Bringing Botany into Focus: Addressing Plant Blindness in Undergraduates Through an Immersive Botanical Experience

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Undergraduate science, technology, engineering, and math students (STEM) are usually not attuned to the intricacies of plant life histories or to the dynamic role plants play in ecosystems and human society, a phenomenon termed plant blindness. *Botany education has declined in the past decades, whereas career paths that need and benefit from a workforce with botanical knowledge have increased. Consequently, there is a need to reduce plant blindness among undergraduate students, regardless of their career trajectories. We provide evidence that participation in a botanical experience as part of a general biology course can positively shift undergraduates' perception of botany, the study of plants. Students participating in the botanical experience showed significant positive shifts in their ability to connect botany to their college major and future careers. In addition, we show qualitative data indicating a new respect for plants and a new appreciation for the diversity among plants.*

Keywords: zoochauvinism, immersive learning, botanical garden, undergraduate STEM education, botanical education

The cognitive bias that results in the widespread lack of awareness of plants in the environment by the general public was coined *plant blindness* at the annual meeting of the Botanical Society of America in 1998 (Wandersee and Schussler 2001). The term has since been used to also describe the lack of plant materials in general biology education in K–12 and college curricula (Nichols 1919, Uno 1994, Bernhadt 1999, Kramer 1999, Wandersee and Schussler 1998, 1999, Sundberg 2000). In general, plant blindness includes the inability to recognize the importance of the study of plants in environmental and human affairs, the inability to see or notice the plants in one's own environment, the inability to appreciate the aesthetic and unique biological features of plants, and the tendency to rank plants as inferior to animals.

Botany, the study of plants, is considered one of the least interesting topics by undergraduate biology students (Uno 2009), making plant blindness extremely relevant to undergraduate biology curricula. In a study of first-year undergraduate biology majors, it was shown that, among various topics of interest, plants rated the lowest. On a scale ranging from 0 to 5 (with 5 being the highest), plants were given a favorable rating of 1.2, animals 3.3, and studies on the human body were rated as 4.3 (Marbach-Ad 2004). Additional studies show that students studying in the United States prefer to learn more about animals than plants, which is often attributed to zoochauvinism: the attitude of considering it more important to study and teach about animals than about plants (Bozniak 1994, Hershey 1996, Wandersee and Schussler 1998, Lindemann-Matthies 2005). In addition, most students in undergraduate biology programs in the United States want to develop careers in health-related disciplines, resulting in a student dislike for plants as a study subject and the view that botany subjects are irrelevant and even a burden on their professional paths (Marbach-Ad 2004, Uno 2009).

This preexisting background level of plant blindness in undergraduate students is exacerbated by zoochauvinism in teaching biology; teachers use animals as examples to explain general biological principles (e.g., natural selection and evolution) much more frequently than they do plants (Pany 2014). In addition, throughout the ranks of the educational system, biology is predominantly taught by professors and teachers that come from a background of studying animals rather than plants. No matter how educated these teachers or professors are, they tend to gloss over the botany sections (Wandersee and Schussler 1999).

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A lack of emphasis on plants in science curricula can lead to undergraduate students thinking that botany is irrelevant to their future studies and educational endeavors. However, career paths that need and benefit from a workforce with botanical knowledge have increased, resulting in a major shortage of botanically qualified professionals (Kramer and Havens 2005, Sundberg et al. 2011). Plant blindness has other serious consequences, including a lack of public support for botanical research, plant conservation, and environmental issues (Allen 2003, Negron-Ortiz 2014, Balding and Williams 2016, Margulies et al. 2019). Therefore, it is critical that we provide undergraduate students with a comprehensive understanding of botany as we prepare them to become informed citizens.

In this study, we aim to provide undergraduate students with an immersive botanical experience to begin to reduce their plant blindness. Immersive experiences, which bring students to locations and settings that cannot be duplicated in the classroom, are effective ways of increasing student interest and engagement with the subject (Behrendt and Franklin 2014). Students are often able to connect the experiential learning with the content that was taught in the classroom, especially when related to outdoor and environmental activities (Braund and Reiss 2006, Lei 2010, Jose et al. 2017, Zaragoza and Fraser 2017). Students can observe natural settings and begin to make personal connections with the experience, and, ideally, course content becomes relevant (Lei 2010).

Most of the previous work in providing students immersive botanical experiences has been with elementary school children. The results have been positive, with immersive botanical experiences resulting in an improvement in elementary school children's attitudes toward and knowledge of plants (Khatz 1995, Mitchell and Gillespie 2007, Fancovicova and Prokop 2011). Far less has been done with immersive botanical experiences at the undergraduate level. Mobile devices are starting to be used by undergraduates to identify plants and have been shown to reduce plant blindness among students in a large, first-year introductory course, but these apps are usually implemented on college campuses and local neighborhoods, not at a botanical garden (Pettit et al. 2014, Hartman et al. 2019). There is a lack of literature on how botanical gardens can be used to engage undergraduate students with botany.

We present a comprehensive analysis of undergraduate students engaging in an immersive botanical experience, with the goal of reducing the students' plant blindness. However, there are currently no validated assessments for measuring plant blindness, preventing us from measuring this directly. Instead, we indirectly measured changes in plant blindness through the following research questions, based off the definition of plant blindness we presented above.

- *Does participating in a botanical experience enable students to better recognize the importance of the study of plants in human affairs?* We asked students before and after the course how they felt about botany in general and whether botany relates to their majors and careers.
- *Does participating in a botanical experience enable students to notice the plants in one's own environment?* We asked the students before and after the course how often they stop and notice a plant. And
- *Does participating in a botanical experience enable students to appreciate the aesthetic and unique biological features of plants?* We asked the students several questions about their perceptions of learning botany through the immersive experience.

We chose to use the word *botany* in our assessments instead of the word *plants* because our target students are biology majors in a department that offers botany or equivalent courses (e.g., plant ecology). It is our intent that by introducing students to botany in an introductory course it may make it more likely that they will opt to take future botany courses as electives.

Study sites and population

Florida International University (FIU) is a public Carnegie R1-ranked urban university and an Hispanic serving institution enrolling 41,794 undergraduates in fall 2019, of which 67% were Hispanic or Latino, 12% were African American or Black, and 57% were women. The biology major had 4,159 students enrolled, composed mostly of Hispanic students and large numbers of first generation (approximately 20%) and Pell-eligible students (approximately 51%).

Fairchild Tropical Botanical Garden (FTBG), located in Miami, Florida, has one of the world's best collections of tropical plants. These collections provide educators a unique opportunity to increase plant awareness among their students.

