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Fragmented and Integral Methods for Botany Teaching: The Need to Integrate Historical and Philosophical Dimensions

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Abstract

Plants are the foundation of the web of life and the key players that shaped the Earth and the course of life's evolution. Yet, botany teaching is often perceived by students as boring or irrelevant. This challenge partly stems from a lack of historical, philosophical, and contextual approaches, reinforcing the perception that plants are inert objects. To better understand how educators have addressed these challenges, we conducted a systematic documentary review and descriptive analysis of Brazilian conference papers (n = 494; 2018–2023) and articles (n = 30; 1997–2025) on botany teaching. Our results reveal a predominance of fragmented approaches focused mainly on teaching practice, which we defined as the educational dimension. Although they discuss methodologies and the importance of botany, these texts rarely address how to assess teaching, prepare teachers, or which central concepts and theories define the field, as evidenced by our results. The botanical contents of great interest and their associated teaching methods were also discussed in the light of fragmented and integral methods. Ultimately, we argue for the integration of historical and philosophical perspectives and direct engagement with live plant material, shifting away from terminological or procedural emphases.

Keywords: Biology Education; Educational dimension; Learning assessment; Science Education in Brazil; Teacher Training in Biology

Introduction

Botany is an integral part of environmental sciences since ancient times (Pease, 1952). Moreover, plants are the foundation of the web of life, and the science of plants is fundamental to the formation of students capable of understanding natural processes and the interdependent relationships among organisms (Uno, 2009). Knowledge about plants should be based on our understanding of how plants have shaped the Earth and influenced the evolution of life, as well as their continued importance for basic processes such as human breathing, and complex and urgent debates like the global

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climate emergency (Krampen, 2001; Raven et al., 2014). However, since the introduction of the “plant awareness disparity” concept (Wandersee & Schussler, 1999; 2001; Parsley, 2020), botanists and botany teachers have focused on how to draw attention to plants, instead of fostering a mindset that integrates plants into the core biological understanding of environmental problems and solutions (Armstrong et al., 2023).

Many studies have concluded that botany is perceived as an uninteresting subject, due to the apparent inertia of plants, which contrasts with the dynamics of animals (Balas & Momsen, 2014; Guerra et al., 2024; Albuquerque et al., 2025). However, this perception is not related to the essence of plant study, but rather to how it is presented. The immobility of plants, *i.e.,* their fixation on substrates, is something that, philosophically, was described as "vegetative torpor", a tendency of life to produce and accumulate biomass (Bergson, 2010). Interestingly, this characteristic is one of the main reasons for studying plants on a large scale and an asset for teaching, as plants are commonly present in most environments and do not flee or hide, making them more accessible as didactic materials (Salatino & Buckeridge, 2016). Nevertheless, most studies overlook the fact that living plants are accessible materials for educational purposes, not in fragmented methods, but instead focusing on integral methods and philosophical approaches.

Accordingly, our primary focus relies on the historical and philosophical approaches that have been presented in recent years regarding teaching botany. Moreover, we analysed the teaching methods that are presented by botanists and educators involved in science education at the proceedings of the main Brazilian botany and science education events. Conference proceedings constitute a strategic starting point for identifying emerging pedagogical tendencies, since they frequently register ongoing projects, preliminary results, and innovative classroom practices that are not yet consolidated in indexed journals. In the field of education, such spaces function as arenas of epistemic circulation, where the community first articulates and debates theoretical positions, methodological choices, and conceptual frameworks (Santos et al., 2003; France et al., 2025). Therefore, the analysis of conference abstracts is not secondary to our objectives, but rather central to understanding how teaching botany has been framed, problematized, and operationalized in recent years in Brazil. Building on this rationale, we conducted a systematic documentary review of works presented at

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academic conferences focusing on botany teaching, complemented by peer-reviewed articles in the field, aiming to understand what has been produced in the area, focusing on the pedagogical practices that aim not only to bring plants into focus, but also to deepen and expand knowledge about the area of botany teaching. In this sense, our main questions are: i) Which teaching methods and techniques are addressed in current research on botany teaching, and to which educational contexts and content areas do they relate? ii) Do these pedagogical practices include assessments of learning outcomes? ii) Are they articulated with teacher education programs?

Material and Methods

This study used a systematic documentary review of conference proceedings and journal articles related to botany and plant biology teaching. Searches for peer-reviewed articles were conducted in the Scopus and SciELO databases using the following descriptors in Portuguese: “ensino AND botanica” (“teaching AND botany”) or “ensino AND biologia AND vegetal” (teaching AND plant biology). Articles written in Portuguese or English were considered eligible. Duplicate records were identified and removed. No additional exclusion criteria were applied, and all selected articles were analyzed in full, regardless of methodological design or theoretical orientation. Conference proceedings were obtained from the official archives of national Brazilian events related to botany and biology teaching that occurred from 2018 onwards: specifically, the editions of 2018 and 2021 of the *Encontro Nacional em Ensino de Biologia* (ENEBio), the editions of 2019, 2021, and 2023 of the *Encontro Nacional de Pesquisa em Educação em Ciência* (ENPEC), and the *Congresso Nacional de Botânica* (CNBot) editions between 2018 and 2023. All abstracts and full texts available in these proceedings were included in the analysis.

The descriptive analysis of the conference proceedings and articles followed a structured protocol. For each conference work and article, the following information was recorded in two standardized tables, where the following information was retrieved: year of publication, source (journal or event), title, keywords, educational level of focus, presence or absence of teacher training, presence or absence of learning assessment, description of the applied teaching methodology, and botanical content

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addressed. Titles originally published in Portuguese were translated into English for consistency of presentation; however, all analyses were conducted using the original texts. The identification of teacher training, learning assessment, and teaching methodology was based strictly on explicit information reported in the text. When no description of assessment procedures was present, the study was classified as not including a learning assessment. Three researchers conducted data extraction from conference proceedings, while two researchers performed article extraction and final standardization procedures. Keyword standardization was conducted manually by grouping semantically equivalent or conceptually related terms under unified descriptors.

