page et al., 2021)

Table 2. Main information of analyzed studies

Description	Result
Timespan	2011-2026
Documents	90
Authors	268
International co-authorship	12.22%
Author's keywords	319
Document average age	3.37
Sources	37
Annual growth rate	15.78%
Authors of single-authored documents	8
Co-authors per document	3.66
References	3,803
Average citations per document	19.68

Note. The annual growth rate of 15.78% represents the unadjusted compound annual growth rate (CAGR) automatically generated by the Bibliometrix package across the nominal timespan of 2011-2026. Because data extraction concluded on August 25, 2026, the 2026 dataset captures an incomplete observation window of approximately eight months. Calculating the CAGR across complete calendar years (2011-2025) yields an annual growth rate of 27.19%.

education or policy frameworks without examining PAD or plant blindness as a core construct (n = 4). After this screening, 90 peer-reviewed publications, comprising 86 original empirical research articles and 4 review articles published between 2011 and August 2026, met all eligibility criteria and constituted the final corpus for analysis.

Analyzed publications

Table 2 summarizes the fundamental characteristics of the 90 publications analyzed in this study. The final corpus consists of 90 peer-reviewed research and review articles published across 37 academic journals over a 15-year period (2011-2026), with an annual publication growth rate of 15.78%. In total, these publications cited 3,803 references, with an average document age of 3.37 years and an average of 19.68 citations per paper. In addition, we identified a total of 319 author keywords. Across the dataset, 268 distinct authors were identified, with single-authored papers accounting for only eight publications. On average, each document involved 3.66 co-authors. In addition, international co-authorship, reflecting cross-national collaborative research, stood at 12.22%, which indicates that cross-border research collaborations in the PAD field remain relatively limited.

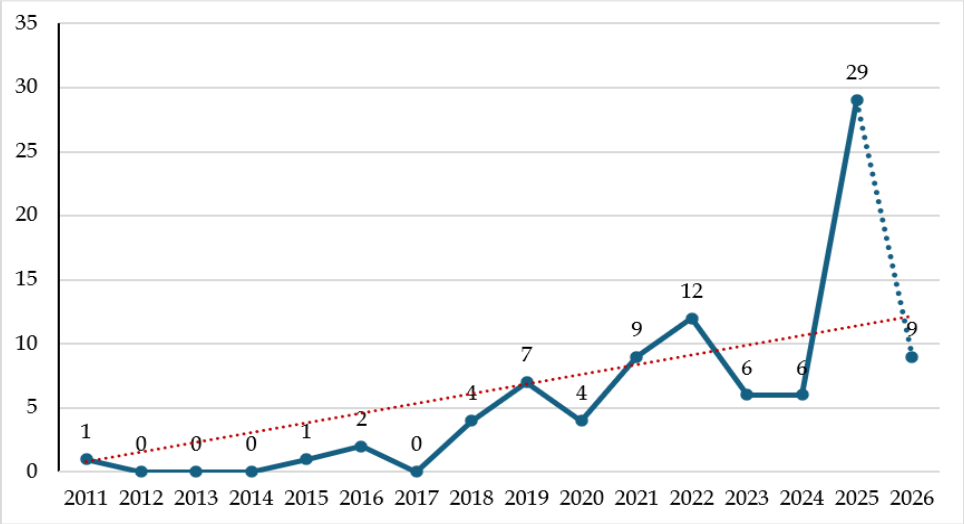

Figure 3. Annual scientific production (the authors' own elaboration)

Table 3. Most relevant sources (top 10)

Sources	Articles
Journal of Biological Education	21
Plants, People, Planet	17
Sustainability	6
The American Biology Teacher	5
Education Sciences	4
International Journal of Science Education	3
Environmental Education Research	2
Journal of Zoological and Botanical Gardens	2
Science Education	2
European Journal of Sustainable Development	1

RESULTS

RQ1. Publication Trends and Citation Impact of PAD Research

Annual scientific production

As indicated by the linear trend line in **Figure 3**, the annual publication volume from 2011 to 2026 showed a steady upward trend. Between 2011 and 2017, publication output remained minimal, fluctuating between zero and two papers per year, with a total of only four publications. Annual output rose gradually in 2018 (4 publications), climbed to 12 publications in 2022, and was recorded at 6 publications each in 2023 and 2024, before recording the steepest increase in 2025 with 29 published articles (representing 32.22% of the 90-article corpus).

Regarding the final observation year, nine publications were recorded for 2026. Because literature retrieval concluded on August 25, 2026, this count captures an incomplete calendar window spanning approximately eight months. Incorporating this truncated observation period into the standard compound annual growth rate (CAGR) calculation yields the nominal rate of 15.78% reported in **Table 2**. However, evaluating publication growth strictly across complete calendar years from 2011 through 2025 demonstrates a steeper CAGR of 27.19%. In addition, the accumulation of nine peer-reviewed articles within the first eight months of 2026 already surpasses the full-year totals of several earlier active periods (e.g., four articles in 2020 and six articles each in 2023 and 2024).

