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Summary

- Understanding plants and how they affect the world is crucial. However, plant awareness disparity, the inability to notice plants, is common and results in lack of interest and positive attitudes toward plants and knowledge on their importance. Innovative and engaging plant science curricula is limited while needed to promote plant awareness. We created a 3D plant modeling module and examined its impact on plant awareness among high school students.

- This module integrates science, art, design, and technology through a project-based STEAM approach where teachers acted as facilitators and students worked collaboratively. Students investigated the biology and importance of plants, created 3D plant models, experienced the application of 3D modeling in augmented and virtual reality platforms, and disseminated their results. Before and after the module, students completed the Plant Awareness Disparity Index and answered reflection questions about its components—attention, attitude, relative interest, and knowledge.

- Quantitative analysis revealed that after completing the module, more students had positive statements about attention, attitude, and knowledge about plants and showed higher relative interest toward plants than animals. Student reflections showed that plants were the most notable feature outdoors, and students had mainly positive feelings toward plants. However, many students wrote that animals were more interesting than plants. Most students acknowledged the importance of plants for humans and the environment.

- Our results indicated that our 3D plant modeling module positively influenced student plant awareness. This module can be implemented in any educational learning environment for high school students, including in-person and virtually.

Keywords: 3D modeling, high school students, plant awareness disparity, plant science, STEAM

Societal Impact Statement

Even though plants are the foundation of the food web, essential for the air we breathe, and provide valuable resources, people tend to disregard plants and their significance to society. Plant awareness disparity can negatively impact students' interest in plant science and agriculture, adversely affecting students' pursuit of botanical careers. Plant awareness disparity can also negatively affect plant conservation, habitat preservation, and global challenges such as climate change and food security. Educating the public on the importance of plants is essential so that citizens can make informed decisions that could influence policy affecting environmental conservation.

1. INTRODUCTION

1.1 Plant awareness disparity and fostering plant awareness

In a world where climate change, deforestation, food security, and sustainability are prevalent in the media, the general population lacks an appreciation and a basic understanding of how plants contribute to our environment and society. Even though scientists have cataloged 350,386 vascular plants worldwide, with new species still being discovered, people often fail to notice plants (Wandersee & Schussler, 1999). This phenomenon is known as plant awareness disparity (PAD, previously called plant blindness, Parsley, 2020). Since individuals do not notice the plants around them, they do not feel connected to plants and recognize their relevancy in their lives (Parsley, 2020; Wandersee & Schussler, 2001, 1999). With PAD, people prioritize other things in their surroundings, such as animals, and find them more meaningful and superior to plants (Hershey, 1996; E. E. Schussler & Olzak, 2008). If given a choice, students would naturally gravitate toward animals, especially mammals, and be more interested in learning about them over plants because animals are more similar to themselves and, therefore, more relatable (Antonelli et al., 2023; Kinchin, 1999; Wandersee, 1986). People also have little appreciation for the aesthetic and distinctive biological attributes inherent to plant life (Wandersee & Schussler, 1999).

Plants and their contributions to the biosphere and human affairs are not prioritized. Even though funding for animal and plant conservation is inadequate, organizations that promote the preservation of wildlife and endangered species still receive more funding than organizations devoted to plant conservation and preserving plant biodiversity (Havens et al., 2014). Plants do not garner the public's attention in the way that larger, charismatic animals do. Plants are essential for human survival since they provide food, oxygen, resources, and shelter. Yet, native habitats are being destroyed to make room for living space and farms. The more extreme weather conditions due to climate change adversely affect plants by lowering food productivity and promoting the spread of harmful invasive species (Janni et al., 2024). Failing to recognize the biological importance of plants could have dire consequences for the planet's health and our species.

PAD has significant implications that affect both educators and students alike. Little to no interest in plant science stems from PAD and the limited plant-based curriculum, how plant science is taught, and a teacher's own bias toward teaching plant biology (Hershey, 1996). Teachers need to foster plant awareness in their classrooms but often have little knowledge and training in botany and related subjects (Bozniak, 1994; Çil & Yanmaz, 2017; Hershey, 1996).

