Journal of Biological Education

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/rjbe20

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To cite this article: Bin Zhu, Kathryn M. Parsley, Heather P. Griscom, Lisa E. Wallace, Robin Castellano, Roxana Gonzalez, David Ospina & Melissa McCartney (12 Aug 2024): Connecting plant science education in undergraduate life science courses to plant awareness disparity, *Vision and Change*, and sustainability careers, Journal of Biological Education, DOI: 10.1080/00219266.2024.2386253

To link to this article: https://doi.org/10.1080/00219266.2024.2386253

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JOURNAL OF BIOLOGICAL EDUCATION
https://doi.org/10.1080/00219266.2024.2386253

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Connecting plant science education in undergraduate life science courses to plant awareness disparity, *Vision and Change*, and sustainability careers

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ABSTRACT

Ensuring that botany and plant sciences are being included in undergraduate life science curricula is necessary for developing a future global sustainability workforce. To gain a baseline understanding, we surveyed life science educators in the U.S. about current botanical education. We further evaluated these data to determine connections to the frameworks of plant awareness disparity (PAD), a framework detailing the inability to notice or appreciate the plants in one's own environment, and *Vision and Change*, an educational framework in the U.S. for preparing undergraduate biology students for the 21st century. Results from 245 responses revealed that most instructors use botanical examples and implement diverse hands-on botanical experiences. Our data suggest that hands-on botanical experiences are better suited to address PAD, the more science practice-centred framework, while plant examples are better suited to increase the understanding of core concepts of *Vision and Change*, the more concept-centred framework. We recommend that life science educators should 1) remain diligent in providing plant examples and hands-on botanical experiences in large introductory courses, 2) incorporate more botany education in general education courses (not required by the major but required by the institutions) and non-major courses, and 3) include educators outside of botany in these efforts.

ARTICLE HISTORY
Received 3 May 2023
Accepted 25 June 2024

KEYWORDS
Plant blindness; plant awareness disparity; sustainable jobs; *vision and change*; botany education

Introduction

Sustainable development is a top priority for every modern society, across the globe, and achieving sustainability is an ongoing goal. According to the Bureau of Labor Statistics (BLS), the United States is projected to have 8.3 million more jobs from 2021 to 2031 (BLS 2022), and this trend is likely to be replicated internationally. Sustainability jobs, such as environmental scientists and specialists, conservation scientists and foresters, and agricultural and food scientists, will have a faster than average growth based on the BLS Occupational Outlook Handbook. Common fundamental knowledge connecting all these fast-growing sustainability jobs is in botany and

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/00219266.2024.2386253
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plant sciences. As such, knowledge and skills in botany and plant sciences are essential requirements for developing the future global sustainability workforce.

Botany and plant sciences have wide-ranging relevance that spans disciplines and have great importance in sustainable careers, yet they are widely overlooked in undergraduate STEM curricula (Brownlee, Parsley, and Sabel 2021; Parsley 2020; Wandersee and Schussler 1999). Botany and plant sciences refer to the scientific study of plants, including the physiology, structure, genetics, ecology, distribution, classification, and economic importance of plants. Plants, and the biological and physical systems to which they contribute, are critical to the future sustainability of both humans and the planet. Technological advancements and novel research in the plant sciences are essential to addressing pressing global issues related to sustainability, including food insecurity, climate change, biodiversity loss, and water and land pollution (Kramer and Havens 2015). Plant systems are the foundation of healthy ecosystems and environments, sentinels of climate change, and the primary sources for food, fibre, energy, and shelter (Henkhaus et al. 2020).

Therefore, promoting plant sciences and general botanical literacy to STEM undergraduates and the general public, across the globe, is a critical foundation for a sustainable future. In general, undergraduates are not attuned to the intricacies of plant life histories, nor to the dynamic ecosystem functional and societal roles that plants play, a phenomenon commonly referred to as 'plant blindness' (Parsley 2020; Wandersee and Schussler 1999). Plant blindness has recently been criticised for its ableist connotations (McDonough MacKenzie et al. 2019; Sanders 2019) and for the implication that it cannot be 'cured'. A new term, plant awareness disparity (PAD), has emerged as a replacement and is similarly defined as the tendency not to notice or appreciate plants within one's environment, which leads to naïve and anthropocentric points of view, such as the idea that plants are unimportant to humans, boring, or have little value (Parsley 2020).

PAD has real world consequences, which include prejudice among biology teachers against plants (Hershey 1996), zoochauvinism (the emphasis of animals over plants), lack of media representation of plants, and even plant neglect in biology textbooks (Brownlee, Parsley, and Sabel 2021; Hershey 2002; Thomas, Ougham, and Sanders 2022). This has manifested to a serious level over the last decade, as botany education, especially field botany, has declined. There has been a marked reduction in the number of faculty members and universities offering botany courses, botanical career preparation, and an increase in the closure of botany departments (Drea 2011; Kramer and Havens 2015; Sidoti et al. 2023; Walsh et al. 2023; Woodland 2007). Consequently, there is a dire need to re-establish a robust botanical education system focused on communicating the importance of plants to undergraduates, regardless of their career goals. We will be unable to provide the required workforce for sustainability jobs without botanical literacy (Sidoti et al. 2023; Walsh et al. 2023). For example, Stagg, Donkin, and Smith (2015) reported that undergraduate students could identify no bryophytes prior to instruction. Establishing and maintaining a robust botanical education system at the undergraduate level will not be trivial.