Journal articles were also framed within six analytical dimensions adapted from Krasilchik (2008) and Ursi et al. (2018), as follows: the environmental, philosophical, historical-cultural, medical, aesthetic, and educational dimensions. The first five analytical dimensions were defined in accordance with the theoretical framework presented in the literature. However, during the analysis, an additional group of studies emerged that was primarily centered on the act of teaching itself, including discussions of pedagogical practices, instructional design, and reflections on the teaching process as the main analytical focus. This set of studies was therefore grouped under an additional category referred to as “educational dimension”. Classification was conducted through interpretative reading of the full text and alignment of their primary objectives, theoretical framework, or central discussion with the operational definitions of each dimension. Studies could be assigned to more than one dimension when their content substantively addressed multiple perspectives.

All extracted data retrieved from these searches were organized into structured tables. The frequency of analytical dimensions over time was grouped into five-year intervals and represented through a stacked area chart to demonstrate the timeline progression of perspectives in articles on botany teaching. Standardized keywords were quantified and visually expressed in word clouds to present group subjectivities, central ideas, tendencies, and dominant topics (Ramlo, 2011). Especially, this method is a robust way to systematically explore and map research tendencies in science education bibliography (Su and Chang, 2025). Word clouds were produced using WordClouds.com (Zygomatic, 2025). Finally, the qualitative data of the botanical contents of the

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conference works and the frequency of the primary teaching methodologies were expressed using a radial tree diagram. In this visualization, botanical topics are organized around a central node, and the associated teaching methods are represented as branches. For each method, a bar indicates its frequency of occurrence within the respective topic, and the methods are arranged from the most to the least frequent. This representation provides a descriptive overview of the distribution of teaching approaches across botany teaching in the analyzed bibliography. Data visualizations were created in Flourish Studio, integrated with Canva™ (Flourish, 2025). All colors used to plot the figures were chosen based on the Color Universal Design (Okabe and Ito, 2002).

Results

The proceedings of the scientific events organized between 2018 and 2023 have a total of 494 conference papers (CP), with the largest part presented at the *Congresso Nacional de Botânica*, 438 CP (88.7%), followed by the *Encontro Nacional em Ensino de Biologia*, with 42 CP (8.5%), and the *Encontro Nacional de Pesquisa em Educação em Ciência*, with 14 CP (2.8%) (Table S1). Most of the CP focused on formal education (421, 85.2%), with an emphasis on “Higher Education”, with 199 CP accounting for 40.3% of the total. The other educational levels were “High School” with 146 CP (29.5%), “Elementary School” with 112 CP (22.7%), and “Non-formal spaces” with 73 CP (14.8%). Thirty-six CP (7.3%) approached more than one level of education. Teaching training appears in only 95 CP (19.2%).

Two hundred and seventy-five (69.8%) CP had proposals or applications of specific methods for teaching botany. The learning evaluations were conducted in only 142 (28.7%) CP (Table S1). Regarding the botanical contents, “Botany Teaching” appears in 128 (25.9%) CP, followed by “Plant Systematics and Diversity” appears in 121 (24.5%) CP, “Plant Morphology” in 44 (8.9%), “Environmental Education” in 43 (8.7%) CP, “Plant Physiology” in 40 (8.1%), “Ethnobotany” in 36 (7.3%), “Plant Anatomy” in 35 (7.1%), “General Botany” in 20 (4%), “Plant Ecology” in 12 (2.4%), “Mycology” in 10 (2%), “Phycology” in 4 (0.8%), and “Palynology” with just one citation (0.2%) in CP.

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The methods for teaching botany were applied in 373 (75.5%) CP, comprising 27 different methods, with “Biological Collections” cited 63 times, “Digital Information and Communication Technologies” 61, “Project-Based Learning” 49, “Models and Teaching Materials” 38, “Educational Games and Gamification” 33, “Gardens and Orchards” (27), “Didactic Sequences” 22, “Art-Based” 22, “Workshops and Lectures” 19, “Theoretical Class” 17, “Field Class and Interpretative Trails” 14, “Pop Culture” 12, “Biological Materials” 11, and “Peer-Learning” cited 11 times. Other methodologies were applied 10 or fewer times (Table S1). The relationship between the botanical contents addressed in the studies and the main associated teaching methodologies is presented in Fig. 1.

We identified a total of 30 articles published in peer-reviewed journals that specifically address botany teaching in Brazil, spanning non-formal to higher education levels, from 1997 to 2025 (Table 1). Most works focused on the educational dimension (13), followed by the environmental (8), cultural-historical (5), philosophical (3), aesthetic (2), and medical (1). The environmental dimension had the highest representativeness over time, with a notable increase in research focusing on the educational perspective from 2011 onwards (Fig. 2). Half of the 30 articles focus on “Higher Education,” comprising both undergraduate and graduate levels. The other levels, “Elementary School” (7), “High School” (7), and “Non-formal spaces" (4), appeared fewer times. Just four articles discussed more than one educational level. Teacher training was the focus of just one article (3.3%). The proposal of methodologies for teaching botany appeared in twelve (40%) articles, but learning assessment methods were applied in only six (20%).

Regarding the analysis of the keywords, articles presented a total of 122 keywords which were grouped in 66 different keywords, with the higher occurrence for “botany teaching” (11), “teacher training” (7), “botany” (6), “teaching” (6), and “plant anatomy” (5), corresponding to 52.2% of the total (Table 1), standing out as dominant themes within these documents (Fig. 3A). On the CP, these documents presented 587 keywords, which were rearranged into 99 words. The most common words were “botany teaching” (45), “teaching” (38), “education” (32), “plant blindness”, and “learning” (17), corresponding to 25.38% of the total (Fig. 3B). Another 32 CPs (5.45%) had no associated keywords.

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Discussion

The limited number of botany teaching articles (30) we identified may reflect indexing issues affecting some Brazilian journals, possibly because they are predominantly published in Portuguese (SciELO, 2024), and/or the specific use of titles and keywords that obscure the direct relation with botany teaching to our search terms. Nevertheless, the articles found in our searches comprise 28 years of publications (1997-2025), revealing an advance in the thematic dimensions inserted in the articles, which required us to adapt the previously dimensional framework (Ursi et al. 2018; Krasilchik 2008) to better reflect contemporary society and biological integration. The first point we highlighted is the inseparability of the ethical and philosophical dimensions, as the former is embedded in the latter and reflects values, moral principles, ethical questions, and the role of science in society (Maxim, 2014). Thus, we inserted the historical-cultural dimension as independent once the cultural, social, and historical roles of the plants are connected to human traditions (Ursi et al., 2018). Besides that, our results demonstrated that the perspectives of several works rely on a direct concern with the teaching act, herein presented as the "educational dimension," which involves pedagogic practices, teaching methods, development of competences, significant learning, and critical citizen formation. All of these are involved in the purpose of using botanical knowledge consciously in human routine. It is important to highlight that the emergence of the "educational dimension" category in our analyses is consistent with broader trends in educational research worldwide and the growing attention given to educational processes as a specific line of inquiry within broader disciplinary fields (Fontal et al., 2023; Semerikov, 2024). Additionally, these studies, which were categorized as belonging to the "educational dimension", only tangentially engage with the botanical content or with audiences specifically interested in botany. In these works, the central emphasis lies on pedagogical or educational issues rather than on the specific conceptual or disciplinary aspects of botany.