Increased training for pre-service teachers has been one avenue for improving PAD (Fiel'ardh et al., 2023). Teachers tend to focus on math and reading in preparation for standardized tests and, therefore, have less instructional time to emphasize science. Plant content is a small portion of the overall curriculum, and textbooks and other materials have a disproportionally large amount of animal examples and photos compared to plants (Link-Pérez et al., 2010; E. Schussler et al., 2010). The plant curriculum is incomplete and often focuses on structure and function with little emphasis on the relevance of plants to students' lives (Amprazis & Papadopoulou, 2018).

For decades, educators have been facing an uphill battle with finding ways to effectively combat PAD through fostering plant awareness inside and outside their classrooms. Depending on the level of plant exposure as a young child, a student's definition and understanding of what a plant is can be very limited (Barman et al., 2003; Gatt et al., 2007). Even before entering the classroom, students are already predisposed to recognize more animal names than plant ones (Kose, 2011; Patrick & Tunnicliffe, 2011). Factors such as background, prior experiences, and exposure to nature contribute to a student's understanding and familiarity with plants. For example, a plant mentor, like a teacher or parent, can greatly influence a student's current and future perspectives on plants (Jose et al., 2019; Wandersee & Schussler, 2001). Modeling an appreciation of plants and their importance is necessary for fostering a love of plants at an early age.

Educators have fostered plant awareness through hands-on and place-based learning to allow students of various age groups to interact with plants directly and gain a greater appreciation of plants in formal and informal educational settings. These experiences have included outdoor educational programs, visits to botanical gardens, and in-class projects. For example, elementary students from a Slovakian elementary school worked alongside forest experts to plant three different tree species, including the national tree, at their school. They learned about forest ecology through lectures and interactions with experts (Fančovičová & Prokop, 2011). This outdoor program positively influenced students' attitudes toward and knowledge about plants, but the sample size was small. In another study, sixth grade students were divided into two groups. One group created picture books about plants with exciting features, and the other group visited a botanical garden and completed activities before, during, and after the visit (İri & Çil, 2020). Even though both approaches improved students' attitudes toward plants, creating a picture book resulted in greater effects. Undergraduate students from a general biology course also toured a botanical garden to illustrate concepts from class and highlight the connection between botany and their own areas of study (Colon et al., 2020).

These students were particularly drawn to plants with interesting traits and plants relevant to humans. In another undergraduate course, students were tasked with growing a plant from seed and monitoring its development while relating lecture concepts to their "pet plants" (Krosnick et al., 2018). This hands-on approach significantly decreased PAD among students, with heightened appreciation and attention toward plants. Many students expressed intentions to cultivate more plants in the future, highlighting the efficacy of experiential learning in fostering a deeper connection with plants.

1.2 Promoting plant awareness through STEAM+Ag® educational opportunities

The plant science community needs to raise awareness about the significance of plants in human affairs and the critical importance and growing need of botanical professionals (Sidoti et al., 2023; Walsh et al., 2023). Collaborations between educators and botanical gardens, non-profit organizations, and research institutions can be an impactful way to foster plant awareness and educate students and the broader community (Krishnan et al., 2019). One notable institution in this effort is the Donald Danforth Plant Science Center (DDPSC) in St. Louis, MO, a non-profit research institution dedicated to improving the human condition through plant science. The Education Research and Outreach Laboratory (EROL) at DDPSC promotes plant and agriculture science education to inspire the next generation of plant scientists. EROL strives to foster plant awareness by promoting enriching, engaging STEAM+Ag® (science, technology, engineering, art, mathematics, and agriculture) educational initiatives. EROL conducts education research, leads teacher professional development workshops, participates in outreach events with the general community and schools, hosts field trips, and offers authentic research experiences (AREs) and course-based undergraduate research experiences (CURE). Through AREs and CUREs, students participate in meaningful research projects that can contribute to ongoing research DDPSC. EROL offers multiple AREs (e.g., Genotype to Phenotype, Discover Volvox Development, Mutant Millets, and Plants Fight Backs) to thousands of middle school and high school students (Arango-Caro et al., 2024). Teachers can implement AREs in their classrooms as part of their course curriculum. AREs have also been done at STEM events and during field trips to DDPSC. Classes can participate in field trips and touring DDPSC's state-of-the-art facilities, meet scientists, learn about plant science research and its relevancy to the community, and hear about scientific career pathways. Two CURES—Data Science and Transposable Elements and Thermotolerance—are available for implementation in undergraduate courses.