Source analysis

An analysis of publication output across the top 10 journals indicates that PAD research is concentrated in a limited number of core journals (**Table 3**). The *Journal of Biological Education* published the largest number of studies, with 21 publications, followed by *Plants, People, Planet* with 17 publications. Other prominent sources include *Sustainability* (6 publications, 3rd), *The American Biology Teacher* (5 publications, 4th), *Education Sciences* (4 publications, 5th), and the *International Journal of Science Education* (3 publications, 6th). Tied for seventh place were *Environmental Education Research* (2 publications), the *Journal of Zoological and Botanical Gardens* (2 publications), and *Science Education* (2 publications), with the *European Journal of Sustainable Development* (1 publication) ranking 10th. The top two journals alone accounted for 38 publications, representing 42.22% of the entire analyzed corpus, while the top 10 journals published a total of 63 articles (70.00%).

Table 4 and **Table 5** display the citation patterns and impact metrics of journals referenced by the analyzed publications. Here, local citations indicate how many times any article published in a given journal (including foundational works outside the 90-article dataset) was cited within the reference lists of our 90 analyzed articles. In contrast, total citations represent the cumulative WoS citations received specifically by the subset of articles from that journal included in our 90-article corpus. Because local citations count references to all historical issues of a journal whereas total citations are restricted

Table 4. Most local & total cited sources (top 10 by local cited number)

Sources	Local	Total
Journal of Biological Education	483	314
Plants, People, Planet	245	588
International Journal of Science Education	184	98
The American Biology Teacher	180	59
Environmental Education Research	130	153
CBE—Life Sciences Education	91	37
Sustainability	77	37
Conservation Biology	74	255
Journal of Research in Science Teaching	73	-
BioScience	72	24

Note. Local citations count references from the 90 analyzed articles to any paper ever published in the source journal, whereas total citations sum the WoS citations of only those articles included in the 90-article dataset. For the *Journal of Research in Science Teaching*, total citations are indicated as '-' because no articles from this journal were included in the analyzed primary dataset.

Table 5. Sources' local impact (top 10 by h-index)

Sources	h-index	g-index	m-index
Plants, People, Planet	11	17	1.375
Journal of Biological Education	9	17	1.000
Sustainability	4	6	0.571
The American Biology Teacher	3	5	0.250
International Journal of Science Education	3	3	0.333
Education Sciences	2	4	0.400
Environmental Education Research	2	2	0.125
CBE—Life Sciences Education	1	1	0.200
Annals of Botany	1	1	0.500
BioScience	1	1	0.143

to articles within the analyzed corpus, journals with a long history of foundational botany education papers (e.g., *Journal of Biological Education*) can record higher local than total citations. For impact metrics, the h-index balances productivity and citation count, the g-index weights the presence of top highly cited papers, and the m-index measures annual impact accumulation by dividing the h-index by the number of years since the journal's first publication in the dataset.

As shown in **Table 4**, the *Journal of Biological Education* recorded the highest number of local citations (483 local citations, 314 total citations), followed by *Plants, People, Planet* (245 local citations, 588 total citations), the *International Journal of Science Education* (184 local citations, 98 total citations), *The American Biology Teacher* (180 local citations, 59 total citations), and *Environmental Education Research* (130 local citations, 153 total citations). In addition, *CBE—Life Sciences Education* (91 local citations), *Conservation Biology* (74 local citations), the *Journal of Research in Science Teaching* (73 local citations), and *BioScience* (72 local citations) ranked among the top 10 most locally cited sources.

Meanwhile, **Table 5** reveals distinct and complementary impact profiles among core journals.

Table 6. Most relevant authors (top 10)

Author	Articles
Pany, P.	7
Lampert, P.	6
Prokop, P.	5
Amprazis, A.	4
Kiehn, M.	4
Papadopoulou, P.	4
Parsley, K. M.	4
Sanders, D.	4
Fančovičová, J.	3
Barrutia, O.	3

Table 7. Authors' local impact (top 10 by h-index)

Author	h-index	g-index	m-index
Pany, P.	6	7	0.750
Lampert, P.	5	6	0.625
Prokop, P.	4	5	0.250
Kiehn, M.	4	4	0.500
Sanders, D.	4	4	0.500
Parsley, K. M.	3	4	0.429
Amprazis, A.	3	4	0.500
Papadopoulou, P.	3	4	0.500
Dünser, B.	3	3	1.000
Fančovičová, J.	3	4	0.188

Regarding the g-index, both *Plants, People, Planet* and the *Journal of Biological Education* scored 17, confirming that both venues host major, highly cited publications in the PAD literature. However, their citation growth patterns differ substantially. *Plants, People, Planet* achieved the highest h-index (11) and a remarkable m-index of 1.375, indicating rapid scholarly diffusion and high impact accumulation for recently published articles. In contrast, the *Journal of Biological Education* recorded an h-index of 9 and an m-index of 1.000, which reflects a stable, continuous citation record built over an extended period.

Author analysis

To examine the scholarly contributions and influence of key authors in the PAD literature, we summarize the most productive authors, their local and total citations, and their individual impact metrics.