As a starting point, we need to know what undergraduate students are currently taught about botany and plant sciences in STEM courses, whether PAD is addressed, and whether students are well-equipped with necessary knowledge and skills to be successful in sustainability jobs. Learning more about these factors will enable us to make recommendations on how to increase botanical content in undergraduate courses. Therefore, we surveyed life science educators in the U.S. to better understand the botanical content they include in their courses and how they deliver botanical content to their students. Our 'State of Botany in the Life Sciences' questionnaire was distributed across the life sciences community (scientists spanning the discipline of biology including botanists, ecologists, geneticists, etc.) between September and December 2020. This questionnaire contained both quantitative and qualitative questions aimed at collecting data about types of botanical content currently being delivered to undergraduates.

We further evaluated these life-science course data to determine if PAD was being addressed and if the necessary knowledge and skills for the next generation of scientists, as well as for the next generation of the global sustainability workforce, were being taught. There are different measurements to achieve this goal across all levels of education. For example, Pany et al. (2022) used four attributes to measure plant awareness in secondary school students: 1) visual perception of plants, 2) categorising plants as living organisms, 3) knowledge about plants, and 4) attitudes towards plants. As we are interested in undergraduates, we evaluated different metrics for undergraduate students based on the recently developed plant awareness disparity index (PAD-I) (Parsley et al. 2022) and one widely cited biological education report, *Vision and Change* (AAAS 2011). Parsley et al. (2022) describes four components of PAD-I: 1) how much **attention** students pay to plants in general, 2) student **attitudes** towards plants, particularly in educational settings, 3) student **knowledge** related to understanding the importance of plants, and 4) how **interesting** students find plants compared with other organisms, namely animals. We analysed our dataset to see if life science course content promoted these components. We also added two other components related to PAD-I in this study: 5) student botanical literacy, and 6) student ability to place plants in a cultural context as these are also essential for students to have a successful career related to global sustainability.

We analysed our dataset to determine if life science course content promoted the concepts and competencies underscored in the *Vision and Change* report, an educational framework in the United States for preparing undergraduate biology students for the 21st century. *Vision and Change* began as a series of conversations and workshops attended by more than 500 biologists and biology educators and culminated in a set of unifying recommendations for better aligning biology education to the needs of a 21st century biological workforce. The overwhelming consensus reached by workshop participants on both the form and substance of modern biology courses is unusual in a discipline as disparate as biology and provides credibility to *Vision and Change* to be applied to global biology programmes (Ledbetter 2012). Specifically, the *Vision and Change* report outlined five core concepts that are important for undergraduate biology majors to understand by the time they graduate and highlighted the six most important skills that undergraduate biology educators should teach in order to modernise biology education and ensure students can be biologically literate and well-prepared for their future careers (AAAS 2011). Therefore, we specifically looked for connections within our data to the five Core Concepts of 1) evolution, 2) structure and function, 3) information flow, exchange, and storage, 4) pathways and transformations of energy and matter, and 5) systems. In addition, we looked for connections to the six Core Competencies, or the ability to 1) apply the process of science, 2) use quantitative reasoning, 3) use modelling and simulation, 4) tap into the interdisciplinary nature of science, 5) communicate and collaborate with other disciplines, and 6) understand relationships between science and society (AAAS 2011).

Our objectives were to determine: 1) what undergraduate students are currently taught about botany and plant sciences in life science courses, 2) whether PAD is addressed, and 3) whether the content and skills presented in life science courses through a plant science lens are connected to those outlined in *Vision and Change*. We conclude with recommendations on how to increase botanical content in undergraduate courses, thereby improving knowledge and skills for the future global sustainability workforce.

Methods

Development of the "state of botany in the life sciences" questionnaire

Four members of a botanically-focused National Science Foundation Research Coordination Network (NSF RCN), 'Seeing Green' (NSF RCN-UBE 1920008), developed a draft questionnaire in July 2020. Eight different members of the same RCN then evaluated the questionnaire items and participated in an online focus group to review, edit, and update the questionnaire. These focus group members were asked for feedback in regard to the wording of each item, the purpose of each item, the length of the entire questionnaire, and their overall experience while completing the questionnaire. The questionnaire was then edited based on the feedback of the focus group and items that were identified as not closely related to our study objectives, poorly written, confusing, too time consuming, or repetitive were removed. No individual data from the focus group participants were included in the current analysis. The questionnaire was submitted to the Institutional Review Board at the Florida International University and was granted IRB approval (IRB-20-0536). The questions used for data collection are presented in Appendix 1.

The majority of the data presented in this article come from two open-ended questions: 1) 'Please tell us about the most engaging plant examples that you use in your course. An example being that you would teach evolution using a plant example' and 2) 'Do you use hands-on botanical experiences with students in any capacity? By hands-on, we mean a research experience, a laboratory experience, a trip to a Botanical Garden, a walk through campus or a nature trail, a trip to the grocery store, bringing plants into the classroom. . .any kind of active experience where students are engaging with plants. Please provide details about the hands-on botanical experience you offer'. The answers to the first question will help determine whether plant examples are used and what examples are used in undergraduate life science courses, providing baseline information about the current status of plant examples in undergraduate education. In the second question, hands-on experience refers to 'activities in the which the students manipulate and observe real objects and materials and their subsequent reflections on the purpose of practical work' as defined by Abrahams and Millar (2008).