All of the participating students were enrolled in General Biology II (Gen Bio 2) at FIU. Gen Bio 2 is one of two classes in the introductory biology sequence, focusing on organismal biology with emphasis on botany and zoology. Most students in these classes are preparing for careers in health sciences, with over half of the students in this study pursuing a career in medicine, dentistry, or other health-focused professions—that is, professions that are generally incorrectly considered separate from botany (supplemental figure S1).

Our population overall was 70% women. We had a diverse population of 81% Hispanic or Latino, 7% African American, 5% white, 4% Asian, 3% who preferred not to answer, and less than 1% who responded with two or more races. Collectively, across the three semesters, we had 11% freshman, 39% sophomores, 37% junior, and 13% seniors. Most of the students were biology (33%) or biochemistry (31%) majors (supplemental figure S2). We did have nonbiology majors (e.g., marketing, economics, business), allowing Gen Bio 2 to reach a nonbiology population. The total number of students enrolled in Gen Bio 2 over the course of this study is found in table 1.

Table 1. The number of students enrolled in Gen Bio 2 compared with the students participating in the botanical experience.

Semester	Total students	Number of students participating in a botanical experience	Percentage of students participating in a botanical experience
Summer 2018	177	88	49.7
Fall 2018	301	111	36.9
Spring 2019	805	275	34.2
Total	1283	474	36.9

Note: Gen Bio 1 is traditionally taken by incoming freshman in the fall semester. Gen Bio 2 is traditionally taken in the spring by second semester freshmen, which is why the spring numbers are so much higher.

An immersive botanical experience. The immersive botanical experience at FTBG was offered to all students in Gen Bio 2 starting in summer 2016 (Francisco-Ortega et al. 2019). The botanical experience was designed by FIU faculty and FTBG botanists, with the aim to use FTBG's world-renowned living collections of tropical plants to illustrate some of the concepts covered in Gen Bio 2 (supplemental figures S3 and S4). Each botanical experience was led by either an FIU instructor or a graduate student teaching assistant assigned to Gen Bio 2.

Although many possible case studies based on FTBG's collections were considered, FIU educators developed the curriculum focused on three key strategies intended to engage students.

First, the curriculum was intended to cover a limited scope of example plants. On the basis of our experience, students disconnect from plants the moment they are overwhelmed with scientific jargon or with too many examples of plant adaptations and features. Therefore, in the botanical experiences at FTBG, only seven themes were covered (figures S3 and S4), each relating to topics covered in Gen Bio 2 with the exception of ethnobotany. Ethnobotany was used to increase the students' engagement with plants. The time provided to the students to ramble through FTBG was also highly valuable and relevant to our goals, and therefore, the students were not rushed as they walked between each of the theme case-study plants.

Next, we followed a critical-thinking approach. We allowed the students to discover by themselves how each case study's concepts relate to topics covered in Gen Bio 2. This critical-thinking process usually stimulated ideas and arguments that helped the student group understand and value particular plant traits.

Finally, we focused the learning content on exceptions to biological rules. We were convinced that the students would engage with high intensity and truly grasp how biological processes operate through cases that highlight exceptions displayed by plants. Exceptions trigger students' curiosity and lead to discussions on why a particular plant trait does not follow the biological rules covered in Gen Bio 2. For example, we generally think of photosynthesis as occurring in leaves, but the baobab and *Ceiba* spp. trees both photosynthesize through their trunk, and the vanilla orchid photosynthesizes through its roots. In addition, *Nepenthes* and *Dischidia* have leaves that perform functions not related to photosynthesis at all. (For more examples of exceptions, see supplemental figure S3.)

These strategies were shared with the students before their botanical experience began. We found that outlining this approach lets the students know that their minds will be challenged through their own discoveries.

The students visited FTBG once during the semester for a 2-hour experience. To date, approximately 1500 students have been engaged in this experience. Overall, 37% of Gen Bio 2 students opted to participate in a botanical experience as part of this study (table 1).

One important lesson from previous pilot FTBG botanical experiences is that the students only truly participated if they received academic recognition for doing so. Because this activity takes place outside the FIU campus, student participation is voluntary, and, without an incentive to participate, attendance is poor, and the students are not necessarily engaged. Therefore, we designed a reward system that allows the students who participate in a FTBG botanical experience to earn extra credit points (worth 18 extra credit points out of 100 total points for the lab). The students who were not able to participate were not given another option for extra credit.

Content included in the FTBG botanical experience. A detailed list of included content can be found in figures S3 and S4. Which case studies were ultimately included depends on various factors, such as weather and the time of year. Our discussions were inspired by botanical questions such as *Why don't orchids develop endosperm to store seed food as most flowering plants do? Why do some gymnosperms not have cones, instead bearing their seeds on the edge of special leaves? Why do plants have amino acids that are not made to build up proteins?* And *Why do some plants exhibit branches that look like roots and therefore do not grow up but down?*

We discussed the importance of plants in the history of religions and the way most civilizations have used plants as connection elements with their deities or supreme beings. We emphasized that plants are much more than sources of food and oxygen for humans, and, within this context, we used FTBG as an example of how gardening and landscaping can lead to artistic creativity and beauty. Finally, we

highlighted plants as systems that can be used to understand basic biological processes related to organisms' adaptations to different environments. For example, while examining the cannonball tree, the students discussed hypotheses about the mechanisms to regulate cell division during the development of pollen, hormone activation of reproductive tissues, and the allocation of resources to produce energy-rich sugar compounds in different parts of the plant.

Development of the questionnaires. We began with a literature review of plant blindness and identified key definitions and research questions related to plant blindness provided in policy documents, research studies, editorials, and commentaries. The final questionnaires, consisting of three parts distributed at different times in the semester, were approved by FIU IRB (IRB-18-0284-AM03) and are shown in figure S5. The questionnaire included questions such as *How do you feel about botany in general? Is botany relevant to your major? Is botany relevant to your chosen career path? How often do you stop and notice a plant? Please describe how you view FTBG as a place to learn botany. Did this botanical experience allow you to see botany (the subject) in a real life setting? Did the botanical experience allow for you to see botany (the subject) as bigger than a classroom?* And *What was the most memorable moment of the botanical experience?*

Questionnaire distribution. All of the questionnaire data were collected using Qualtrics (online survey software; Provo, Utah, and Seattle, Washington). Online links to the questionnaire were provided to the students using the Canvas classroom management software. At the beginning of the semester, the questionnaire was administered to all of the students in Gen Bio 2 as a voluntary precourse assignment. The students who completed the questionnaire were given extra credit points, regardless of whether they agreed for their data to be included in the study. The students who participated in the FTBG botanical experience were then given a second questionnaire related to the botanical experience content. At the end of the semester, all of the students, whether they had participated in a FTBG botanical experience or not, were given a postcourse questionnaire and were again provided with extra credit on completion.