In terms of productivity and scholarly impact, the research collaboration led by Pany, P. and Lampert, P. was particularly prominent (**Table 6** and **Table 7**). Pany, P. was the most prolific author, publishing seven papers with strong impact metrics, including an h-index of 6, a g-index of 7, and an m-index of 0.750. Lampert, P., who actively collaborated with Pany, P. as a frequent co-author, also showed substantial influence, publishing six papers with an h-index of 5 and a g-index of 6.

Within the University of Vienna research group, Kiehn, M. published four articles (h-index of 4, g-index of 4, and 45 local citations) and Dünser, B. recorded an h-index of 3, a g-index of 3, and an m-index of 1.000.

Table 8. Most local & total cited authors (top 10 by local cited number)

Author	Local	Total
Parsley, K. M.	79	260
Balding, M.	49	255
Williams, K. J. H.	49	255
Pany, P.	48	147
Kiehn, M.	45	109
Dillon, J.	38	126
Stagg, B. C.	38	126
Sabel, J. L.	31	80
Amprazis, A.	26	67
Papadopoulou, P.	26	67

Other prominent scholars with substantial publication output and citation impact include Prokop, P. (5 publications, h-index of 4), Fančovičová, J. (3 publications, h-index of 3), Amprazis, A. and Papadopoulou, P. (4 publications, h-index of 3, and 26 local citations each), and Sanders, D. (4 publications, h-index of 4).

In the local citation analysis, Parsley, K. M. recorded the highest frequency with 79 local citations and also received the highest number of total citations (260 citations; **Table 8**), followed by Pany, P. (48 local citations, 147 total citations) and Kiehn, M. (45 local citations, 109 total citations).

In addition, several authors who were not among the most prolific in **Table 6** nonetheless achieved substantial citation impact (**Table 8**). These scholars include Balding, M. and Williams, K. J. H. (49 local citations and 255 total citations each), Dillon, J. and Stagg, B. C. (38 local citations and 126 total citations each), and Sabel, J. L. (31 local citations and 80 total citations).

Document analysis

To examine the foundational literature underpinning PAD research and identify its most influential publications, we analyzed both the most frequently co-cited references across the broader academic literature (**Table 9**) and the top-cited papers within our primary dataset of 90 publications (**Table 10**).

First, an examination of the most frequently cited references across the bibliographies of the 90 articles (**Table 9**) shows that Wandersee and Schussler (1999) recorded the highest local citation count (59 citations), followed by Balding and Williams (2016) (49 citations) and Parsley (2020) (48 citations). High citation frequencies were also recorded for Balas and Momsen (2014) (46 citations), Schussler and Olzak (2008) (39 citations), Lindemann-Matthies (2005) (36 citations), Wandersee and Schussler (2001) (32 citations), Amprazis and Papadopoulou (2020) (30 citations), Fančovičová and Prokop (2011) (30 citations), and Strgar (2007) (28 citations).

Next, among the top-ranked papers by local citations within our analyzed corpus (**Table 10**), Balding and Williams (2016) (49 local citations, 255 global citations) and Parsley (2020) (48 local citations, 180 global citations) recorded the highest citation counts. They were followed by systematic review studies conducted by Stagg and Dillon (2022) (24 local citations) and Jose et al. (2019) (23 local citations).

Alongside these conceptual benchmarks, diverse empirical studies ranked prominently. One group of empirical studies focused on diagnosing students' conceptions and botanical attitudes. These include surveys of elementary students' perceptions of living organisms (Amprazis et al., 2021; 20 local citations), assessments of factual botanical knowledge and its correlation with attitudes (Kubiatko et al., 2021; 18 local citations), and validated scales measuring student plant awareness (PA) (Pany et al., 2024; 23 local citations).

Another group investigated practical instructional interventions and curricular materials. These studies evaluated hands-on interventions such as growing companion plants (Krosnick et al., 2018; 22 local citations), mobile-supported botanical garden learning (Kissi & Dreesmann, 2018; 20 local citations), and visual

Table 9. Most local cited references

Title	PY	1st author	n
Preventing plant blindness	1999	Wandersee, J. H.	59
Plant blindness and the implications for plant conservation	2016	Balding, M.	49
Plant awareness disparity: A case for renaming plant blindness	2020	Parsley, K. M.	48
Attention 'blinks' differently for plants and animals	2014	Balas, B.	46
It's not easy being green: Student recall of plant and animal images	2008	Schussler, E. E.	39
'Loveable' mammals and 'lifeless' plants: How children's interest in common local organisms can be enhanced through observation of nature	2005	Lindemann-Matthies, P.	36
Toward a theory of plant blindness	2001	Wandersee, J. H.	32
Plant blindness: A faddish research interest or a substantive impediment to achieve sustainable development goals?	2020	Amprazis, A.	30
Plants have a chance: Outdoor educational programmes alter students' knowledge and attitudes towards plants	2011	Fančovičová, J.	30
Increasing the interest of students in plants	2007	Strgar, J.	28

Note. PY: Publication year; n: Number of citations

Table 10. Most local & global cited articles (top 10 by local citations)