EROLs's Education Technology Program uses cutting-edge technologies to engage and inspire students to develop interests in STEAM+Ag® subjects and careers (DDPSC, 2024). Immersive educational experiences are offered through augmented and virtual reality experiences (AVR), 3D modeling, geospatial activities, and computer gaming. Through these STEAM+Ag® opportunities, students benefit from hands-on, real-world activities, see what scientists do, and learn why plant science and agriculture are vital for adapting crops to an ever-changing environment and ensuring food security.

1.3 STEAM education

Using a STEAM educational approach provides an excellent opportunity for students to learn about plants, fostering plant awareness while addressing the disconnect among science, art, design, and technology. STEAM education is an emerging discipline that integrates art and design into the STEM curriculum to encourage creativity, innovation, and design thinking (Henriksen et al., 2019; Liao, 2016). This approach moves away from the traditional view of students as separate identities, offering students a transdisciplinary and transformative learning experience where science, technology, engineering, art, and math are interwoven to achieve learning objectives. STEAM education offers meaningful engagement for students and educators through authentic learning experiences emphasizing student-centered approaches such as project-based learning. STEAM enables problem-solving within real-world contexts to better prepare students to meet the demands of economic competition (Guyotte et al., 2014; Land, 2013; Liao, 2016; Taljaard, 2016). Technology is rapidly evolving and transforming society and the workplace. Many professions will require workers to be digitally literate, manage large amounts of data, and learn and apply emergent technologies (e.g., artificial intelligence, robotics, AVR, and 3D and multimedia design) (Leavy et al., 2023). By seamlessly integrating STEAM disciplines and leveraging technology, students are empowered to assess problems from multiple perspectives. The workforce of the future will also need to think creatively and critically, communicate effectively, work collaboratively, and form social networks (Aguilera & Ortiz-Revilla, 2021; Ananda et al., 2023; Bertrand & Namukasa, 2020; Perignat & Katz-Buonincontro, 2019). STEAM learning approaches motivate students to become more proactive learners, promoting self-confidence and a sense of ownership (Lin & Tsai, 2021; Wahyuningsih et al., 2020).

1.4. 3D Modeling STEAM learning module

EROL's Education Technology Program team designed and implemented a 3D plant modeling module with high school students, highlighting the intersection of science, art, design, and technology. This project-based module positions educators as facilitators while students work collaborate in teams to research the biology and importance of plants researched at DDPSC, sketch concept art, create 3D plant models, participate in plant-related AVR immersive experiences, and disseminate their results. This module was designed to foster plant awareness among high school students, encourage interest in STEM careers and subjects, promote science communication and collaboration, and showcase the application of 3D modeling in AVR platforms. In this study, we investigated the impact of implementing this module in formal and informal high school learning environments on fostering plant awareness and enhancing students' appreciation and understanding of the importance of plants.

2. MATERIALS AND METHODS

2.1 Plant 3D modeling project-based module

To understand how science, art, design, and technology can be combined to enhance high school students' learning experience and interests in STEAM+Ag® subjects and careers, EROL created a project-based 3D plant modeling learning module. This module was designed as a learning-by-doing experience where educators acted as facilitators and students worked in collaborative teams. The module can be implemented over three weeks or one or two semesters in formal and informal settings across Missouri and Illinois. In this module, students investigated the biology, uses, and importance of plants researched at DDPSC; 2) created 3D models of those plants; 3) used AVR to explore the applications of 3D modeling; and 4) presented project results through handouts and PowerPoint or poster presentations. EROL created protocols and tutorial videos to facilitate the module's implementation in virtual and in-person settings.