Quantitative analysis. Using student ID numbers, we matched all of the students' data using the VLOOKUP function in Excel, ensuring that only data from the students participating in both the pre- and postcourse questionnaires were analyzed. We used a paired *t*-test to compare population means (before and after treatment for students who participated in a botanical experience and before and after treatment for students who did not), using Excel, on the data shown in figures 1 and S6.

We also used Excel to perform an analysis of covariance (ANCOVA) to determine whether the mean differences occurred by chance, considering the possible election bias of which students decided to take advantage of the botanical experiences, for the data shown in figures 1 and S6.

Qualitative analysis. The students' short answer responses were analyzed using inductive coding (thematic analysis) and Nvivo version 12 (Braun and Clark 2006; QSR International). Four of the present authors (JC, SO, AS, and MM) read all of the short answer responses (over 1200 responses) and independently created lists of the different perceptions, attitudes, and opinions that arose from student responses. The initial findings were discussed among the four researchers, and a preliminary codebook, consisting of short, descriptive phrases that could be used to describe particular perceptions, attitudes, or opinions expressed by participating students was developed. The four researchers then divided the data sets so that each short answer question would be recoded by two researchers. Each researcher then used the codebook to independently code their assigned data sets, and reconvened between each set to discuss and further define and reduce codes in the codebook that were unclear. All coding with the final codebook was conducted using NVivo. The analysis of coding considered only the presence or absence of specific themes within each short answer, not the frequency with which a single participant expressed a particular theme. Most of the student responses corresponded to more than one theme and were therefore coded to different themes within the same question. Kappa values measuring interrater reliability (the extent to which researchers assign the same code to the same data) were over .8, which represents a higher standard than is recommended (.65; Syed and Nelson 2015).

Student responses to the botanical experience

How do students feel about botany in general? The first question to answer was whether participating in a botanical experience enabled the students to better recognize the importance of the study of plants in human affairs. The data were cleaned to include only those students who completed both the pre- and postcourse questionnaire. To address this question, we used a five-point Likert scale (with 5 being the high score) to ask the students *How do you feel about botany in general?* A paired *t*-test showed a significant ($p < .001$) positive shift in responses from the students who participated in a botanical experience ($n = 258$), with no change for the students who did not participate in a botanical experience ($n = 55$, $p = .449$; figure 1, figure S6). Because we surveyed the students at the end of the semester, likely several weeks after they had participated in the botanical experience, we also show that the impact of the botanical experience persists and was not simply a day-of artifact of the botanical experience.

We performed an ANCOVA to determine whether the mean differences occurred by chance, considering the possible election bias of which students decided to take advantage of the botanical experiences. The ANCOVA showed

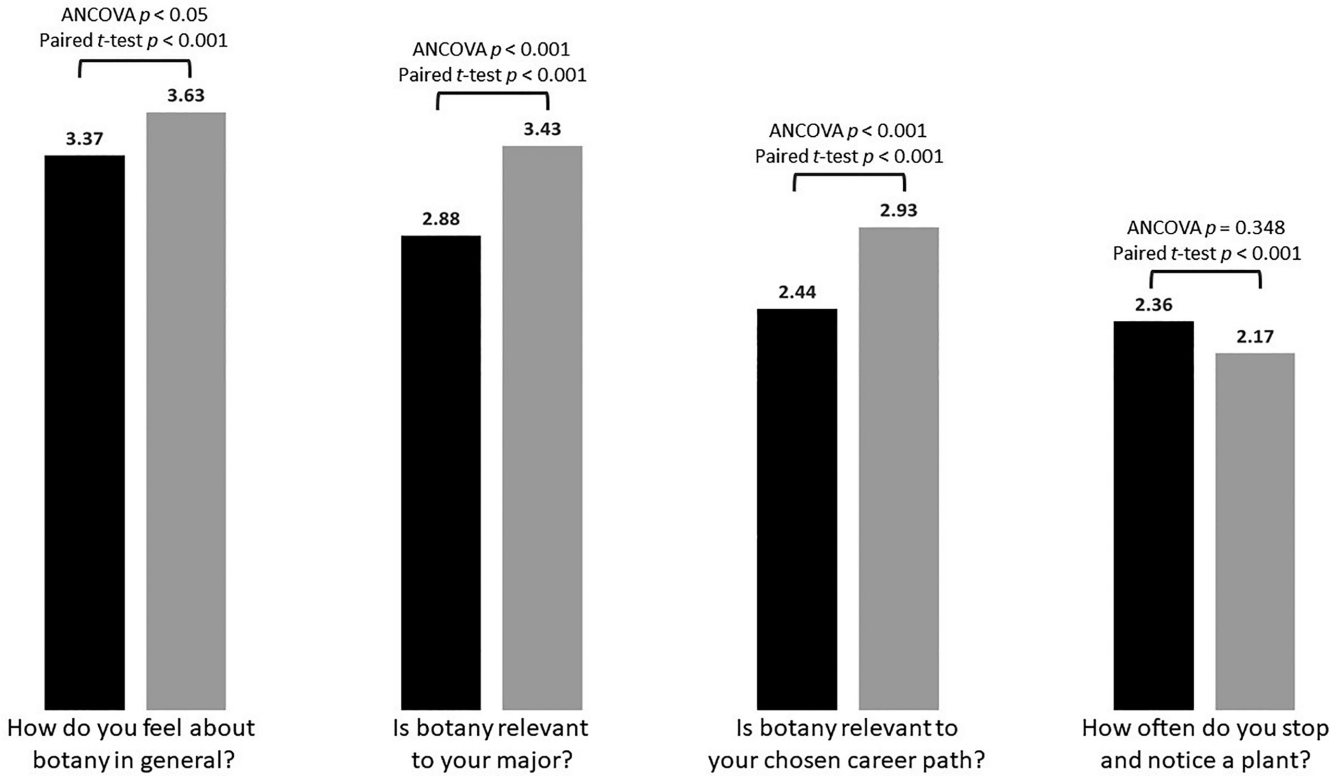

Figure 1. Statistical analysis of quantitative Likert-scale data for students who participated in the botanical experience. A five-point Likert scale was used (with 5 being the highest) for the questions* How do you feel about botany in general? Is botany relevant to your major? *And* Is botany relevant to your chosen career path? *The question* How often do you stop and notice a plant? *used an opposite Likert scale, with 1 being the highest, therefore a decrease in score represents a positive result. Paired* t*-tests were performed between pre- (black bars) and postcourse (gray bars) questionnaire data. An ANCOVA was performed between the pre- and postcourse questionnaire data. The data for students not participating in a botanical experience are shown in supplemental figure S6.

statistically significant ($p < .05$) differences in student postcourse responses between the botanical experience ($n = 258$) and the no botanical experience ($n = 55$) groups when adjusted for precourse scores; that is, the students who participated answered significantly higher in the postcourse questionnaire regarding their general interest in botany than did the students who did not participate. In addition, participating in the botanical experience was found to be a significant factor in the students' postcourse responses regarding their general interest in botany.