Distribution of the questionnaire

The questionnaire was administered through Qualtrics (online survey software; Provo, Utah and Seattle, Washington). Links to the questionnaire and a description of the research study were sent to relevant organisation and association email lists and electronic newsletters, individual contacts of the Seeing Green RCN network, and distributed using social media (*i.e.* Twitter and LinkedIn) and snowball protocols (research participants were asked to share the questionnaire link with other potential participants, organisations, and websites). For example, the Botanical Society of America included the questionnaire in their monthly newsletter. The questionnaire was open from October 2020 through December 2020. A total of 245 complete responses were recorded.

Qualitative data analysis and deductive coding

Open-ended responses were coded using deductive coding techniques to target specific constructs (Creswell 1994). Deductive coding is a top-down approach where predetermined codes are used to analyse data. In our case, we used constructs from the *Vision and Change* report (the five core concepts and the six competencies) (AAAS 2011) and the six previously mentioned Plant Awareness Disparity Indices. Four researchers read all of the open-ended responses and independently coded each response to the deductive codes of the five core concepts, six competencies, and six PAD indices. Initial findings were discussed among the four researchers and any coding that remained unclear was discussed until a consensus was reached. Analysis of coding considered only the presence or absence of specific codes within each open-ended response, not the frequency with which a single participant expressed a particular code. Kappa values measuring inter-rater reliability (the extent to which researchers assign the same code to the same data) were over 0.85, which represent higher standards than recommended (0.65) (Syed and Nelson 2015). All qualitative analyses were completed using NVivo software (NVivo version 12, QSR International).

Statistics analysis

Descriptive statistics for both our quantitative and qualitative data were calculated using Microsoft Excel. For most multiple-choice questions, respondents were allowed to choose more than one answer, which is why the percentages of answers do not add up to 100%.

Results

Demographics of respondents

The majority of our respondents (79%) are faculty (tenure or permanent staff and non-tenure or non-permanent staff; professors who have responsibility for instruction and curriculum development) (Table 1). As faculty, most respondents are affiliated with academic-based institutions, public or private institutions, and bachelor, master, or doctoral institutions (Table 2). Respondents are mainly from Biology departments (68%), with a few respondents (9–11%) from Environmental Sciences and Plant Sciences/Botany departments and 1% from Agriculture and Earth Science departments (Figure 1). Responses for the 'other' category included Landscape Architecture and Regional Planning and variations of Natural Sciences (Mathematical and Natural Sciences, Natural Resources, Natural Resource Management), and Ecology (Ecology, Evolution, and Environmental Biology, Ecology and Evolutionary Biology, Ecology and Field Biology).

Table 1. Respondent's role at their institutions.

Role at Institution	% responding
Faculty	79
Director/Executive Level	5
Education Staff or Educator	4
Graduate Student	4
Science/Research Staff	3
Other	2
Teaching Assistant (TA)	1
Postdoctoral Fellow	1
Outreach Staff	1

Table 2. Types of institutions respondents are affiliated with. Respondents were allowed to choose more than one answer which is why the percentages of answers do not add up to 100%.

Type of Institution	% responding
Baccalaureate colleges	37
Doctorate-granting universities	33
A public institution	24
Master's colleges and universities	23
A private institution	14
Research Intensive Institution	11
Community College (2 year)	5
High school	2
Other	2
Botanical Garden/Arboretum	1
Tribal college	1
Science center/Museum	1
Non-governmental organisation (NGO)	0
Government	0

Are botanical examples being used in life science courses?

We asked respondents to tell us about the courses where they use engaging botanical examples, e.g. teaching evolution, energy, and community interactions (such as competition and parasitism) using plants. First, 97% of respondents reported teaching using botanical examples (Figure 2(a)). Second, 81% of respondents reported teaching botanical examples mostly in smaller classes (40% in a class of 20 students or less and 41% in a class of 21–50 students) (Figure 2(b)). Only 10% used botanical examples in a class of 51–100 students, and only 8% used botanical examples in a class of 100 or more students. Finally, although the level of courses seems to be evenly split (Figure 2(c)), 77% of respondents reported teaching botanical concepts in a course classified as a biology major

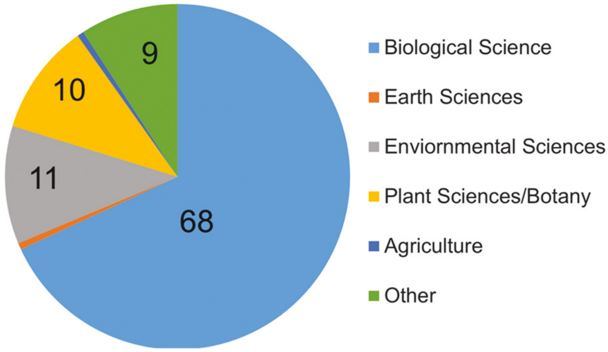

Figure 1. Types of departments that respondents are affiliated with.