Title	1st author	LC	GC
Plant blindness and the implications for plant conservation	Balding, M.	49	255
Plant awareness disparity: A case for renaming plant blindness	Parsley, K. M.	48	180
Plant awareness is linked to plant relevance: A review of educational and ethnobiological literature (1998-2020)	Stagg, B. C.	24	87
Overcoming plant blindness in science, education, and society	Jose, S. B.	23	100
Measuring students' plant awareness: A prerequisite for effective botany education	Pany, P.	23	56
The pet plant project: Treating plant blindness by making plants personal	Krosnick, S. E.	22	42
Plant visibility through mobile learning? Implementation and evaluation of an interactive Flower Hunt in a botanic garden	Kissi, L.	20	37
Plant blindness and children's recognition of plants as living things: A research in the primary schools context	Amprazis, A.	20	44
Factual knowledge of students about plants is associated with attitudes and interest in botany	Kubiatko, M.	18	42
An analysis of plant awareness disparity within introductory biology textbook images	Brownlee, K.	17	43

Note. LC: Local citations; GC: Global citations

representation disparities in biology textbook images (Brownlee et al., 2023; 17 local citations).

RQ2. Intellectual Structure and Thematic Evolution of PAD Research

To examine the intellectual structure of PAD research, we conducted a keyword co-occurrence network analysis in VOSviewer using all keywords available in the WoS records, including both author keywords and keywords plus. Combining these two keyword sources enabled the analysis to capture author-designated concepts as well as additional index terms associated with the cited-reference records. Keyword co-occurrence analysis is an established bibliometric method that reveals the core themes and conceptual structure of a research field by examining how frequently pairs of keywords appear together in the same publications (Donthu et al., 2021).

Regarding the counting method, we applied fractional counting instead of full counting. Fractional counting assigns proportional weight to each keyword connection so that every publication contributes equally to the total link strength regardless of how many keywords it contains. This approach prevents papers with an unusually large number of keywords from exercising a disproportionate influence on the network structure (van Eck & Waltman, 2010).

The minimum occurrence threshold was set to 3, meaning that only keywords appearing in at least three publications across the 90 analyzed articles were included in the network. In VOSviewer, the minimum occurrence threshold filters which concepts enter the visualization (van Eck & Waltman, 2026). This threshold is not a fixed universal number; rather, researchers should determine it by considering sample size, thematic breadth, the intended coverage of core and specialized topics, and overall visual clarity (Zupic & Čater, 2015).

In this study, a threshold of 3 was selected to reduce the influence of idiosyncratic low-frequency keywords while retaining recurrent specialized topics in the network. This threshold has been routinely adopted in keyword co-occurrence studies analyzing focused literature corpora (e.g., Cândido et al., 2023; Chiu et al., 2021). Through this procedure, 26 keyword nodes and five distinct clusters were identified as the empirical baseline for mapping the intellectual structure and temporal evolution of PAD research.

Network visualization of keyword co-occurrence

The co-occurrence network analysis of the 26 retained keywords partitioned the intellectual structure of PAD research into five distinct clusters (**Figure 4** and **Table 11**). Centered on 'plant awareness disparity' as the primary hub node of the network, each cluster comprises terms that co-occurred frequently across the analyzed publications:

Cluster 1 (red; 7 keywords) is designated as 'affective and evolutionary approaches to overcoming zoocentrism in ecological and conservation contexts' and comprises 'affective and aesthetic learning', 'animals', 'biodiversity', 'conservation', 'fungi blindness', 'preferences', and 'secondary education'. Cluster 2 (green; 7 keywords), positioned at the core of the network, represents the 'diagnosis of PAD, conceptual constructs, and curriculum critique in school biology education', encompassing 'attention', 'biology education', 'botanical literacy', 'plant awareness disparity', 'students' conceptions', 'textbook analysis', and 'traditional ecological knowledge' (TEK). Cluster 3 (blue; 5 keywords) is labeled 'place-based outdoor inquiry, technology integration, and teacher professional development' and includes 'green', 'mobile learning', 'outdoor inquiry learning', 'place-based informal education', and 'teacher training'. Cluster 4 (yellow; 4 keywords) represents the 'relationship between plant knowledge and attitudes toward sustainability values', consisting of 'attitudes', 'education for sustainability', 'environmental education', and 'plant knowledge'. Finally, Cluster 5 (purple; 3 keywords) is identified as 'multisensory direct