We asked the students to explain why they answered the Likert-scale question *How do you feel about botany in general?* the way that they did. These qualitative data were used to further understand the results we see in figure 1. Using thematic analysis, the research team read each short answer response and grouped them according to themes (figure 2; the student responses are shown in supplemental figure S7). It is important to note that these are qualitative data, allowing the students to answer with what was on their mind rather than selecting from a given set of choices. Therefore, a decrease in responses with qualitative data does not mean that fewer students chose that response. Instead, it means that fewer students specifically mentioned that response in their answer at the time they completed each questionnaire. Because of this, qualitative data are not as easily interpreted or presented as quantitative data. However, we are able to see some general trends.

In general, we saw a decrease in responses mentioning theme 1 (*I'm not really interested*) from the students immediately after participating in the experience, which persists through the end of the semester. We did not see a decrease with the students who did not participate in the botanical experience. In general, we saw a gain in the percentage of responses from the students participating in the botanical experience immediately after the experience with theme 3 (*I appreciate plants after seeing them in person*), theme 5 (*I see why plants matter*), theme 7 (*botany can be applied to other sciences*), theme 8 (*I enjoy learning about botany*), and theme 10 (*botany is easier to learn in person*). Unlike the qualitative results, these responses did not persist over time.

We saw a decrease in theme 4 (*I like the field of botany*) from the students participating in the botanical experience. It is important to remember that the students were telling us what was on their mind at the time they completed the

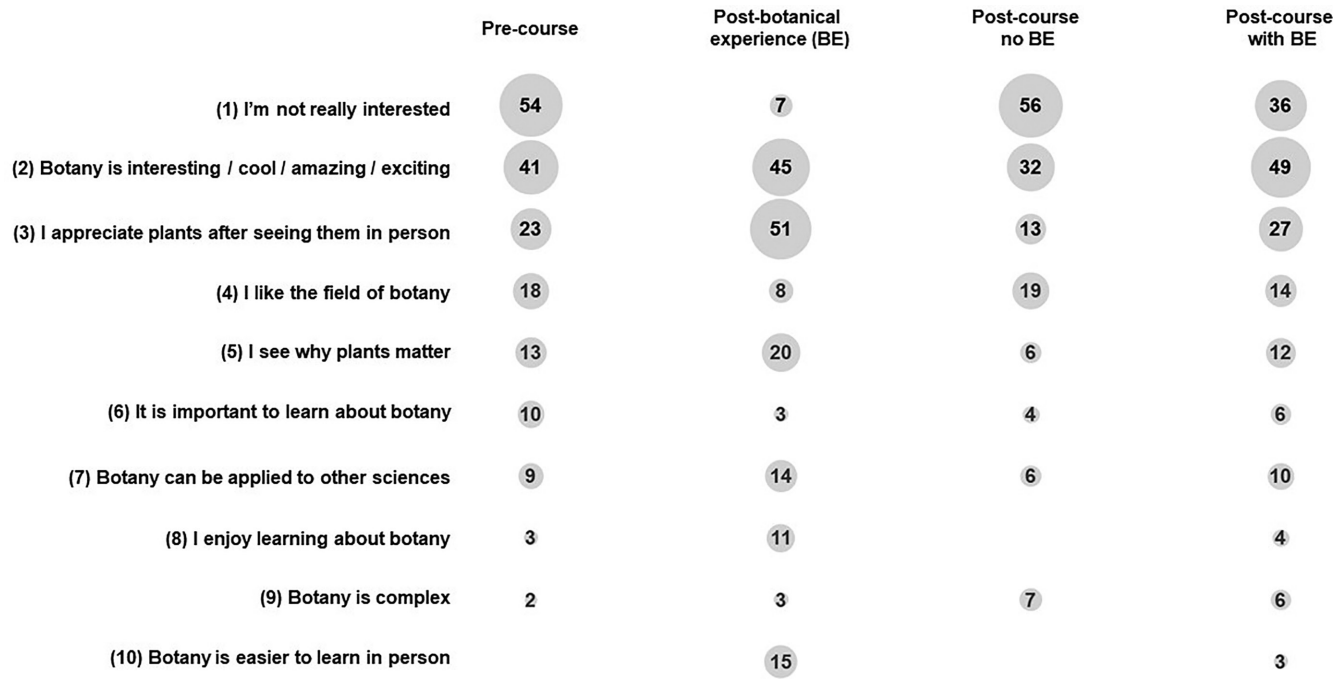

Figure 2. Student short answer responses to the question* How do you feel about botany in general? *The responses were coded using inductive coding, as was described in the text. The* y*-axis shows the 10 themes that were identified from the students' responses, and the* x*-axis indicates which questionnaire the students were completing. The data are shown graphically, with the area of each circle being representative of the percentage of students including each theme in their response (the exact percentage is noted within each circle). The students who included more than one theme in their responses had their responses coded to more than one theme. The individual student responses for this data set are shown in supplemental figure S7.

questionnaire rather than choosing a specific option or rating their agreement on a Likert scale. This result is likely due to the large increases we saw in themes 3 (*I appreciate plants after seeing them in person*), 8 (*I enjoy learning about botany*), and 10 (*botany is easier to learn in person*), suggesting that the students were expressing their interest in botany through these themes rather than truly exhibiting an actual decrease in liking the field of botany. This explanation is further supported by the rebound we saw in theme 4 at the end of the semester.

Do students see botany as relevant to their major or chosen career path? We used a five-point Likert scale to ask the students *Is botany relevant to your major?* A paired *t*-test shows a significant ($p < .001$) positive shift in the responses from those students who participated in a botanical experience ($n = 285$), with no change for the students who did not participate in a botanical experience ($n = 55$, $p = .096$; figure 1, figure S6). Because we surveyed the students at the end of the semester, likely several weeks after they had participated in the botanical experience, we also show that the impact of the botanical experience persists over time. We found the same results when we asked the students *Is botany relevant to your chosen career path?* with the students participating in the botanical experience showing a positive shift ($n = 285$, $p < .001$) and no change for the students who did not participate in a botanical experience ($n = 55$, $p = .0568$; figure 1, figure S6).