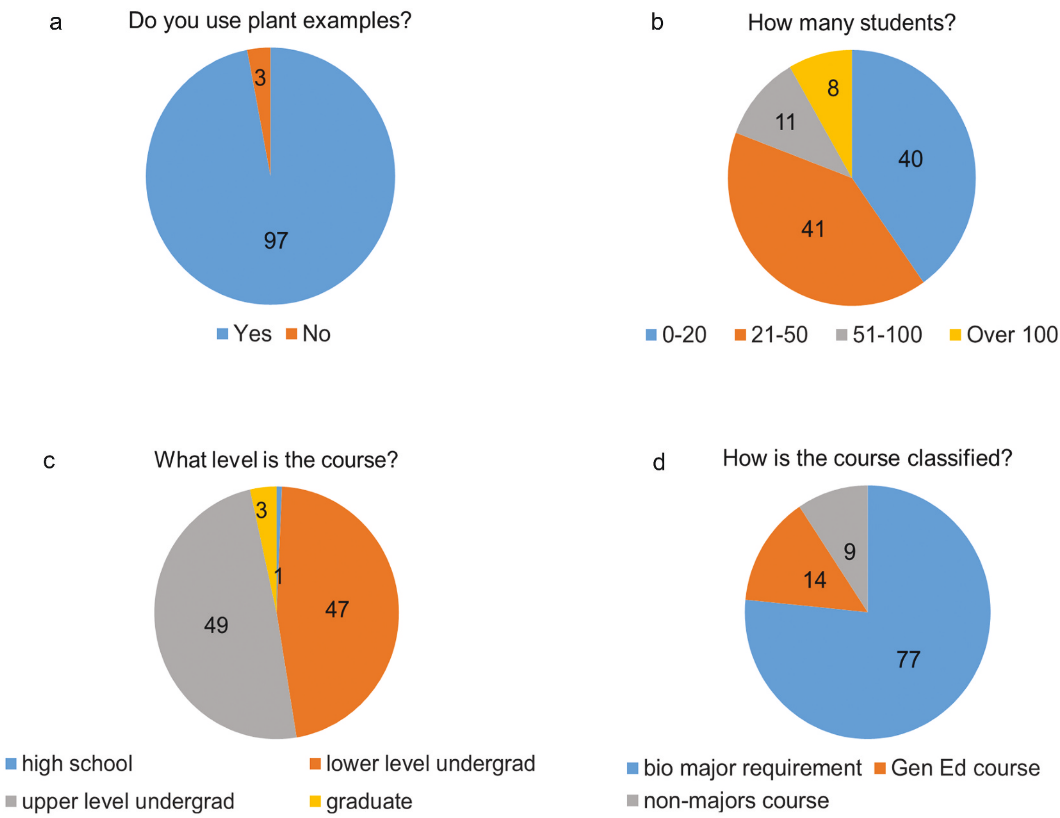

Figure 2. Results from the 'state of botany in the life sciences' questionnaire. Results are shown as percentage responding.

requirement, while only 14% reported teaching botanical concepts in a General Education course (Gen Ed; required courses for a degree programme that are often interdisciplinary, including courses in art, natural and social sciences, technology, and humanities, to develop students' general knowledge, skills, and competencies) and only 9% reported teaching botanical concepts in a non-major course (designed for students whose plan of study and career does not focus on the course subject) (Figure 2(d)).

There were 261 botanical examples provided by respondents (respondents were allowed to enter more than one example) (Appendix 2). These examples are extremely diverse and cover many topics in life sciences, e.g. experimental design and statistics, evolution, plant structure and function, invasive species, climate change, medicine, and natural history of local flora. Five specific responses are provided here as examples, with the botanical example, e.g. teaching evolution, energy, and community interactions (such as competition and parasitism) using plants, outlined in bold text:

(1) *Discuss **relationships between threatened and endangered species** of insects often being associated [with] specific hosts plants (e.g. violets, milkweeds). Discuss **evolutionary races** between plants and insects, as well as **coevolution**.*
(2) *American chestnut – restoration, ethnobotany, speciation, **invasive species ecology***
(3) *As a botanist teaching the **community ecology** portion of this course, most of my examples of **community interactions** (e.g. competition, predation, parasitism, mutualism, food web dynamics, succession, spatial patterns, etc.) are built around plant-based examples.*
(4) *Use herbarium specimens and fresh herbs and spices for course lectures. I integrate a lot of sensory and hands-on engagement with plants as we cover concepts of cuisine, **food chemistry** and cultural contexts of foods. There is also a community engagement assignment in the class, which requires students to volunteer in community gardens, at food banks, or other food security initiatives in town.*
(5) *I use a lot of plant examples when talking about **experimental design**, particularly completely randomized, Latin square, and split-plot ANOVAs.*

Are hands-on botanical experiences being implemented in life science courses?

We asked respondents to describe any hands-on botanical activities they engaged in with their students. The majority of these hands-on activities take place outside of the classroom (66%) and a significant amount involve research (42%) or lab activities (25%) (Table 3).

For specific examples of hands-on experience, 189 respondents provided examples (Appendix 3). Again, the examples provided were diverse and wide-ranging. Five specific examples are listed here, with the hands-on component in bold:

(1) *During a 16-week course, students are exposed to plants in a wide range of contexts. For example: **monitoring phenology of plants** outdoors; **measuring resource allocation** to various organs as an annual plant completes its life cycle; ecological restoration; experimental design and data analysis/interpretation using experimental plants; identifying plant structure and functions; comparing representatives of various plant groups in an evolutionary context; and many other types of studies.*
(2) *We use **field trips** to local parks and the New York Botanical Garden to help students study the 'ecology of their place'. Because most students are not familiar with the plant diversity in our neighborhood, we are able to use this low-intensity approach as an introduction to diversity, as well as to address the other items checked above.*

Table 3. Types of hands-on botanical activities described by our respondents. Respondents were allowed to choose more than one answer which is why the percentages of answers do not add up to 100%.