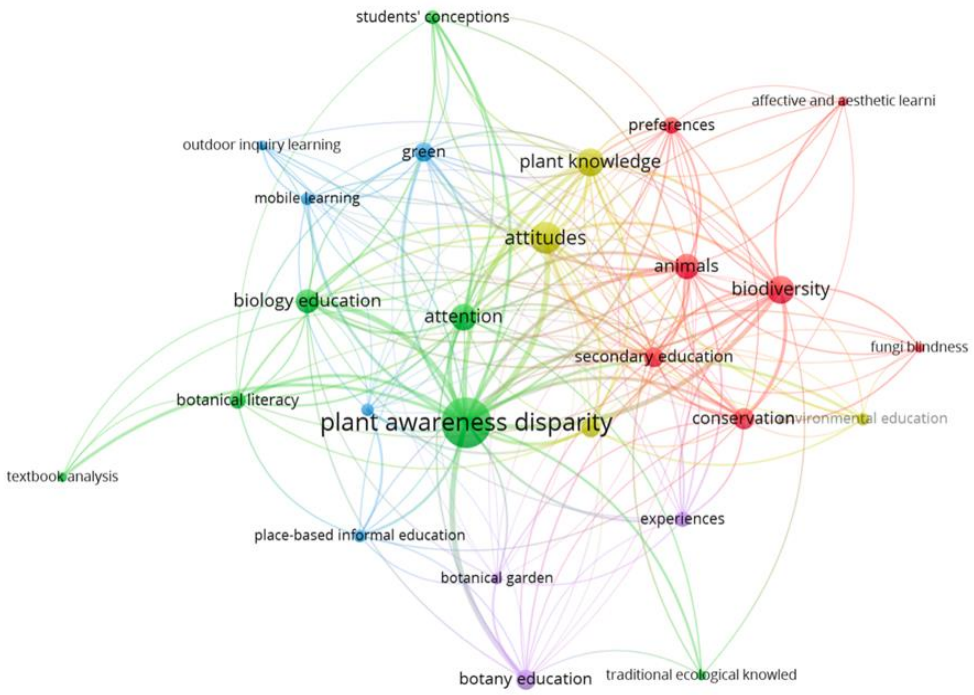

Figure 4. Network visualization of keyword co-occurrence in PAD research (the authors' own elaboration, using VOSviewer)

Table 11. Clusters of the keyword co-occurrence network

Cluster	Theme	Keywords
1 (red)	Affective and evolutionary approaches to overcoming zoocentrism in ecological and conservation contexts	Affective and aesthetic learning, animals, biodiversity, conservation, fungi blindness, preferences, secondary education
2 (green)	Diagnosis of PAD, conceptual constructs, and curriculum critique in school biology education	Attention, biology education, botanical literacy, plant awareness disparity, students' conceptions, textbook analysis, traditional ecological knowledge
3 (blue)	Place-based outdoor inquiry, technology integration, and teacher professional development	Green, mobile learning, outdoor inquiry learning, place-based informal education, teacher training
4 (yellow)	Relationship between plant knowledge and attitudes toward sustainability values	Attitudes, education for sustainability, environmental education, plant knowledge
5 (purple)	Multisensory direct experiences based in specialized informal educational institutions	Botanical garden, botany education, experiences

experiences based in specialized informal educational institutions', containing 'botanical garden', 'botany education', and 'experiences'.

Overlay visualization of keyword co-occurrence

The overlay visualization of the keyword co-occurrence network, weighted by average publication year (**Figure 5**), illustrates the chronological distribution of the 26 retained keywords across the study period. The average publication years of the retained keywords range from 2020.67 to 2025.20 across three consecutive intervals: 2020-2021, 2022-2023, and 2024-2025.

First, keywords situated in the 2020-2021 interval (purple and blue nodes) include 'outdoor inquiry learning' (2020.67), 'botanical garden' (2020.75), 'experiences' (2021.00), 'animals' (2021.37), 'preferences' (2021.50), 'green' (2021.73), 'mobile learning' (2021.80), and 'secondary education' (2021.92).

Second, during the 2022-2023 interval (teal and green nodes), 'plant awareness disparity' (2022.76), the central hub of the network, appeared alongside 'botany education' (2022.00), 'attitudes' (2022.07), 'students' conceptions' (2022.17), 'biodiversity' (2022.43), 'environmental education' (2022.60), 'plant knowledge' (2022.70), 'attention' (2022.76), 'biology education' (2023.00), 'conservation' (2023.08), 'education for sustainability' (2023.18), and 'fungi blindness' (2023.33).

Third, the most recent interval from 2024-2025 onward (yellow-green and yellow nodes) comprises 'botanical literacy' (2024.13), 'teacher training' (2024.60), 'textbook analysis' (2024.67), 'affective and aesthetic learning' (2024.67), 'traditional ecological knowledge' (2025.00), and 'place-based informal education' (2025.20).