An ANCOVA showed statistically significant differences in student postcourse responses between the botanical experience ($n = 258$) and the no botanical experience ($n = 55$) groups when adjusted for precourse scores (*Is botany relevant to your major?* $p < .001$; *Is botany relevant to your chosen career path?* $p < .001$); that is, the students who participated answered significantly higher in the postcourse questionnaire regarding both the relevance to their major and the relevance to their chosen career than did the students who did not participate. In addition, participating in the botanical experience was found to be a significant factor in the students' postcourse responses.

We asked the students to explain why they had answered the career-focused Likert-scale question the way they did. The data from these responses were very difficult to reduce to coherent themes. However, when we looked more closely at individual responses, we began to see a pattern of how the students' attitudes and perceptions changed over the course of the semester and of how the quantitative and qualitative data did not always agree. From the fall 2018 data set, we identified eight students who represented the entire sample and answered all three questionnaires (table 2). We divided the students into three groups that we feel represent the study results as a whole: the students whose perception

Table 2. How the eight selected students compare to the total population of the fall 2018 data set they were selected from.

Gender/Major	Fall 2018 population	Eight selected students
Gender	70% female	87.5% female
Biology major	60%	50%
Biochemistry major	11%	12.5%
Environmental Studies major	3%	12.5%
Psychology major	7%	12.5%
Marketing major	1.5%	12.5%

of botany became more negative, the students whose perceptions of botany remained the same, and the students whose perception of botany became more positive (table 3).

Students 1 and 2 acknowledged botany in that they liked plants but showed little interest in botany beyond a very general understanding, and, despite the students' participation in the botanical experience, this negative perception persisted over the course of the semester. Although their quantitative scores remained steady for interest in botany, their qualitative responses remained negative. With regards to botany being related to their career path, these students entered the course believing they would not need botany in their future careers, and again, despite participating in the botanical experience, they exited the course feeling the same way. Their already low quantitative scores dipped lower, and so did their corresponding qualitative responses (table 3, students 1 and 2).

Students 3, 4, and 5 remained essentially unchanged in their perceptions of botany across the semester, despite participating in the botanical experience. Although students 4 and 5 showed a decrease in their quantitative scores for interest in botany, the qualitative responses for all three students remained unchanged before and after the course. All three students had the same career score before and after the course, and again, despite participating in a botanical experience, their qualitative responses remain unchanged (table 3, students 3–5).

We saw a quantitative gain in student 7, with no changes for students 6 and 8, with respect to interest in botany, coupled with slight qualitative gains for students 6 and 7. Where we saw large gains with this group was in regard to their connection of botany to their future career path. We saw this both quantitatively and qualitatively, because all three students connected their premed future careers to botany at the end of the semester. Although the data analysis necessary to determine the percentage of students pursuing health-related careers reporting quantitative and qualitative gains with respect to career relevance and botany was beyond the scope of this project, anecdotally, we believe the prehealth majors benefited the most from this aspect of the botanical experience.

How often do students notice plants? Our second research question was whether participating in a botanical experience enabled the students to notice the plants in their own environment. We used a five-point Likert scale to ask the students *How often do you stop and notice a plant?* This question was coded differently from the other questions in figure 1 (1, *very often*; 2, *often*; 3, *sometimes*; 4, *rarely*; 5, *never*), which is why a decrease in score is a positive result. A paired *t*-test reveals a significant shift ($p < .001$) in responses from the students who participated in a botanical experience ($n = 258$), with no change for the students who did not participate in a botanical experience ($n = 55$, $p = .1609$; figure 1, figure S6).

An ANCOVA did not show a statistically significant difference in the students' postcourse responses between the botanical experience ($n = 258$) and the no botanical experience ($n = 55$) groups when adjusted for their precourse scores ($p = .348$). Participating in the botanical experience was not found to be a significant factor in the students' postcourse responses regarding how often they noticed plants. Taken together, these data suggest that the botanical experience had some impact on the students noticing plants in their own environment, but it was not quite significant. We did not ask any follow-up qualitative questions to accompany these data.

How do students view FTBG as a place to learn botany? Our third question was whether participating in a botanical experience enabled the students to appreciate the aesthetic and unique biological features of plants. We collected data only from the students who participated in the botanical experience ($n = 474$).

We asked the students to describe how they viewed FTBG as a place to learn botany, as a way to collect qualitative data on the students' perception of the aesthetics and unique biological features of plants, and we found that the students overwhelmingly enjoyed their experience at FTBG (table 4). Representative quotes showing the students appreciating the aesthetics and unique biological features of plants, as shown in the bold and italics text in table 4, are found in almost every theme, suggesting that most of the students were able to experience this. Because there was no specific mention of plants in the question prompt, the students mentioning or describing plants in their response suggests that the botanical experience truly resonated and influenced their perceptions.

Although we were not attempting to measure this directly, a number of student responses mentioned both the amount of plants and the diversity of plants. Although this is somewhat tangential to our research question, we consider these important data. The students' realization regarding the diversity of plants is shown in bold in table 4 and further suggests that the students became more appreciative of

Table 3. Eight students were selected to represent the general data we saw from the fall 2018 data set relating to how students feel about botany in general and how botany is relevant to their future career plans.