Based on the dimensional analysis, it is possible to trace the evolution of botanical contextualization in the articles, with the earliest studies addressing the environmental dimension (Fig. 1). Examples include the use of floristic inventories to introduce botanical taxonomic concepts to children and to support the training of biologists through field courses (Leitão-Filho et al. 1997; Rissi & Cavassan, 2013). Over

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time, the historical-cultural, medical, and aesthetic dimensions appear in the articles exploring plants as resources for humans (Borges et al., 2015; Oliveira & Lucena, 2015) but also bring perspectives on the history of botany research and teaching in Brazil (Bovini & Peixoto, 2012; Pereira-Silva, 2024). Notably, Borges et al. (2015) connect botany to environmental education by using a flagship species, the *juçara* palm (*Euterpe edulis* Mart. – Arecaceae), putting students in contact with a discussion of plants as vital threads rather than objects. The philosophical dimension discusses the importance and value of learn and teaching botany and on botany itself as a field of science with its own identity (Salatino & Buckeridge, 2016; Ursi et al., 2018), while the educational dimension emphasizes teachers' perspectives, and how and what to teach to make botany accessible, meaningful, and interesting (Stanski et al., 2016; Neves et al., 2019; Dias et al., 2020; Silva & Freixo, 2020; Severo et al., 2025).

The boom in articles focused on the educational dimension over the past decade, as well as the prevalence of words related to "plant blindness" and teaching in our results, suggests an ongoing profusion of discussions on the causes of challenges in botany teaching and students' interest, particularly concerning the concept of plant awareness disparity. Since its original introduction by Wandersee and Schussler (1999, 2001), this concept has become a microfield in botany teaching research, focusing on itself, with numerous citations in both articles and conference papers presented at scientific events. We also note that, despite the criticisms regarding the potentially ableist tone of the term "plant blindness" and the proposals suggesting alternative expressions such as "plant awareness disparity" (Parsley, 2020) and "plant imperception" (Ursi & Salatino, 2022), our results expressed in the tables and word clouds indicate a clear predominance of the original term in the analyzed bibliography. Although these alternatives were introduced to address concerns about ableist language, they still refer to processes related to noticing, perceiving, or becoming aware of plants (Albuquerque et al., 2025), and in practice, they are frequently used as conceptual equivalents of "plant blindness" (see Bobo-Pinilla et al., 2024; Ferreira & Simões, 2024; Guerra et al., 2025; Amprazis & Papadopoulou, 2026), reinforcing that the original expression has become conceptually consolidated within the literature. Since the initial critique of the ableist connotations of the term "plant blindness", it has been argued that replacing the term should involve more than simply introducing a

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non-ableist synonym, and that the new terminology should promote a broader shift toward plant appreciation and engagement (see MacKenzie et al., 2019). Beyond that, we have not taken a normative position regarding the preference for one term or another. Here, we only present the patterns observed in the literature and employ the concept in the same descriptive sense in which it appears in the works analyzed. In our view, plant awareness disparity (or its conceptual equivalents) is a well-diagnosed factor contributing to the decline of botanical education and appreciation (Salatino & Buckeridge, 2016; Neves et al., 2019; Stroud et al., 2022); however, it should not guide the research on botany teaching but rather focus on seeking solutions.

Other questions deserve special attention, particularly those that have been underexplored in the literature, such as: How should botany teaching be evaluated? What integrative concepts or theories define botany? How can we make botany more accessible and less formal? What basic preparation do teachers need to teach botany? Unfortunately, these questions have not yet been the focus of research on botany teaching in Brazil, as indicated by the results from the analyzed articles and conference papers. Particularly regarding the limited number of studies that address or implement teacher training, a greater emphasis is placed on training biologists within Biological Sciences programs, rather than training biology teachers (Fonseca & Ramos, 2018; Copetti & Canto-Dorow, 2019; Castro et al., 2023). This inadequate teacher training has repercussions in basic education, as future teachers often tend to undervalue botanical content, relying primarily on textbooks as their main teaching resource (Carmo-Oliveira & Carvalho, 2015). For the period between 2002 and 2017, before the timeframe of conference proceedings analysed in this study, Copetti & Canto-Dorow (2019) identified a scarcity of research addressing initial teacher education in botany. The studies reviewed presented diverse theoretical frameworks, with no clear theoretical consensus. Moreover, they observed a strong emphasis on scientific knowledge regardless of the teaching context, alongside limited discussion on how to teach specific botanical content, how to become a botany teacher, or how to approach the teaching of teaching itself.

Main research topics in botany and education-related events

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Most of the conference papers retrieved from event proceedings focus primarily on “Botany Teaching” itself, reinforcing the educational dimension as a prevailing trend (Fontal et al., 2023; Semerikov, 2024). This is particularly significant in botany-focused events, considering that market-driven demands are directly linked to the decline in society’s appreciation of botany, also contributing to the extinction of courses, departments, herbaria, and the overall erosion of botany worldwide (Crisci et al., 2020). Moreover, the weakening of botanical education fosters a self-reinforcing cycle that affects the training of future botanists and results in biologists being unable to identify plants (Stroud et al., 2022) or even advocate for the importance of this group of living beings in supporting the web of life. This fact may also explain the growing interest in research on botany teaching, especially in higher education, which is likely to have an inefficient focus and methodologies.