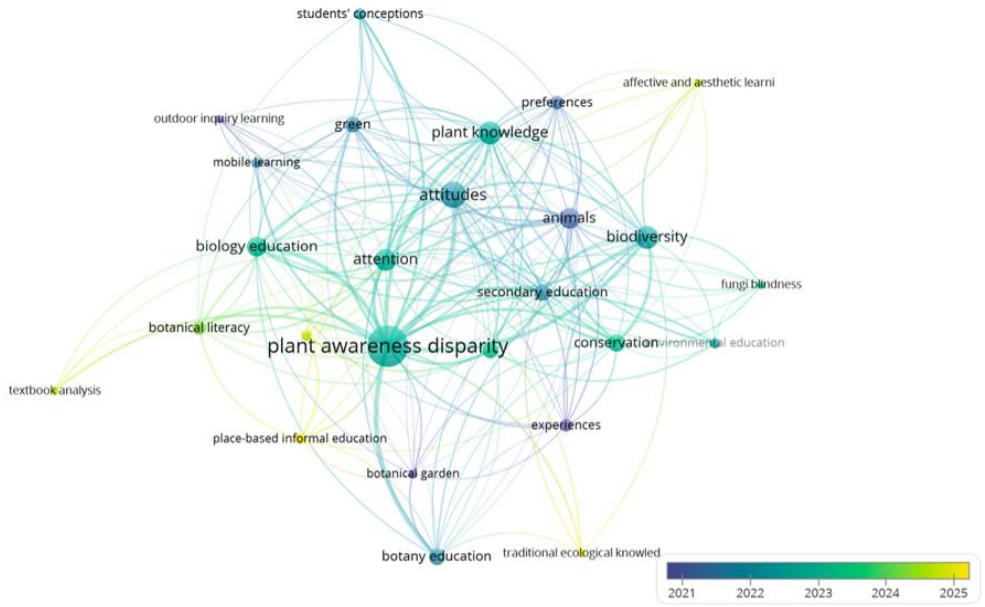

Figure 5. Overlay visualization of keyword co-occurrence in PAD research (the authors' own elaboration, using VOSviewer)

DISCUSSION

Publication Trends and Research Collaboration

For more than a decade following Wandersee and Schussler's (1999, 2001) introduction of 'plant blindness', scholarly output remained modest and was largely confined to localized conceptual commentaries (**Figure 3**, **Table 2**). The marked upward trend in annual publications, culminating in the 2025 peak of 29 articles (representing nearly one-third of the analyzed corpus), appears to reflect three converging academic developments beyond a transient statistical fluctuation. First, the conceptual transition from an ophthalmological deficit metaphor toward a sociocognitive and educational disparity (PAD) (Parsley, 2020) helped initiate the development of standardized diagnostic instruments, specifically the PAD index (Parsley et al., 2022) and multidimensional inventories (Dünser et al., 2025; Pany et al., 2024). As Brkovic et al. (2025) observed in their review of 46 empirical contributions, establishing reliable measurement instruments enabled researchers to design controlled pre- and post-intervention classroom studies that extended beyond exploratory surveys (e.g., Zhu et al., 2025); the maturation of these multi-year empirical designs appears to have contributed to the concentrated volume of peer-reviewed publications between 2024 and 2025. Second, this empirical momentum was further facilitated by targeted journal initiatives, such as the dedicated special issue in *Plants, People, Planet* (2025, vol. 7, issue 4) (New Phytologist Foundation, n.d.), which provided an international venue for empirical submissions. Third, situating PA within transdisciplinary scientific literacy for climate challenges (Kubisch et al., 2022) and the framework of the United Nations sustainable development goals (SDG) (in particular, SDG 15: life on land) reframed plant learning from an isolated botanical topic into an essential foundation for global biodiversity conservation and broadened the scope of empirical inquiry (Akpınarlı & Köseoğlu, 2025; Amprazis & Papadopoulou, 2020).

The source and citation metrics documented in **Table 3**-**Table 5** and **Table 9** and **Table 10** suggest that PAD scholarship has gradually diversified beyond its historical disciplinary boundaries. Although initial scholarship was firmly rooted in formal biology education, with the *Journal of Biological Education* sustaining the highest publication volume (21 articles; **Table 3**) and local citation count (483 citations; **Table 4**) through studies on students' alternative conceptions and hands-on models (e.g., Adler et al., 2024; Lampert et al., 2020, 2025), the field has increasingly extended toward multidisciplinary environmental and conservation platforms. *Plants, People, Planet* has emerged as a prominent forum (17 articles; **Table 3**) with an h-index of 11, a g-index of 17, and an m-index of 1.375 (**Table 5**), complemented by contributions in sustainability and environmental education venues (e.g., Panitsa et al., 2021) as well as zoological and botanical garden outlets (e.g., Bavcon et al., 2024). This dual structure indicates that the field maintains its core cognitive and didactic foundations (Balas & Momsen, 2014; Schussler & Olzak, 2008; Wandersee, 1986) while engaging with broader socio-ecological issues (Balding & Williams, 2016; Parsley, 2020). As Stagg and Dillon (2022) demonstrated in their 22-year systematic review, PA is substantially mediated by 'plant relevance', conceptualized as the extent to which learners perceive plants as meaningful to culture, daily life, and ecological well-being. The observed diversification across journal categories

suggests that contemporary research is moving away from framing plant blindness merely as an instructional defect toward examining the socio-ecological relationships that connect humans and plants.

A distinct bibliometric pattern identified in **Table 2** is the low international co-authorship rate of 12.22%, with single-country publications representing 87.78% of the corpus. When benchmarked against broader bibliometric analyses in science and STEM education where multinational research networks are relatively common (e.g., Ha et al., 2020; Wardat et al., 2025), the national focus within PAD research is evident. Author productivity and citation distributions (**Table 6**-**Table 8**) further suggest that research activity remains clustered within specific regional groups, particularly in Central Europe (e.g., University of Vienna). This geographic concentration appears to stem from the epistemic characteristics of botanical education: unlike physics or chemistry curricula that focus on universal physical laws, plant learning is intrinsically place-based, relying on direct observation of native local flora and adapting to country-specific biology curricula and national textbook frameworks (Stagg & Dillon, 2022). As a result, researchers have often focused on local or national educational interventions. Because biodiversity loss and environmental degradation represent global challenges, however, this localized focus suggests the potential value of cross-cultural research partnerships. Future studies could benefit from balancing place-based pedagogical authenticity with multinational comparative designs supported by standardized diagnostic instruments.