			How do you feel about botany in general?			Is botany relevant to your chosen career path?		
Change in score	**Student**	**Career**	**Pre-/post-Likert scale responses**	**Precourse quote**	**Postcourse quote**	**Pre-/post-Likert-scale responses**	**Precourse quote**	**Postcourse quote**
More negative	1	Environmental consulting	4/4	I do love plants and flowers, but they're not my passion	I like plants in general, I wouldn't want botany as my career path but I don't hate it, I also just don't love it	2/1	I plan to work in a more specific field where I can solve environmental problems with natural resources.	Because my future Career has nothing to do with plants
	2	Medicine	2/2	I like plants but not the specific characteristics of them and I don't know if I would like to study about those specific things everyday	I don't really like it because it goes too in depth. I like the general things	2/1	For my career plan I won't be needing botany in the process	My career path has nothing to do with botany, it has to do with people
Stayed the same	3	Medicine	3/3	It's interesting	When I was participating in the Fairchild expo I found the whole thing interesting.	1/1	My career path focuses on the human body not on plants	Botany is not relevant for my chosen career path since medicine doesn't really dabble into botany I personally don't consider it relevant to my career path.
	4	Toxicology	5/3	I like plants, nature, and gardening a lot and would like to learn more. I've visited botanical gardens before and enjoyed it greatly.	I find botany interesting	2/2	My current career choice isn't very related to botany; toxicology is more related to chemistry and physiology.	I want to have a career in forensic science or toxicology so botany isn't very relevant
	5	Market analysis	4/3	I feel like I would like botany if I knew more about it but my current lack of experience keeps me from enjoying the study.	I like botany because it's interesting learning about plant biology and relating it to the environment as a whole. Many concepts were new to me and I thought I should've known more about botany.	2/2	My chosen career path does not involve botany; though there is a possibility that botanist need to consider marketing and advertisement to make choices about their craft.	My chosen career path is entrepreneurship or possibly being a market analyst for a business. Since I am not positive about which a specific business, it could include botany but it's not definite.
More positive	6	Medicine	3/3	I would like to learn a bit more about the care for the plants I grow	I like to garden specular succulents and different angiosperms, it is interesting to learn about my interests	1/3	For my career path I will be dealing with human patients I will need to understand medicine, pathology, patient care, etc.	Plants provide us with new resources for research on the creation of new medicines to help patients. This is important to understand for pre med students
	7	Dentistry	2/4	Plants don't really interest me	In the lab, I prefer animal work. However after visiting Fairchild Gardens and learning interesting case studies I like it more now.	1/4	I am a dentist and do not believe botany will help	I am premed track and plants provide medicine
	8	Medicine	2/2	I appreciate the topic but I don't enjoy learning about it.	I don't enjoy studying plants because the topic does not interest me as much as other aspects of biology.	1/4	I feel like I don't need to know about plants in order to be a doctor but I may be proven wrong.	It's because some of the medicine used now a days has components of botany. Some plants play a big role in medicine.

Note: The Likert-scale responses were on a five-point scale, with 5 being the high score, for each student in parallel with the qualitative data shown to the right.

Table 4. Student responses to the prompt **Please describe how you view FTBG as a place to learn botany.**

Theme	Percentage of responses	Example response
Great place to learn botany	46	I believe Fairchild Tropical Botanical Garden is an excellent place to learn botany, with its strong involvement in research, outreach into the community, commitment to education throughout its school projects, its tours and **diversity of plants**.
		I think this is the perfect place to learn about plant biology. Sometimes concepts regarding plants can seem boring or complicated but ***this experience showed me that plants are actually fascinating and beautiful***. It's amazing to learn while actually being able to see the concepts literally come to life.
		I think Fairchild is a great place to learn botany. It is the only tropical garden in the US apart from Hawaii. It also has labs where they study the genes of plants and test different experiments. It has both the visual learning experience and a laboratory experience that give you a full understanding of botany and the studies behind it.
Large amounts of plants	43	I feel that it is a great place to learn about botany because it has a very large and **diverse collection of species** that are present. A lot of these species are not native to Florida which makes coming here a special opportunity.
		I believe it is excellent. **It has many different plants ranging from very exotic to not very exotic endangered to common and harmful to helpful**. The things that can be learned here are very diverse and enjoyable
		The **diversity in Fairchild Tropical Botanical Garden was very much noted**. The instructor make sure to ask every question you might have and give you so many facts about each and every plant, palm, leaf, etc. It is a friendly environment with research opportunities that help you grow educationally.
Can visualize what was taught in class	14	It helps facilitate learning in that ***you are seeing what you are learning***. The vocabulary and terms you learn in class come into perspective when you are seeing them in real life.
		Fairchild was a great place to learn about botany because you ***get a firsthand look at things that are hard to describe in class through pictures***. You are also very stimulated and are more likely to pay attention and get to really experience it from any angle you please. You also come up with questions you may not have thought of in class.
		It is a place where ***you can do more than just look at a PowerPoint and hear names, at Fairchild you actually experience different rare species of plants*** and you can see the path of evolution through a tour. Such as seeing the evolution from ferns to cycads, how they started producing seeds through leaves. ***We got to see the missing link cycad that actually showed this evolution and it really put synapomorphies on a whole different perspective for me. We also got to see primitive plants with only one vascular tissue and that was very interestin***g.
Hands on botany experience	13	I believe that it is a very ideal place to learn botany, since it shows a large variety of plant species from all around the world, yet still also focuses on the native Florida plants. ***Being able to physically touch and see the plant makes learning about much more easy and interesting,*** rather than just looking at pictures.
		I think Fairchild Gardens has an immense array of plants available, and directly highlights all the information we learned during lecture. ***With the tour guide, you can physically see the pieces of the plants, from the cones of the gymnosperms to the spores on the leaves of the early primitive plants.*** You learn much more when you can physically see and touch the plants you see in class. The tour only went through half an acre, and the gardens are apparently 80 something acres. I can't even imagine the amount of plants located throughout the gardens.
		Fairchild provides a hands-on experience place to learn botany. It is easy to connect concepts from the lecture outside of the classroom as ***one can visually see and feel the plants***.
Botany laboratories in the garden	9	It's a perfect place to learn botany. To the many plants they have growing here and many more to come to the labs and research facilities they have on site.
		It has many research opportunities for students to work with scientists to ***understand the dynamics of certain plant species*** and how to preserve certain species that are endangered. A very good place to learn especially for a medical major student as myself. It could broaden my knowledge on plant medicine.
		Fairchild is a great place to learn botany because they have an abundance of research projects going on and data stored on all the tagged plants. Plants from all over and they are grown in certain labeled plots making it easy to find and go back to, to track that specific plant or species.

Note: The data were collected from students immediately following the experience (n = 474). Themes resulting from inductive coding are shown in the first column. Students who included more than one theme in their responses had their responses coded to more than one theme. Quotes directly relating to the aesthetic and unique biological features of plants are in ***bold italics***. Quotes relating to diversity of plants are in **bold**.

plants and more aware of the diverse and unique characteristics of plants, an important element of reducing plant blindness.

Did this botanical experience allow the students to see botany (the subject) in a real-life setting? We opted to code answers as either positive or negative feedback from the students (table 5). The student responses showed that, yes, the botanical experience overwhelmingly allowed them to see the botany they learn in class in a real-life setting. Representative quotes where we again see the students showing signs of appreciating the aesthetics and unique biological features of plants are shown in bold in table 5.