The scenario demands investment in contextualized botany teaching, allied with technology resources and active methodologies, which appears as a trend in our results, indicating the relative interest in Environmental Education. Also, there is a growing emphasis on “Digital Information and Communication Technologies”, which may help reverse the inability to teach botany, as well as other critical topics. The limited use of technology in botany teaching was a challenge in addressing plant awareness disparity (Ursi et al., 2018), which is currently being overcome. However, an alternative explanation for the interest in educational technology may be the influence of the COVID-19 pandemic, which forced many teachers to engage students by adapting their methodologies, particularly through the use of social media, mobile apps, and digital biological collections (Cota-Sánchez, 2020; Lobão et al., 2022; Chozas et al., 2023; Silva et al., 2025). Similarly to the increase in digital tools, the pandemic may explain the revival of “Gardens and Orchards”, especially related to Environmental Education, Ethnobotany, and Plant Systematics and Diversity topics, in many conference papers and articles from the analyzed period. Alongside social isolation and the broader health crisis, the pandemic sparked the interest of the general public and students in medicinal plants, traditional forms of treatment, and the well-being promoted by plants (Burke et al., 2022; Maurício et al., 2024), which was subsequently explored by teachers in various studies. Traditional herbal knowledge predates modern biology and has its own historical and epistemological foundations (Pease, 1952; Rocha et al., 2022), but its

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integration with botanical education is essential for valuing and critically examining traditional knowledge while promoting critical scientific literacy. After all, many people remain unaware of the toxicity risks associated with the continued medicinal use of certain plants (Oliveira & Lucena, 2015; Maurício et al., 2024).

The integration of botanical knowledge with social themes that permeate the environment highlights the crucial role of plants in mitigating socio-environmental impacts within the context of a global climate emergency and promotes the perception of plants as protagonists (Isaias et al., 2025; Stagg & Dillon, 2023). In this sense, school gardens and orchards can serve as spaces that foster connections among students and school staff, extending beyond the traditional teacher-student relationship. They also serve as valuable platforms to promote contextualization of botanical concepts and facilitate knowledge exchange among students, teachers, and the wider school community, particularly concerning local issues (Oliveira et al., 2018; Chiesi et al., 2024). This integration is also one of the ways to support other relevant topics in our survey, such as Plant Systematics and Diversity, using students' prior knowledge and interests as entry points for teaching taxonomic and evolutionary concepts (Silva & Freixo, 2020), which are essential for biology teaching.

The use of digital and physical "Biological Collections" and "Biological Materials", including herbaria, histological slides, and fresh specimens, has been widely adopted as a teaching method in Plant Systematics and Diversity, Plant Morphology, Plant Anatomy, Mycology, Phycology, and Palynology (Stanski et al., 2016; Cota-Sánchez, 2020; Pereira-Silva, 2024). This merging of classical botanical research practices with teaching traces its roots back to the "cabinets of curiosities", which showcased extensive natural history collections during the great voyages of the naturalists in the 15th to 17th centuries. These collections of plant specimens, whether living or dried, were often gathered in herbaria and botanical gardens associated with these cabinets, primarily valued for their purported medicinal properties and preservation potential. It is essential to acknowledge that many of these collections were acquired through looting in the Americas and subsequently transported to Europe (Pereira, 2006; Merewether, 2024). The very practice of botanical collection, inherited from the naturalist origins of biological sciences, is a traditional method for training botanists in higher education

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(Leitão-Filho et al., 1997), sometimes combined with approaches such as “Field Classes and Interpretative Trails” or “Project-Based Learning”.

Field classes and interpretative trails are essential teaching tools that bring students into direct contact with green spaces, promoting the development of an integrated understanding of natural phenomena and favoring greater emotional, aesthetic, and reflective engagement with natural environments (Seniciato & Cavassan, 2009; Pedrini, 2022b). Project-based learning methodology is sometimes associated with field classes; however, they are guided by pre-defined objectives, inquiries, or hypothesis-driven activities. This method stands out in the survey as a teaching approach that encourages students to work cooperatively to solve problems while engaging more deeply with specific areas of plant knowledge (Pedrini, 2022a) and appears as an important teaching methodology in topics such as Plant Physiology, Plant Ecology, Environmental Education, and Plant Anatomy. These projects mainly involve scientific initiation, practical classes, experiments, and some extension activities, which are essential for training students in formulating research questions, planning sampling strategies, and carrying out tasks independently, while also promoting peer learning (Leitão-Filho et al., 1997; Rissi &Cavassan, 2013; Pedrini, 2022a), being fundamental integrative ways of teaching botany as well as natural sciences.

Classical methods, such as the use of “Models and Teaching Materials”, enhance teaching effectiveness as they require bibliographic research on the structures (Souza et al., 2021) and processes involved in life maintenance. Furthermore, three-dimensional and textured models support the inclusion of students with low vision or total blindness (Silva et al., 2022). We emphasize the importance of critically examining these models in the classroom. Since any model is inherently incomplete, stimulating students' ability to recognize its limitations is essential, serving as a bridge between material and abstract knowledge without becoming epistemological barriers when students rely exclusively on them (Pessanha, 2025). Together with the models, educational games and gamification also emerge as strategies for improving student interest, as they promote both competition and collaboration. This type of teaching technique has become an emerging trend in botany education in Brazil, particularly since 2019. However, its application remains concentrated on specific topics such as morphology, systematics, and general botany, while areas like physiology, anatomy, and ethnobotany remain

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comparatively underrepresented (Santos & Silva, 2024). However, engagement alone does not address the challenges of teaching botany, mainly when these approaches rely on memorization without reflection or contextualization (Neto, 2019). On the other hand, theoretical classes still tend to focus on formal aspects of botany teaching, a practice that often results in shallow, rote-based learning marked by an overload of terms (Wandersee, 1985; 1988; Ganiko-Dutra et al., 2022). These limitations may be overcome by combining the multiple strategies presented in this work through "Didactic Sequences", or multimodal teaching, which allows for prolonged contact with the subject and promotes a deeper exploration of the strengths and weaknesses of students in the classroom (Stanski et al., 2016; Franco, 2018; Stagg & Dillon, 2023).

It is evident that, although the research topics in botany teaching addressed in the conference papers are methodologically diverse, they remain fragmented from a broader scientific education perspective, often limited to specific interventions following the botanical approach of academic settings, and lacking efficient learning assessment. This underscores the need for stronger integration between botany educators and the latest advancements in science education centered on critical thinking, discussion of pluralisms, and empowering students (Potvin & Bélanger, 2024). In this sense, the combination of art and botany, whether "Art-based" or influenced by "Pop Culture", is an interesting approach considering that this intersection can transcend the usual contradictions between science and art, promoting interdisciplinarity and enabling differentiated forms of knowledge construction. Art, as an ally of science, facilitates the integration of objective scientific knowledge with emotions, beauty, and subjectivity, humanizing education (Cachapuz, 2014; Silva et al., 2025).