Type of hands-on botanical experience	% responding
Field trip outside of the classroom	66
Volunteer opportunity	50
Student research projects	42
A plant focused lab activity	25
Service learning/community engagement	8
A tour of a botanical garden, arboretum, or other plant focused institution	4

(3) *Basic science:* ***experiment on seed germination****; diversity explanation at botanical garden (building appreciation for diversity).*
(4) *I manage the greenhouse for my institution. Each semester I have 5-7 students that work part-time in the greenhouse helping me to care for/maintain the living plant collection. We have over 200 species of plants including a tropical and a desert/succulent collection. Students are also welcome to introduce new species to the collection. For example, students* ***have brought in seeds from wild and cultivated specimens that we have raised and now maintain*** *in the greenhouse including a cherimoya tree (Annona cherimola), a date palm (Phoenix dactylifera), and avocado (Persea americana).*
(5) ***Students measure*** *DBM of various tree species at our field station and then calculate the cost per yard foot of the timber versus the tree's ability to sequester* CO_2*. Leaf stomata across a landscape. Gibberellic acid application to leaf surfaces and resultant growth. Winter Woody Plant ID. Plant diversity in quadrats at our field station. Dispersal of seeds in a grassland.*

Connecting botanical examples and hands-on experiences to PAD

To determine if the botanical examples (Appendix 2) and hands-on experiences (Appendix 3) presented in our study were connected to PAD, we analysed open-ended responses for connections to the four components of PAD-I, 1) attention, 2) attitudes, 3) knowledge, and 4) interests (Parsley et al. 2022), as well as botanical literacy and cultural context. As an example, please see the following description of a hands-on experience:

> I teach a class in Plants in Human Affairs that has a lab component. Each lab explains the role of plants in society, history, economy, past, and current uses. Each lab has observation stations that include plants either grown in our greenhouses or that have been collected on our campus. Each lab has a hands-on activity that is set in an inquiry-based environment. Students need to state their hypothesis and test them.

Here, we see connections to PAD1: how much attention students pay to plants and PAD3: student knowledge of plants. We also see connections to enabling students to develop science literacy around plants and to place plants in a cultural context. These are the codes we would connect to when analysing this example. Collectively, data across all examples suggest that hands-on botanical experiences have a high connection to student attention towards plants (66%, the percentage of total botanical experience examples provided by respondents addressing the attention aspect of PAD) (Figure 3). In general, hands-on botanical experiences had equal or greater connections to PAD, science literacy, and cultural contexts than plant examples did.

Connecting botanical examples and hands-on experiences to vision and change

We further analysed respondent open-ended responses detailing their botanical examples (Appendix 2) and hands-on botanical experiences (Appendix 3) for connections to the five Core Concepts and the six Core Competencies of *Vision and Change* (AAAS 2011). With the exception of transformation of energy, we found a somewhat even spread of the five Core Concepts across plant examples, although overall these connections remain low (less than 30%) (Figure 4). We observed even fewer connections to the five Core Concepts with the hands-on experiences, with the exception of structure function.

In addition, we found far less connections to the six Core Competencies with both plant examples and hands-on experiences (Figure 5). Plant examples connect to tapping into the interdisciplinary nature of science (19%) and quantitative reasoning (11%), whereas the hands-on botanical experiences primarily connect to applying the process of science (49%) and use modelling and simulation (16%). Neither plant examples or hands-on activities connect to the ability to understand the relationship between science and society or to communicate and collaborate with other disciplines (<8%).

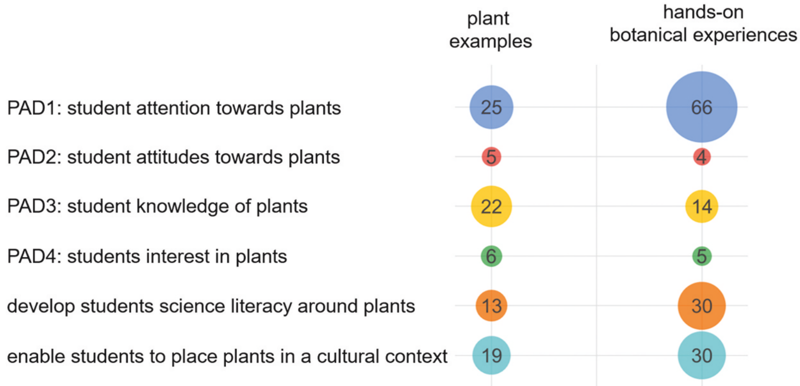

Figure 3. Deductive coding of short answer responses provided by respondents connects their botanical examples and hands-on botanical experiences to the four components of plant awareness disparity, science literacy, and placing plants in a cultural context. The y-axis shows the four PAD components, science literacy, and cultural context. The data are shown graphically, with the area of each circle being representative of the percentage of participant responses connecting to each component (the exact percentage is noted within each circle). In all situations, respondents were able to include more than one component (or no components) in their open-ended response which is why the percentages of answers do not add up to 100%.