Did the botanical experience allow the students to see botany (the subject) as bigger than a classroom? Although we intended

Table 5. Student responses to the question **Did this botanical experience allow you to see botany (the subject) in a real-life setting?**

Theme	Percentage of responses	Example response
Positive response	98	Yes definitely!! We saw so many examples of plants we learned about in class. I recognized a lot of them before the tour guide even told us about them. **It is so cool to walk around now and know information about certain plants that I didn't know before.**
		Yes it did and it was very impressive, I didn't expect to feel so passionate about learning in that setting but it was so engaging and fun that it really helped me to see things that I would otherwise probably forget, such as monocots and dicots. **We actually got to see the synapomorphies change from ferns to cycads and the process that took hundreds of years all in one tour.** All the plants that we saw such as the palms and the ferns and cycads, we had actually covered in class and it was good to see how the reproductive processes actually work in real life.
		Yes it did, **I was able to see the pictures in my textbook and on PowerPoint slides in real life which makes it much more interesting to learn topics in class.** I now know why Dr. Ortega is so enthusiastic about what he studies, and it has created an interest in me to potentially study it, or at least become very well versed in botany.
Negative response	1	No, I think there is a lot variety of plants that you can learn from it.
		We haven't learned too much botany yet so I don't know.

Note: The data were collected from students immediately following the experience (n = 474). The themes resulted from inductive coding are shown in the first column. The students who included more than one theme in their responses had their responses coded to more than one theme. Examples of where we see students showing signs of appreciating the aesthetics and unique biological features of plants are shown in bold text.

Table 6. Student responses to the question Did the botanical experience allow for you to see botany (the subject) as bigger than a classroom?

Theme	Percentage of responses	Example response
Increased interest and understanding	74	Yes, botany or ethnobotany is greater than what you learn in the classroom. **Not only are you learning about the system of plants but how they are incorporated with humans and animals and other living beings.**
		Yes. In class I just assumed that plants don't do much in our world and just help to breathe but they help all around in life. We consume various amounts of different plants, seeds or fruits. Which help us stay healthy and even cure some diseases.
		Yes, it intertwined day-to-day life, medicine, and botany. It made me think deeper into biology and how botany plays a big role.
New respect for plants	30	Yes, because in the tour, rather than just explaining the functions of the plant (such as how it reproduces), **it also explained how humans and other animals interact with the plants as well as their importance in their environments and the history it has in cultures of different societies.** An example being how *Pseudophoenix vinifera* is used for its sap, or how all the parts of the zombie palm are used in its native land.
		Yes, it showed me that my knowledge in botany can be applied to many other careers such as medicine. For example, when the people started getting mental diseases such as dementia, Alzheimer's and Huntington's in Guam doctors figured out that they were consuming bats that ate cycad, which is toxic to humans.
		Definitely. This tour taught me a lot about all the different significant roles of plants in society. They not only provide oxygen and food for humans, **but they also aid in cultural practices and rituals they help in medicine and remedies for disease. They also cause disease at times, which is where research and studying of plants is so important.**
No	0.21	Not necessarily. The reason being is because my teacher does a very good job on showing the importance within each thing he teaches. So coming to this tour just showed me again how big botany is.
		No because I already knew that there was more to botany than just slides and what we do in lab.
		Not really. I personally just see plants as plants and trees as trees so the same ones we've observed here were almost the same ones from lab.

Note: The data were collected from students immediately following the experience (*n* = 474). The themes resulting from inductive coding are shown in the first column. The students who included more than one theme in their responses had their responses coded to more than one theme. Specific instances of students better recognizing the importance of the study of plants in human affairs are noted with bold text.

this question to be a part of research question 3, we mainly saw connections to research question 1 in these data,—specifically, the students better recognizing the importance of the study of plants in human affairs, as was shown in table 6 in bold. Because mentions of the importance of the study of plants in human affairs was mentioned across both themes and was not specifically mentioned in the question prompt, we conclude that the botanical experience did enable the students to better recognize the importance of the study of plants in human affairs.

Table 7. Student responses to the question **What was the most memorable moment of the botanical experience?**

Theme	Percentage of responses	Example response
Butterfly garden	56	The butterfly garden was pretty neat, I got to touch a butterfly and let it spit on me! Very cool, very scientific
		The butterfly garden. I didn't know butterflies can be so big. Also I didn't know when they stick on you that means they like you and can feed off with their feet
		Most memorable moment of this tour was the butterfly garden as it had a diverse amount of butterflies that are nonnative to Florida. This was memorable, as I have never seen some of those butterflies before, not even on the internet. Also the fact that butterflies were attracted to my shorts for some reason.
Specific or general names of plants	28	The zombie palm was my favorite to learn about and the *Pseudophoenix vinifera*. They both come from Hispaniola and they have very interesting backgrounds for their use.
		I really enjoyed talking about the baobab tree aka the resurrection tree. In places where this tree is native (Africa and Madagascar) it has a huge importance in the lives of people. This tree not just serves as shelter and form of nutrition due to its fruit with a high level of vitamin C but it also serves as religious purposes in many places in which the deceased are buried next to it.
		The Brazilian nut tree, and the fact that has tea that can make you hallucinate
Orchids	18	The most memorable moment was when we went to learn about the orchids. It was cool to walk into the lab and see how they are growing the orchids without fungi. It was also interesting to learn the process of growing the orchids.
		The most memorable moment was learning about orchids and the way they are able to simulate the pseudopheromones in order to attract pollenators.
		Seeing the orchids. Orchids always seemed like basic decorative house plants but are diverse unique species that are very beautiful.
Walking and engaging with the garden	16	I really enjoyed walking into the exhibit with the fern trees. I didn't know such things existed. There were many plants in that exhibit that I have never seen before and sparked my interest in learning more about their structures and adaptations.
		The butterfly garden was spectacular, however I truly enjoyed walking through the greenhouse. There was a unique collection of plants that I had never seen before. Most descended from Asia or the Caribbean. It opened my eyes to the diversity of plants and their adaptations.
		The walk around the garden, where one experiences the rich history behind the plants we learned about.
Research in real life	13	I really enjoyed the orchid lab, as I am interested in participating in botany research while I go through school. I found it interesting how they are finding different combinations to propagate native Floridian orchids.
		I really enjoyed the butterfly exhibit, but I think that seeing the million orchids project lab was the highlight of the tour. I want to go into research in the future, so it was cool to see how a lab worked in a botanical garden. I also think that the idea of the million orchids project is really cool; I hope that it continues to be a success.
		Going into the lab and understanding how botanists use equipment to research and also the new technology of finding the entire genome of a plant was incredible to see take place in a lab.
Topics discussed in class	7	The most memorable moment of the tour for me was **being able to see the product of hybridization with the *Zombia* and *Cocothrinax* plant and having a physical display of an essential genetic concept: dominant alleles.**
		Understanding how the trees actually go through their meiosis and mitosis and actually comprehending it by seeing it close
		Seeing the lifecycles introduced in class such as sporangia and sporophytes
Getting to connect with the professor	2	The passion and knowledge the tour guide (Dr. Ortega) had in giving the tour most definitely improved the tour and is, in my opinion, essential to a successful tour.
		Besides the butterflies, the most memorable part was that I could get close to my professor and ask him questions in a small group and look at the plants face to face as well
		Seeing Dr. Ortega explain *Boswellia sacra*, his excitement was very inspiring on how it's useful for religion and medicine.