Integrative Methods for Botany Teaching

Our analysis of hundreds of conference papers revealed that none of them addressed the articulation of botany with the history and philosophy of science or explored aspects of the nature of science. This finding is concerning, as the integration of the history and philosophy of science as a teaching approach, emphasizing not only scientific content but also how it was historically constructed, is fundamental both for

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science education and for teacher training (Mathews, 1994). In contrast, our integrative methodological proposal for botany teaching emphasizes the potential of using botanical collections as a means to reflect on the epistemological foundations of the field. We argue that botany, as a classical science, is based on accessible empirical methods, and its teaching should incorporate historical, philosophical, and nature-connected perspectives.

Beyond Linnaeus, we believe it is valuable for elementary and high school students to learn about prominent botanists throughout history and the research problems they addressed within their historical contexts. This approach not only historicizes botany as a classical domain of scientific knowledge but also provides a means to explore fundamental aspects of science itself. Rather than limiting ourselves to biographical accounts celebrating national botanical figures (Bovini & Peixoto, 2012; Pereira-Silva, 2024), we propose a broader engagement with philosophical reflections on plants. Collaborations with thinkers such as Johann Wolfgang von Goethe (*The Metamorphosis of Plants*) can broaden botany education by introducing the concept of plant metamorphosis, helping students to understand plant organs as transformations of the same organ, the leaf (Dornelas & Dornelas, 2005). In a similar perspective, Agnes Arber (*The Natural Philosophy of Plant Form*) contributes through the concept of the "partial shoot theory", which interprets the leaf as an incomplete shoot with a latent tendency toward full shoot development, broadening morphological understanding and showing students that botanical theories remain open to alternative interpretations and ongoing debate (Arber, 1950). Henri Bergson (*Creative Evolution*) work can contribute to promoting a holistic understanding of living organisms beyond mechanistic explanations, highlighting plants as life forms oriented toward energy production and accumulation, encouraging reflection on functional and evolutionary aspects of plant life (Bergson, 2010). Stefano Mancuso (*Plant Revolution*) can present plant organisms with distributed functions capable of sensing and responding to their environment, and at the same time, the use of anthropomorphic metaphors such as "decision" or "intelligence" provides useful opportunities to discuss the limits of analogy and the ongoing conceptual debates within plant science (Minorsky, 2024). Sir Jagadish Chandra Bose's (*The Nervous Mechanism of Plants*) work and history can demonstrate that plants exhibit electrical signaling and complex physiological responses to environmental

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stimuli, revealing an early framework for systemic plant signaling. At the same time, the history of the reception of his work, marked in part by scientific racism and dismissal by Western researchers, offers an important case for discussing how social and cultural biases can shape the acceptance of scientific ideas (Minorsky, 2021). As well, many other plant thinkers could enrich teachers' cultural perspectives, enhancing their understanding of plant organisms and enabling the development of more contextualized, engaging, and meaningful botany lessons.

Nevertheless, what emerges from our analysis is that research on botany teaching in Brazil primarily focuses on discussing the need for more engaging, contextualized, and dynamic teaching methodologies, largely due to the diagnosis of "plant awareness disparity " (Wandersee & Schussler 1999; 2001; Parsley 2020). However, these methodologies are commonly applied in point interventions with ineffective learning assessment, followed by conceptual problematizations. This vicious cycle in the educational dimension has fragmented approaches, leaving gaps that are temptingly filled by the following methodology, thus perpetuating a micro field of recurring discussions. Teaching methods and techniques should serve the educational process rather than determine it. Beyond merely bringing plants into focus, it is necessary to consider which knowledge and skills are actually being developed in students, highlighting the importance of learning assessment and teacher education. Science education is not limited to the presentation of pedagogical practices, which should be shaped by educational goals; therefore, their pedagogical value depends on how they support meaningful interaction between teachers, students, and the learning content (Araújo, 2013). It requires teaching strategies and methods focused on argumentation and integration with the history and philosophy of science. Furthermore, other fundamental issues in botany teaching, such as research on pedagogical content knowledge, teachers' attitudes, beliefs, and knowledge, as well as the analysis of textbooks, curricular issues, and teacher training, often fail to be adequately developed (Cofré et al., 2023). We believe that our proposal for working with botanical collections, combined with the history and philosophy of science, or using live plants as didactic material for Project-Based Learning, can be interesting paths to be put into practice and evaluated, as they integrate historical, procedural, and conceptual aspects of botany, in addition to placing students in direct contact with these organisms.

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Authors' Contributions

POT: conceptualization, investigation, methodology, writing – original draft, review and editing; ÍAA: data curation, formal analysis, investigation, visualization, methodology, writing – original draft, review and editing; BKFS: data curation, investigation, writing – original draft; RF: data curation, investigation, writing – original draft; RMSI: conceptualization, supervision, funding acquisition, project administration, resources, writing – review and editing.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Data Availability Statement

All data supporting the findings of this study are included in the article and its supplementary material.

AI Usage Statement

The authors declare that ChatGPT (OpenAI) was used in selected parts of the manuscript to assist with language editing and text refinement. The scientific content and interpretations were developed by the authors. All AI-assisted text was reviewed

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and approved by the authors, who remain fully responsible for the content and final version of the manuscript.

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Supplementary Material

Table S1: Inventory and descriptive analysis of conference papers focused on botany teaching from the proceedings of the *Encontro Nacional em Ensino de Biologia* (ENEBio), *Encontro Nacional de Pesquisa em Educação em Ciência* (ENPEC), and the *Congresso Nacional de Botânica* (CNBot) that occurred between 2018 and 2023 in Brazil, with their respective keywords, educational levels of focus, teaching methodologies, botanical contents, and procedural activities.