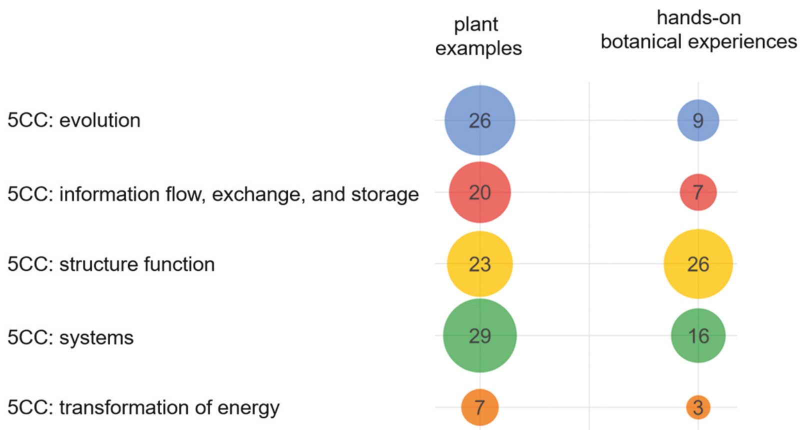

Figure 4. Deductive coding of short answer responses provided by respondents connects their botanical examples and hands-on botanical experiences to the five core concepts (5CC) of *Vision and Change*. The y-axis shows the five core concepts and the x-axis indicates either an example or a hands-on activity. The data are shown graphically, with the area of each circle being representative of the percentage of participant responses connecting to each core concept (the exact percentage is noted within each circle). In all situations, respondents were able to include more than one core concept (or no core concepts) in their open-ended response which is why the percentages of answers do not add up to 100%.

Discussion

In order to better prepare a global sustainability workforce, we need to ensure that botany and plant sciences are being included in all undergraduate life science curricula across the globe because PAD is a global issue (e.g. in Austria - Pany et al. 2022; in Sweden – Nyberg, Hipkiss, and Sanders 2019; and in U.K. – Stagg, Donkin, and Smith 2015). Our research findings reveal a baseline status of what botanical education looks like in higher education in the U.S. today, what botanical content life science educators include in their courses, what courses life science educators include botanical content in, and how educators deliver botanical content to their students. We also discovered that hands-on botanical experiences have a high connection to PAD, science literacy, and cultural contexts, whereas there were low connections of both plant examples and hands-on botanical experience to *Vision and Change*, a framework that is applicable to all biology students across the globe.

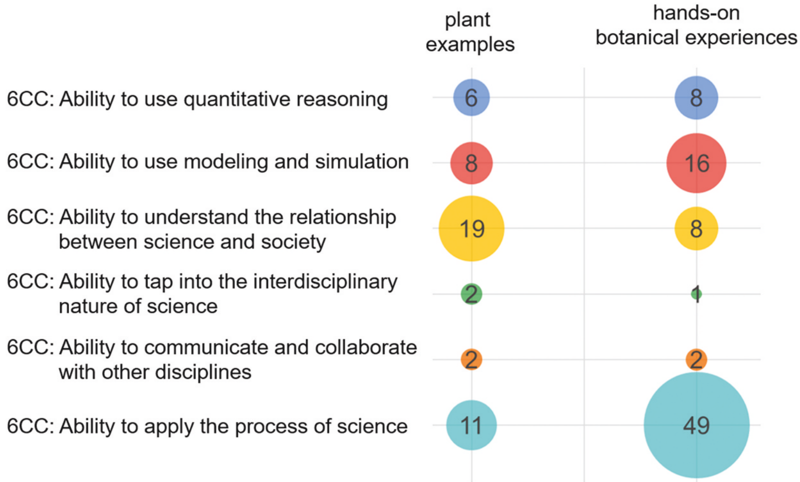

Figure 5. Deductive coding of short answer responses provided by respondents connects their botanical examples and hands-on botanical experiences to the six core competencies (6CC) of *Vision and Change*. The y-axis shows the six core competencies and the x-axis indicates either an example or a hands-on activity. The data are shown graphically, with the area of each circle being representative of the percentage of participant responses connecting to each core competency (the exact percentage is noted within each circle). In all situations, respondents were able to include more than one core competency (or no core competencies) in their open-ended response which is why the percentages of answers do not add up to 100%.

Our study population are mostly academic staff from biology departments

These results are not surprising, as we intended to specifically survey life science academics teaching life science courses. It is encouraging that so many biology staff are using plant examples, and these data suggest that staff are pushing back against zoochauvinism, the attitude of considering it more important to study and teach about animals than about plants (Lindemann-Matthies 2005). It also suggests that despite the large number of biology students interested in pursuing careers in health-related disciplines, academic staff still value botanical content. Only 10% of our respondents are from plant science/botany departments. This could be the result of our outreach efforts, but it is more likely to be the result of botany departments either closing or being merged with other related departments (Crisci et al. 2020).