Note: The data were collected from students immediately following the experience (n = 474). The themes resulting from inductive coding are shown in the first column. The students who included more than one theme in their responses had their responses coded to more than one theme. Quotes called out in the text are in bold.

What was the most memorable moment of the botanical experience for the students? The data for this question bring all three of our research aims together (table 7). We saw student responses relating to research question 1 (the importance of the study of plants in human affairs), such as the following:

"I really enjoyed talking about the baobab tree, aka the resurrection tree. In places where this tree is native (Africa and Madagascar) it has a huge importance in the lives of people. This tree not just serves as shelter and form of nutrition due to its fruit with a high level of vitamin C, but it also serves as religious purposes

in many places in which the deceased are buried next to it."

We saw responses in which the students noticed plants in their own environment (research question 2), such as this:

"Seeing the orchids. Orchids always seemed like basic, decorative house plants but are diverse unique species, that are very beautiful."

Finally, we saw responses in which the students appreciated the aesthetic and unique biological features of plants (research question 3), such as the following:

"Being able to see the product of hybridization with the *Zombia* and *Cocothrinax* plant, and having a physical display of an essential genetic concept: dominant alleles."

What do our data tell us?

As comprehensive botany education declines and career paths that need and benefit from a botany-literate workforce increase, the focus on reducing plant blindness is becoming a critical function of general biology courses (Woodland 2007, Drea 2011). Because of the lack of a validated assessment for measuring plant blindness directly, we relied on quantitative Likert-scale questions in combination with qualitative short answer responses to indirectly measure student changes in plant blindness. In the present article, we provide evidence that participation in a botanical experience as part of a general biology course can increase the positive perception of botany and shows promise for alleviating plant blindness.

We saw significant increases in the students' positive perception of botany in general for the students participating in the botanical experience, with no change in the students who did not participate (figures 1, 2, S6, and S7, table 5). We saw similar shifts in data for the students connecting botany to their majors and careers (figures 1 and S6, table 3). We saw further evidence of these trends in the qualitative data collected at the end of the botanical experience (table 4, theme of botany laboratories in the garden; table 6, themes of increased interest and understanding and new respect for plants). These data remain an indirect measure of plant blindness, but we are encouraged that participating in a botanical experience did enable the students to better recognize the importance of plants in human affairs.

Although they were not quite significant, we saw students participation in a botanic experience more frequently noticing plants (figures 1 and S6). Again, although this remains an indirect measure of plant blindness, we are encouraged that participating in a botanical experience enables students to notice the plants in their own environment.

Through a series of qualitative data, we detailed the students' responses to being able to experience the botany presented in their Gen Bio 2 course through a botanical experience (tables 4–7). We saw examples of the students describing how they viewed their course material in a different light after they had seen plants in real life (table 4, theme *I can visualize what was taught in class*; table 5, theme *positive response*; table 7, theme *topics discussed in class*). We saw examples of the students describing a new appreciation of plants (table 5, theme *positive response*; table 6, themes *increased interest and understanding* and *new respect for plants*; table 7, theme *orchids*). We saw examples of the students appreciating the wide diversity of plants (table 4, theme *large amount of plants*; table 7, theme *walking and engaging with the garden*). Finally, we saw several mentions of the unique biological features of plants (table 4, theme *can visualize what was taught in class*; table 5, theme *positive response*; table 7, themes *orchids* and *topics discussed in class*). Collectively, these results suggest that participating in a botanical experience enabled the students to appreciate the aesthetic and unique biological features of plants.

Overall, we believe that two specific design aspects of our botanical experience proved successful. First, focusing on plants possessing some exceptional traits—that is, exceptions to biological rules—caught the attention of the students, as was shown in this student response from table 4: "We got to see the missing link cycad that actually showed this evolution and it really put synapomorphies on a whole different perspective for me. We also got to see primitive plants with only one vascular tissue and that was very interesting." This student was referring to ferns, which transport water via tracheids and which are also found in cycads, some of these cone-bearing gymnosperms lack cones. The students were able to visualize how ferns and cycads have evolved into the more advanced gymnosperms.

Second and perhaps most important, identifying plants with high human connections really seemed to resonate with the students. This is shown extensively in the students' responses in tables 6 and 7, where numerous examples of the students connecting plants to both human health and disease and human cultural rituals are presented.

For fellow educators who are interested in implementing a similar botanical experience on campuses and in areas without a collaboration such as the one we have with FTBG, we recommend that you select plants using these design principles. It is not necessary to have access to tropical plants; many different plants exhibit biological exceptions, and many different plants connect to humans. We encourage you to select plants native to your specific regions. For example, we asked the students to look at *Sabalites* and *Sabal* fossils from Wyoming, tropical species of palms that were not from the tropics, therefore supporting the boreotropical hypothesis. In addition, carnivorous plants, which are native to bogs throughout the Northeast, would be great examples, as would parasitic plants, such as mistletoe, which don't use roots for the uptake of water but instead extract water and nutrients from their host.

Finally, we have found that allowing time for the students to walk among the plants and to be able to ask spontaneous questions enhanced the students' engagement. Time and

space to wander and think are not restricted to botanical gardens; they will be available in any version of a botanical experience offered to students in any location.

Conclusions

Moving forward, we aim to gain a more comprehensive understanding of the data relating to how often students notice plants. This was our one data set that was not quite significant, and further data collection can help us understand why. We envision collecting additional data both quantitatively (e.g., *How many plants do you notice each day? Please select plants you notice from the following list.*) and qualitatively (e.g., *Can you please list plants you notice each day (or recently)? Can you describe how you noticed a plant today (or recently)?*)

In this current implementation of botanical experiences, we adapted research question 1 from our definition of plant blindness "the inability to recognize the importance of plants in environmental and human affairs" to focus mainly on human affairs. Moving forward, we will begin to include more tour content and more assessments on the environmental side of this definition.

There are several limitations to our study—primarily, the lack of a validated plant blindness assessment tool. When such a tool becomes available, we will implement it in parallel with our current assessments. Currently, we do not have any information on the motivation of the students who participated in the botanical experience, and more information on this will be valuable for our data analysis and interpretation. Finally, we realize that we are in a unique position to be located so close to a premiere botanical garden and appreciate that many institutions will be unable to directly replicate our study.

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Supplemental material

Supplementary data are available at *BIOSCI* online.

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