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Table and Figure Captions

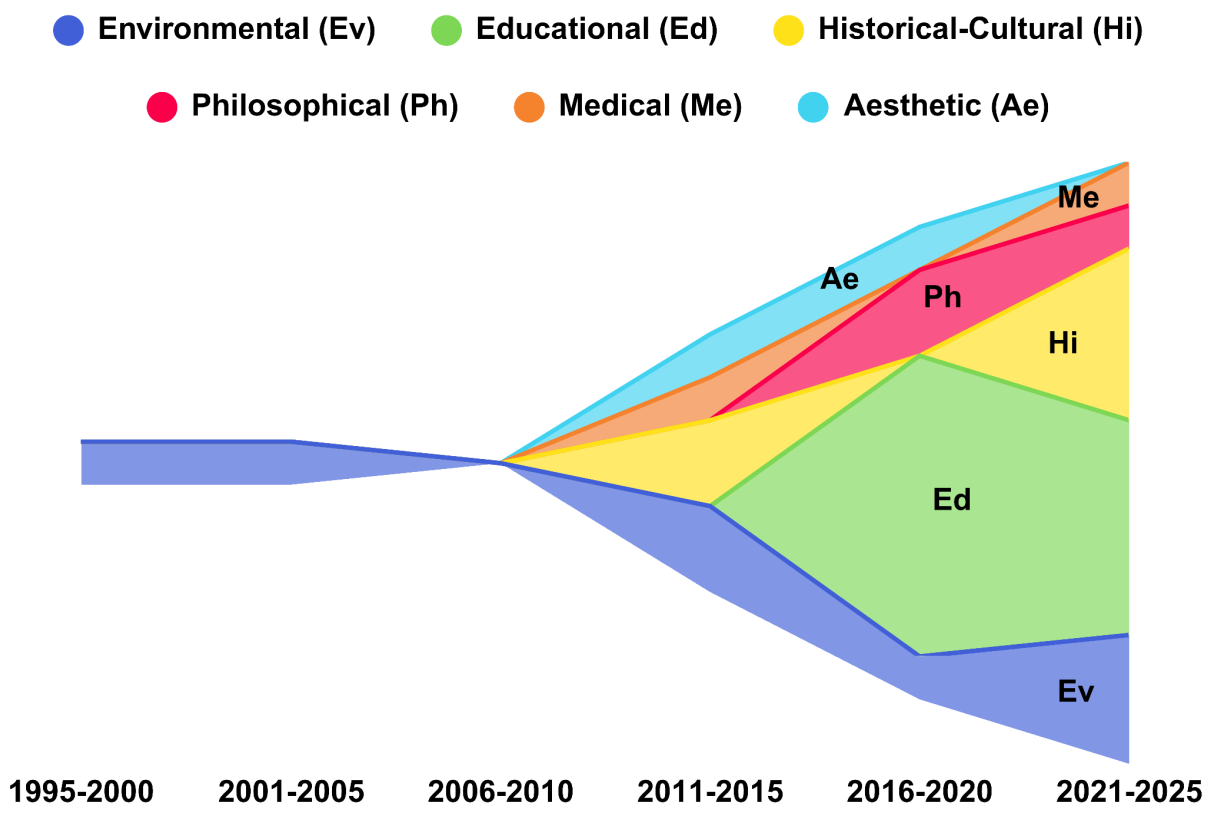


Figure 1. Radial tree representing the main botany teaching methodologies associated with botanical contents in conference papers of the proceedings of the *Encontro Nacional em Ensino de Biologia* (ENEBio), *Encontro Nacional de Pesquisa em Educação em Ciência* (ENPEC), and the *Congresso Nacional de Botânica* (CNBot) that occurred between 2018-2023.

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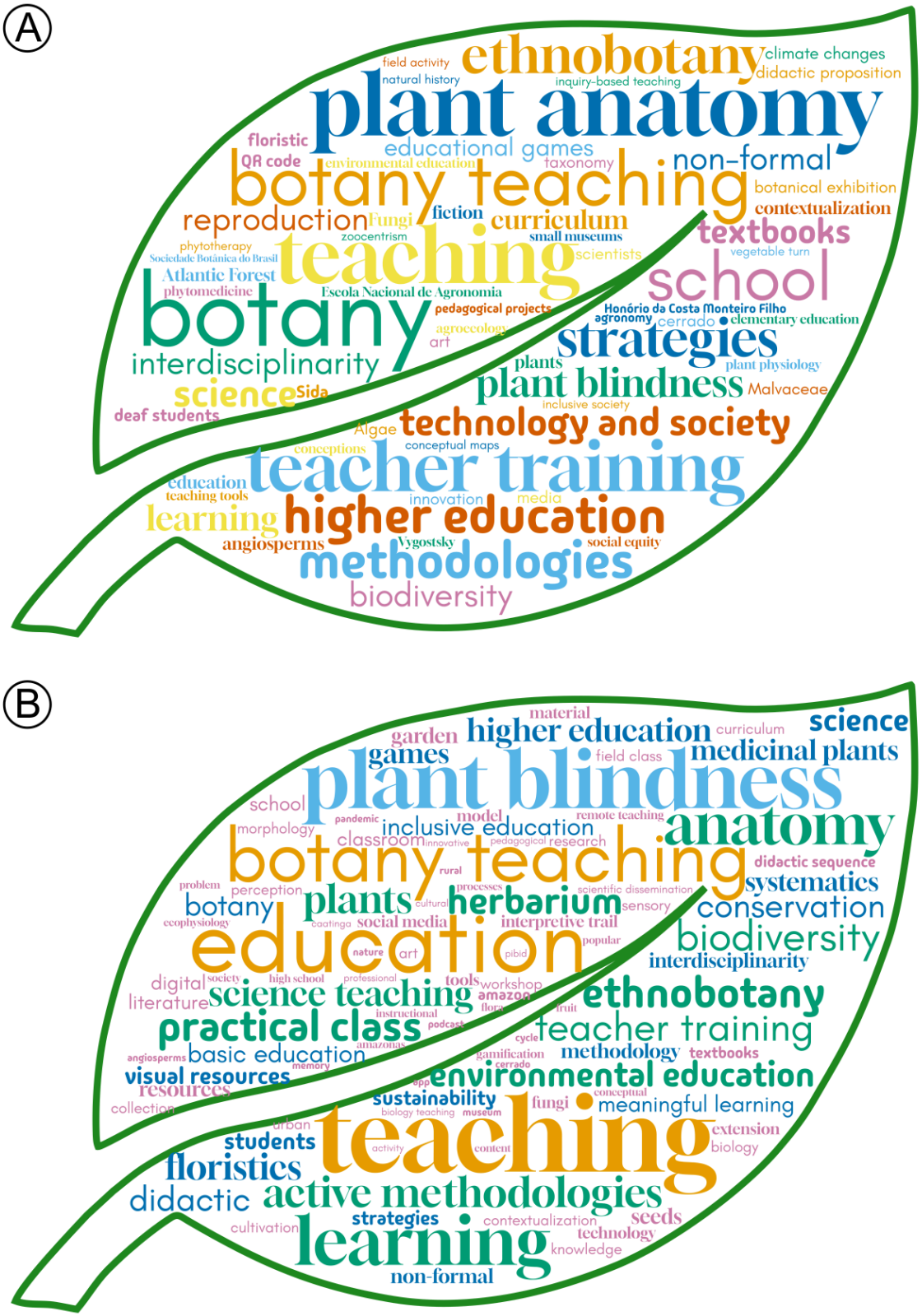