Botanical examples are being implemented in life science courses

On the surface, our results are very encouraging and suggest that yes, botanical examples are being used in life science courses. Almost all respondents (97%) from this survey implemented botanical examples in their courses (Figure 2(b)). However, a deeper look into these data reveals some deficiencies. A large percentage of respondents reported using botanical examples mostly in smaller classes (Figure 2(a)), suggesting that the majority of botanical examples are being used in smaller, more specialised courses and not in the large introductory courses, even though we see an even split between upper- and lower-level courses (Figure 2(c)). Very few respondents reported using botanical examples in a Gen Ed course and a non-major course (Figure 2(d)). These findings align with an observation recorded a century ago by Nichols (1919) who determined that even the first general biology courses being developed were ‘responsible for the popular delusion that biology is the study of animals: that the words biology and zoology are synonymous’. Collectively, these data suggest that botanical examples are mostly provided to students who have successfully completed the larger, introductory courses and have somewhat self-selected into upper-level, and possibly more plant-focused, biology courses. This is a missed opportunity, as it is likely that, for some students, the large, introductory life science course is the only science course they will take. It is possible that we lose some students with strong potential for joining the global sustainability workforce by limiting plant examples to courses they may never enrol in. Additionally, including botanical concepts into more Gen Ed and non-major courses within the life sciences will result in a more well-rounded citizenry, across the globe, as many pressing environmental and social challenges require knowledge and understanding of botanical concepts across borders. Therefore, a botanical education should not be limited only to biology majors.

Types of botanical examples being used in life science courses are diverse

A variety of plants are used to teach different topics in different courses. For example, instructors use herbarium specimens, fresh herbs and spices, and vegetables and fruits from grocery stores in lectures, labs, and research projects. Some teach evolution and diversity through the form and function of plant flowers, cells, and tissues. Some teach plant secondary chemistry by having the students mix their own herbal teas from a selection of herbs and spices, then introduce the main groups of secondary compounds (such as alkaloids and phenolics), and finally have them look up what chemicals they are personally consuming in their teas. Others may spend six weeks outdoors working on collecting plot data, classifying habitats according to NatureServe (a website that provides proprietary wildlife conservation-related data, tools, and services to private and government clients, partner organisations, and the public), and comparing sites using Floristic Quality Assessments (a tool used to assess an area's ecological integrity based on its plant species composition). A complete list of botanical examples used by our respondents can be found in Appendix 2.

Hands-on botanical experiences are being implemented in life science courses

There is great enthusiasm among our respondents for sharing their hands-on botanical activities for this study (Appendix 3). Hands-on activities can lead to lasting knowledge and make learning more enjoyable for students (e.g. Sieg and Dreesmann 2022; Zhu and Levesque 2021). We found a high percentage of respondents including field trips (66%) and volunteer opportunities (50%) (Table 3) in their courses. While we strongly support these efforts, we simultaneously remind the community that not all students will have the resources, including time, money, and transportation, to participate in these experiences (at least 23% of our respondents didn't provide hands-on experiences). We encourage educators to be mindful of equity and inclusion when engaging in these activities.

We also found a large amount of research related activities: 42% report engaging students in research projects and 25% report engaging students in a plant-focused lab (Table 3). Increased numbers of students that are able to engage in undergraduate research provides society several valuable benefits, including 1) more well-rounded scientists in the workforce in general and the sustainability workforce specifically, 2) more ambassadors for explaining the scientific research enterprise to their families and friends, and 3) more informed citizens concerned about sustainable and environmental issues who have the potential to become more engaged citizens and voters (Sidoti et al. 2023; Walsh et al. 2023).

Botanical examples and hands-on botanical experiences influence PAD

PAD is a direct threat to developing the next generation of the global sustainability workforce. It is important to note that in this study we did not directly measure the level of PAD among students engaging in these hands-on experiences, we simply evaluated the connections these hands-on experiences have to the components of PAD. We see a low connection to PAD with plant examples alone (<25%). This is not surprising, as the four factors of PAD are somewhat active and easier to connect to real life encounters with plants. It is also likely that while the lecture itself cannot directly address PAD, the use of plant examples has the potential to have downstream effects on students. However, as the global plant science community works to promote botanical literacy wherever we can, we need to, on some level, work with the resources that are available. In the face of declining botanical departments and course offerings, we should take opportunities to alleviate PAD whenever possible (Crisci et al. 2020). This is especially critical in the large, introductory life science courses for reasons described above. It is possible to reach a large number of students in these courses, including students who may not go on to take additional science courses. These lecture classes are also less likely to encounter the equity and inclusion issues described previously with field trips and volunteer opportunities. Using plant examples in lecture courses is not the ideal method for addressing PAD, but it is also a method we should not overlook.

We observed greater connections to PAD with hands-on botanical experiences. Our data showed the largest connection to PAD1: increasing student attention towards plants (66%) (Figure 3), suggesting that it is highly likely that any inclusion of a hands-on experience will help increase students' attention towards plants. We found less of a connection to the other three components of PAD, which aligns with a finding in a previous study that indicates improving knowledge alone does not improve the other three components of PAD (Parsley et al. 2022). Similarly, while these hands-on botanical experiences can be quite effective at improving student attention to plants, our data suggest that this is not the case for the other three components. However, attention is the phenomenon in which PAD is originally rooted, and therefore, is important enough to warrant its own specific approach within botanical educational interventions. We found moderate connections of hands-on experiences to developing science literacy around plants and to placing plants in a cultural context, which is essential to the next generation of the sustainability workforce.