Pedagogical Theorization of the Knowledge Clusters

The five thematic clusters identified through the keyword co-occurrence network (**Figure 4**, **Table 11**) move beyond a descriptive catalog of isolated topics; they can be interpreted through established educational frameworks that connect cognitive processing, curriculum design, experiential learning, and pedagogical content knowledge (PCK). As mapped across the overlay visualization (**Figure 5**), the thematic evolution suggests an expansion from visual-perceptual constraints toward systemic sustainability education. Specifically, cluster 1 (red), representing 'affective and evolutionary approaches to overcoming zoocentrism in ecological and conservation contexts', appears to reflect evolutionary and cognitive perspectives on human attention biases. Cluster 2 (green), addressing the 'diagnosis of PAD, conceptual constructs, and curriculum critique in school biology education', can be understood through sociocultural learning theory and critical curriculum studies. Cluster 3 (blue), centering on 'place-based outdoor inquiry, technology integration, and teacher professional development', can be viewed as engaging place-based education and teacher PCK. Cluster 4 (yellow), representing the 'relationship between plant knowledge and attitudes toward sustainability values', corresponds to cognitive-affective learning theories and education for sustainable development. Finally, cluster 5 (purple), focusing on 'multisensory direct experiences based in specialized informal educational institutions', exemplifies experiential learning theory (Kolb, 1984), where learning is understood to occur through the transformation of concrete sensory experience.

The connection between cluster 1 and cluster 2 reflects a reciprocal relationship between biological predispositions and formal schooling. Research in cluster 1 indicates that human visual systems developed to treat static, uniformly green vegetation as background visual noise, creating an innate cognitive bias that prioritizes moving animals (Achurra, 2022; Balding & Williams, 2016) and extends to other non-animal taxa such as fungi ('fungi blindness') (Melis et al., 2020), which has prompted affective approaches encouraging compassion and appraising botanical rarity (Prokop et al., 2025; Prokop & Fančovičová, 2023). Instead of mitigating this evolutionary predisposition, formal educational institutions have historically reinforced it. As demonstrated by recent curriculum investigations in cluster 2, science textbooks and school standards persistently marginalize botanical content, where plants frequently appear to have been relegated to brief introductory chapters or passive ecological backdrops (Brownlee et al., 2023; Pedrera et al., 2025). To counteract this institutionalized neglect, contemporary research has increasingly embraced sociocultural frameworks by integrating 'traditional ecological knowledge' (**Figure 5**) (Stagg & Dillon, 2022) and local cultural practices into science classrooms (Cheng & Cowie, 2026; Compan et al., 2025). Connecting botanical concepts with indigenous and local cultural narratives regarding ethnobotanical uses, foodways, and seasonal practices allows educators to convert abstract morphological memorization into culturally grounded botanical literacy, which is thought to help establish the sociocultural relevance necessary to overcome innate inattention.

A clear theoretical tension can be observed between the technological interventions in cluster 3 and the specimen-based pedagogies in cluster 5. On one hand, introducing mobile plant-identification applications and gamified digital tools into outdoor inquiry (Abrie & Coetzer, 2026; Corbacho-Cuello et al., 2025) may present certain pedagogical risks. Excessive reliance on digital screens can induce a form of digital detachment, wherein learners look at pixels within camera viewfinders instead of engaging with living organisms, potentially reducing botanical encounters to superficial point-and-click tasks. In contrast, cluster 5 centers on botanical gardens, where living plants are placed at the forefront of observation (Nyberg et al., 2019) and prioritizes direct, unmediated multisensory interaction through olfactory,

tactile, and visual observation (Hodkinson, 2025; Wandersee & Schussler, 2001). However, when examined through cognitive scaffolding and experiential learning theories, these contrasting approaches reveal a constructive pedagogical complementarity. Traditional botanical identification keys often impose substantial cognitive load on novices due to technical terminology, creating affective barriers and frustration (Stagg & Donkin, 2013). Mobile identification applications in cluster 3 act as an accessible cognitive scaffold by lowering the threshold of species determination and providing immediate feedback that supports learner self-efficacy. Once this initial taxonomic barrier is overcome, the multisensory living collections of botanical gardens in cluster 5 enable learners to progress through Kolb's (1984) experiential learning cycle, moving from concrete observation to reflective inquiry regarding ecological adaptations, evolutionary principles (Domínguez & Pina, 2026), and laboratory-based karyotype investigations (Kriemadi et al., 2026). Therefore, mobile tools can be interpreted as an initial cognitive entry point that complements, without displacing, the deep sensory immersion afforded by botanical gardens.