Figure 2. Timeline of progression in the dimension perspectives in botany teaching articles in Brazilian journals, published between 1997 and 2025.

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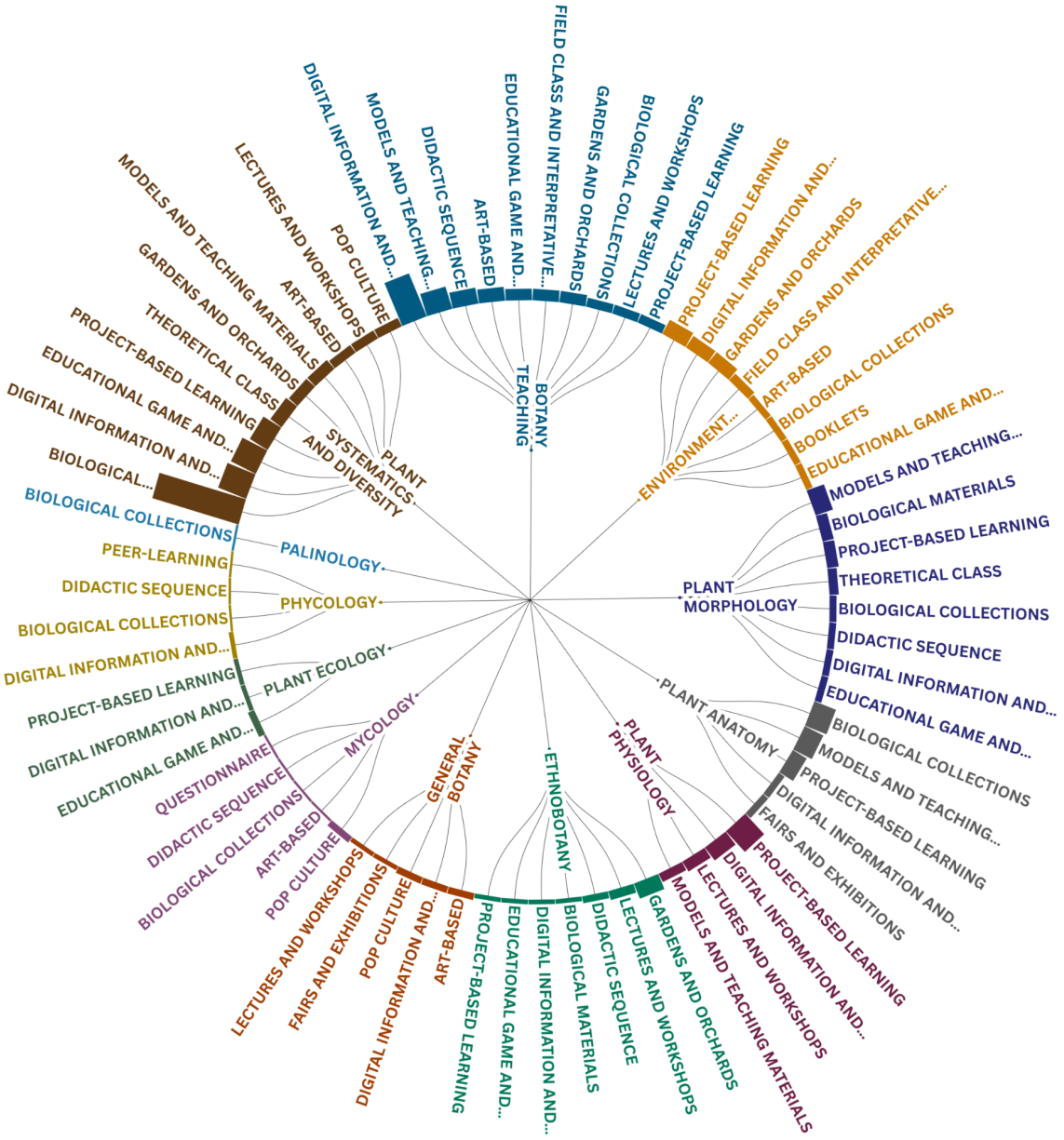


Figure 3. Word clouds representing the weight of the keywords retrieved from Brazilian articles and conference papers focused on botany teaching. (A) Words from peer-reviewed articles published between 1997-2025. (B) Words from the conference papers in the proceedings of *Encontro Nacional em Ensino de Biologia* (ENEBio), *Encontro Nacional de Pesquisa em Educação em Ciência* (ENPEC), and the *Congresso Nacional de Botânica* (CNBot) occurred between 2018-2023.

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Table 1: Inventory of articles focused on botany teaching in Brazil published between 1997 and 2025, and analysis of the contents of their respective keywords, educational levels of focus, teaching dimensions, and procedural activities.