Botanical examples and hands-on botanical experiences connect to Vision and Change

We found a reversal of connections to the five Core Concepts of *Vision and Change* (compared with PAD), with the plant examples showing greater connections than the hands-on experiences. This suggests that there are multiple ways to use lecture courses to promote botanical literacy. More specifically, it confirms that life science educators can effectively use plant examples to teach general biological principles, especially given that General Biology courses neglect plants. We discovered an outlier with the Core Concept of transformation of energy, and encourage our colleagues not to overlook this Core Concept, as plants are a perfect example. Plants, as well as algae, play a critical role in transformation of energy as primary producers conducting photosynthesis, which is an indispensable part of a food web in terrestrial or aquatic ecosystems.

We did not find a clear division between plant examples and hands-on botanical experiences with respect to the six Core Competencies of *Vision and Change*. There was an overlap with the PAD dataset. For plant examples, we see a 19% connection to the ability to understand the relationship between science and society (Figure 5), which is also what we found with plant examples and enabling students to place plants in a cultural context (Figure 3). Almost half (49%) of hands-on experiences described by respondents connect to the ability to apply the process of science (Figure 5), which is likely connected to data in Table 3 (research 42% or lab activities 25%). The lack of connection to tapping into the interdisciplinary nature of science as well as communication and collaboration with other disciplines is concerning. This confirms the finding by Thomas, Ougham, and Sanders (2022) that incorporating botany education using multidisciplinary approaches in the undergraduate curricula is not widely appreciated, and PAD still exists due to strong socio-economic forces of resistance. Our study showed that even within the botanical community, botany education is far from reaching its full potential for preparing students for future sustainability jobs.

Recommendations

In order to best prepare the next generation of the sustainability workforce, we recommend several strategies based on our data. First, we need to be more diligent in providing plant examples and hands-on botanical experiences in large, introductory courses. Our data (81% classes with < 50 students) suggested that botanical examples are often missing, possibly due to instructors responding to the high number of students focused on careers in the healthcare sector. When students have experience with plants early on in their undergraduate life, it is more likely that students will have more positive attitudes towards plants and more interest in plants, thereby considering plant-related careers as a possibility (Bennett, Knight, and Bell 2020). When implementing plant examples and hands-on experience, we should also design them related to the concept of transformation of energy, and the two core competencies of being able to tap into the interdisciplinary nature of science and being able to communicate and collaborate with other disciplines. Given that our results indicate these competencies are not naturally incorporated into existing plant examples and hands-on experiences, we suggest considering them especially when designing these types of interventions and curricula. We encourage the life science community to use datasets found in Appendix 2 and Appendix 3 as a source of inspiration for bringing more botanical examples and hands-on botanical experiences into their own courses. These datasets are applicable to any life science course, taught anywhere across the globe.

Secondly, general education and non-major courses should incorporate more botany education. Our data show only ~ 20% courses where plant examples are used were for general education and non-majors. As many pressing environmental and social challenges require knowledge and understanding of botanical concepts, a botanical education should not be limited to only biology majors. Because there are significant changes both in the organisation of work and in the nature of work in these modern days, general education must broaden the breadth of knowledge and improve students' ability to think critically (Lynton 1991). Therefore, incorporating botanical education in general education and non-major courses can better prepare students not only for a potential career in sustainability, but also as an informed citizen who will encounter sustainability issues throughout their life.

Finally, botanical education should expand to educators outside of botany. Our data demonstrated 97% of educators used botanical examples in courses. However, it is important to remember that this questionnaire was sent to the life sciences community with no incentive to participate, so the audience was somewhat self-selected. Unsurprisingly, botanists are committed to promoting their own discipline. Our data can be used to support a plan to specifically target undergraduate educators outside of botany, such as biomedical and environmental educators, who may not be as committed to using botanical examples or may not know how to use botanical examples, to ensure botanical content gets to as many undergraduates as possible. Our recommendations are consistent with the idea that multidisciplinary approaches to education and public engagement would help alleviate PAD and these opportunities should be implemented in undergraduate curricula across the globe (Thomas, Ougham, and Sanders 2022).

Limitations of this study

We recognise several limitations in this study. The data were collected in one survey that was open for three months and had 245 respondents. A longer period of time and more respondents would have provided more data and a larger sample of the life science community (e.g. Ryu and Zhu 2021). Our questionnaire was sent to the life science community that was somewhat skewed to the botanical community, and with no incentives being offered to complete the survey respondents tended to be botanists or related professionals. Therefore, data presented in this study likely represent how botanists or plant scientists implement plant examples and hands-on botanical experiences in their courses, and it is reasonable to speculate many other biologists or educators in other disciplines may not implement to the same level. This again supports our call to involve more educators outside botany to incorporate botany education into courses in their own disciplines as well as general education and non-major courses. Finally, the data analysis is mainly descriptive. Descriptive data can provide a comprehensive understanding of people's experiences, but without statistical significance some might not find these data convincing. In future studies, we would ideally have more respondents, including educators in other disciplines and those who teach general education and non-major courses, and include statistical analyses of additional data.

Acknowledgments

We thank the entire NSF RCN "Seeing Green" for their help with designing the "State of Botany in the Life Sciences" questionnaire and for sharing the questionnaire throughout their networks. This work was supported by the National Science Foundation (NSF DBI 1920008) and a collaborative grant from the Donald Danforth Plant Science Center.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Donald Danforth Plant Science Center [Award 22028] and the National Science Foundation [NSF RCN-UBE 1920008].

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