Translating these combined pedagogical approaches into sustained educational practice appears to depend substantially on developing teachers' specialized instructional competencies, as suggested by the emergence of 'teacher training' within cluster 3 (**Figure 5**) (Bobo-Pinilla et al., 2024; Oryza et al., 2026). Under Shulman's (1986) framework of PCK, science educators require a specialized 'Plant PCK' that combines botanical subject-matter knowledge with diagnostic proficiency in using assessment instruments, familiarity with local native flora, and the pedagogical judgment to balance digital tools with outdoor inquiry. Pre-service and in-service professional development programs that build Plant PCK can be considered essential to support teachers' instructional self-efficacy, potentially helping them move beyond textbook-dependent instruction. In turn, this instructional capacity connects directly with cluster 4, where factual plant knowledge and affective experiences converge to encourage positive attitudes toward sustainability (Kubiatko et al., 2021). As shown by Stagg et al. (2025), PA develops along an interconnected continuum of attention, interest, knowledge, and attitude. When botanical learning is framed within broader socio-ecological systems, such as plant ecosystem services and climate change resilience (Ryplova et al., 2023), it may contribute to developing an informed biocentric citizenship capable of supporting biodiversity conservation and sustainable decision-making (Amprazis & Papadopoulou, 2020, 2025).

Limitations and Future Directions

Although this study examined the intellectual structure of PAD research within science education, it has several methodological limitations and suggests the following directions for future research.

First, this study relied exclusively on the WoS core collection to preserve metadata consistency and citation linkage integrity. Although WoS captures core peer-reviewed international journals, this choice necessarily excludes literature indexed exclusively in other databases such as Scopus, regional and non-English publications, and pedagogical grey literature (e.g., reports and curriculum frameworks) indexed in ERIC. Therefore, the findings reflect research trends and intellectual structures within WoS-indexed journals instead of the absolute totality of all educational materials. Second, the keyword-based filtering process has an inherent limitation. Because bibliometric analysis relies on predetermined keyword combinations, some meaningful educational studies related to PAD may have been omitted during the search stage if their authors used alternative conceptual terms, despite the researchers' careful review. Third, the citation time lag of publications must be considered when interpreting the results, as recently published papers have had less time to accumulate citations.

Based on these limitations, future research should address three key areas.

First, research trend analysis provides an important foundation for organizing the scope of a field, identifying knowledge gaps, and setting directions for future studies (W. M. Lim et al., 2022). Future research should therefore evaluate multi-database retrieval pipelines that combine Scopus and specialized educational databases such as ERIC with transparent deduplication and normalization protocols to map a broader structure of PAD scholarship. Second, longitudinal studies that track the long-term retention of PA and ecological sensitivity beyond short-term educational interventions are needed, alongside meta-analyses that synthesize the actual effect sizes of diverse teaching and learning strategies. Third, because PAD is known to vary in degree and form across cultures (Stagg & Dillon, 2022) and the plant species familiar to students differ by region, international collaborative research could be expanded. Such collaborative studies should compare and examine the effects and needs of plant education across diverse sociocultural backgrounds, particularly in regions with high biodiversity and TEK.

Finally, the recent theoretical discourse surrounding botanical education offers meaningful directions for future inquiry. While our bibliometric dataset captured literature centered on the historical and transitional constructs of 'plant blindness' and 'plant awareness disparity (PAD)' (Parsley, 2020), educational researchers have recently advocated for an affirmative, multidimensional framework: 'plant awareness (PA)' (Dünser et al., 2025; Pany et al., 2024). Instead of defining botanical education primarily through the lens of

cognitive neglect or perceptual disparity, the PA construct conceptualizes plant engagement as an active, teachable capacity encompassing attitudes, knowledge, attention, and relative interest. Because our search parameters were deliberately designed to map the foundational literature addressing the disparity phenomenon, future bibliometric and empirical investigations should examine how this new positive construct is operationalized in instructional designs and whether it alters the intellectual structure of science education.

CONCLUSION

This study conducted a systematic bibliometric analysis of 90 peer-reviewed publications indexed in the WoS core collection (2011-2026) using the R 'bibliometrix' package and VOSviewer to identify the publication trends and intellectual structure of 'plant awareness disparity (PAD)' research within science education.

The findings indicate that PAD extends beyond learners' individual visual attention and constitutes a multidimensional educational challenge shaped by zoocentric curricular representations, limited opportunities for direct plant engagement, and gaps in teacher preparation. Therefore, future science education may benefit from pursuing three interconnected priorities: establishing multisensory, place-based inquiry environments that combine living plant experiences with appropriate cognitive scaffolds; strengthening pre-service and in-service teacher education grounded in plant-specific PCK (Plant PCK); and integrating culturally relevant botanical literacy and broader ecological interactions, encompassing both plants and symbiotic organisms, into education for sustainability.

Author contributions: **KB:** conceptualization, data curation, validation, visualization, writing – original draft; **YL:** data curation, validation, visualization; **YS:** conceptualization, supervision, validation, writing – review & editing. All authors agreed with the results and conclusions.

Funding: This study was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2021S1A5C2A04089214).

Ethical statement: Ethics committee approval and informed consent were not applicable because this study analyzed only publicly available bibliographic metadata from the Web of Science core collection and did not involve human participants, animal subjects, or confidential personal data.

AI statement: During the preparation of this manuscript, the authors used Gemini 3.8 Flash (Google) solely for the purpose of translating the original Korean text into English and polishing language readability. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the published article.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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