Year	Title	Keywords	Educational level	Dimensions	Teacher training?	Teaching methodologies?	Learning Assessment?	Reference
1997	Structure of taxonomy field course: the model applied at Ubatuba-São Paulo	taxonomy; floristic; teaching; didactic proposition	Higher Education	Environmental	No	Yes	Yes	Leitão-Filho *et al.*, 1997
2005	Interrelations between plant anatomy and plant production	plant anatomy; botany teaching; plant production; agronomy	Higher Education	Environmental	No	No	No	Silva *et al.*, 2005
2012	Teaching, research, and extension service: botanist Honório da Costa Monteiro Filho	Malvaceae; *Sida*; Honório da Costa Monteiro Filho (1899-1978); Escola Nacional de Agronomia; Sociedade Botânica do Brasil	Higher Education	Historical-Cultural	No	No	No	Bovini and Peixoto, 2012

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2013	A proposal for teaching material based on existing Vochysiaceae species on a trail in the cerrado of Bauru - SP	biodiversity; botany teaching; practical field activity; cerrado	Higher Education	Environmental	No	Yes	No	Rissi and Cavassan, 2013
2015	Juçara goes to school: Learning between persons, things and institutions	agroecology; Atlantic Forest; environmental education; learning	Elementary School	Environmental; Aesthetic; Historical-Cultural	No	No	No	Borges *et al.*, 2015
2015	The use of medicinal plants to habitants from Quixada-Ceara	phytomedicine; phytotherapy; ethnobotany	Non-formal	Medical	No	No	No	Oliveira and Lucena, 2015
2016	But what good is it for you to know botany?	botanical blindness; teaching; interdisciplinarity; media; plant blindness; zoocentrism	Higher Education	Philosophical	No	No	No	Salatino and Buckeridge, 2016

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2016	Botanical teaching at the Elementary School: studying the pollen through multimodes	botany; conceptual maps; significative learning	Elementary School	Educational	No	Yes	Yes	Stanski *et al.*, 2016
2017	Science in the elementary school: Contextualisation of relations science, technology and society in the teaching of botany	sts (science, technology and society); botany; inquiry-based teaching; science; elementary education	Elementary School	Environmental	No	No	Yes	Carvalho and Barreto, 2017
2018	Botany Teaching in the Biological Sciences Teacher Training Program at a Public University in Rio de Janeiro: Contributions from Higher Education Professors	botany teaching; biological sciences teacher training; university teachers	Higher Education	Educational	No	No	No	Fonseca and Ramos, 2018

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2018	The Teaching Internship in the training of graduate students of the Instituto de Botânica, São Paulo State, Brazil	faculty training; graduate program; higher education; scientists; teacher learning	Higher Education	Educational	Yes	No	No	Rodrigues *et al.*, 2018
2018	Teaching Botany: Knowledge and Enchantment in Science Education	botany teaching; contextualization, teacher education, biodiversity education, trail of global climate changes	Higher Education	Philosophical	No	Yes	No	Ursi *et al.*, 2018
2019	Plant blindness: is it possible to overcome it through Education?	plant blindness; botany teaching; curriculum; teaching methodology	Higher Education	Educational	No	No	No	Neves *et al.*, 2019

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2019	A botanical content analysis under the Science-Technology -Society (STS) approach in Biology high-school textbooks	textbooks; botanical teaching; secondary school; Science; technology and society; STS	High School	Educational	No	No	No	Souza and Garcia, 2019
2020	The role of the Science Fair as a motivating strategy for teaching Botany in basic education	plant biology; teaching alternative methodology; teaching tools	Elementary and High School	Educational	No	Yes	Yes	Dias *et al.*, 2020
2020	QR Code technology in a sensory garden as a study tool	botany; non-formal learning environment; public high-school; quick-response-code	High School	Aesthetic	No	Yes	Yes	Prestes *et al.*, 2020

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2020	Teaching of Botany and Biological Classification in a Family Farm School: A Dialogue of Knowledges in the Countryside	family farm school; ethnobotany; scientific knowledge; local knowledge	Elementary School	Educational	No	No	No	Silva and Freixo, 2020
2022	There is no hermaphrodite flower: an investigation of the terminology used for the reproductive structures in the alternation of generations of Angiosperms	botany teaching; higher education; textbooks; angiosperms; spore reproduction	Higher Education	Educational	No	No	No	Ganiko-Dutra *et al.*, 2022
2022	Didactic games in the teaching of Botany: Enraizando and Batalha Algal	active methodology; Algae; board games; plant physiology; teaching strategies	Elementary and High School	Environmental	No	Yes	No	Neto *et al.*, 2022

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2022	Teaching Botany from the Perspective of Licensed Biologists: Possibilities and Challenges	teaching; strategies; botany	Higher Education	Educational	No	Yes	No	Oliveira and Nobre, 2022
2023	Indicators of botany teaching in biological sciences courses at public universities in Bahia: implications for initial teacher training	pedagogical projects of course; national curriculum guidelines; initial training; teaching strategies	Higher Education	Educational	No	Yes	No	Castro *et al.*, 2023
2023	The BioArt of Francisco Brennand Ceramic Workshop Institute: a study of the contributions to teaching and learning in Biological Sciences through the	biology teaching; non-formal spaces; biology and art; interdisciplinarity	Non-formal	Historical-Cultural	No	No	No	Silva *et al.*, 2023

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	mediator's perspective							
2023	Encounters and Fictions: Talking with Plants	botany teaching; vegetable turn; fiction; plants	High School and Higher Education	Philosophical	No	No	No	Silveira, 2023
2024	Plant anatomy - history and interfaces	comparative plant anatomy; functional plant anatomy; systematic plant anatomy; wood anatomy	Higher Education	Historical-Cultural	No	No	No	Machado and Oliveira, 2024
2024	Revisiting the Historical Trajectory of the "Dr. João Barbosa Rodrigues" Botanical Museum at the São Paulo Botanical Garden	small museums; natural history; botanical exhibition; inclusive society; social equity	Non-formal	Historical-Cultural	No	No	No	Pereira-Silva, 2024

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2024	Teaching Practice and the Dialogue Between Knowledge in Botany Teaching	education; teacher training; biology education; teachers' conceptions	High School	Educational	No	Yes	No	Silva *et al.*, 2024
2024	Games for Teaching Botany	educational games; teaching of botany; innovation	Elementary and High School	Environmental	No	Yes	No	Vieira *et al.*, 2024
2025	Representativeness of Mycology in the Initial Training of Biology Teachers: A Documentary Analysis of Syllabi and Teaching Materials	biology education; Fungi; professional Training	Higher Education	Educational	No	No	No	Barcelos *et al.*, 2025
2025	The Teaching of Botany in a Portuguese-Libras Bilingual Context Based on the	botany, deaf students, Vygostsky	Higher Education	Environmental; Medical; Historical-Cultural	No	Yes	Yes	Rodrigues *et al.*, 2025

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	Historical-Cultural Theory							
2025	Teaching Practicum: A Look at Didactic Approaches in Botany Education	botany education; teacher training; high school	High School	Educational	No	No	No	Severo *et al.*, 2025

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