After recruiting educators and discussing how to implement the module, EROL researchers introduced the project objectives and the module structure to the students virtually or in person. They also shared their career pathways and answered student questions. Students formed collaborative teams of three to five members, each self-identifying as science-, tech, or art-oriented students. Team roles—scientist, technophile, artist, and/or science communicator—were assigned based on individual interests. Students selected their plant species from a list of plants researched at DDPSC and decided on the plant part to model. They researched the biology and significance of their chosen plant species to society and its importance for DDPSC research. They were given the option to contact DDPSC researchers to ask questions about

their research on their species. Plant specimens were provided when available. Students examined their selected plant's structure and drew the concept art based on reference photos. Students self-trained in 3D modeling by watching tutorial videos created by EROL to learn the free, web-based 3D modeling software Tinkercad® and Fusion 360® (Autodesk Inc., 2023). An expert modeler was available for consultation. Students also practiced science communication in writing and verbally. They wrote a one-page handout of their chosen plant species based on their investigations and presented the results of their work during class time, a school event, or a scientific event.

During the module, students were invited to DDPSC for a field trip, during which they took a tour of the facilities and learned about STEM careers. To demonstrate the application of 3D modeling, students experienced augmented reality (AR) with zSpace and virtual reality (VR) with a head-mounted Oculus device (Oculus, 2023, zSpace, 2023). Students used an AIO zSpace and 3D glasses to complete a pollination and seed dispersal pre-made lesson. To explore VR, students immersed themselves in the "Soybean Saga to Food and Climate Security," a game developed by EROL researchers. In this immersive experience, students learned about the uses of soybeans, their reproduction, their role in nitrogen fixation, and the issues with synthetic nitrogen. In addition to gaining knowledge about the importance of soybeans, information about soybean research conducted at DDPSC was presented. All protocols and procedures for the module and details about the "Soybean Saga to Food and Climate Security" VR experience can be found at the DDPSC's Education Technology Program website (DDPSC, 2024).

This module was implemented in 10 educational institutions, including urban (private, public) and rural schools, and during informal education programs. From fall 2021 to fall 2023, 176 high school students completed the module (Table S1). Approximately half of these students identified as female while the remainer identified as male (34.7%) or did not specify gender (13.1%). Most students identified as white (42.6%). Hispanics/Latinos were the next largest group at 19.3%. Asian and African American/Black students were represented at 13.1% and 11.4%, respectively. A few students identified as American Indian/Alaska Native (1.1%), Native Hawaiian/Pacific Islander (0.6%), and others as mixed and biracial (4.5%). Several students (7.4%) did not provide their race/ethnicity.

2.2 Plant Awareness Disparity Index Assessment

To evaluate the impact of integrating science, art, design, and technology in student learning and interests in STEAM+Ag® subjects and careers, students completed pre- and post-

assessments and reflection questions. For this study, we focused only on student changes in plant awareness. We administered the Plant Awareness Disparity Index (PAD-I, Parsley et al. 2022) through Qualtrics^{XM} software (Provo, UT) before and after the module (S2). The assessment methodology was approved by DDPSC's Institutional Review Board. We used a mixed-methods approach of quantitative and qualitative analysis of the PAD-I. The PAD-I is a validated survey at the undergraduate level that we used here for the high school level. Collecting data at the high school level is the first step to validating PAD-I at this academic level. Only student responses that had student assent, parent consent from minor students, and both pre- and post-responses, if needed, were included in these analyses.

PAD-I is a survey instrument used to measure all four components of PAD: 1) attention, 2) attitude, 3) relative interest, and 4) knowledge (Figure 1, Parsley et al., 2022). Attention refers to whether an individual notices plants in the environment. Attitude is someone's feelings toward plants. Relative interest includes if a person finds plants or animals more interesting. Knowledge refers specifically to why plants are important. The PAD-I expands upon the original four components of PAD and is a six-factor model where the factors fit into the original four components.

The 25 Likert-type questions in the PAD-I survey are divided into these factors and reflect the negative and positive connotations toward plant awareness. The attention component includes the Attention Towards Plants factor and four general attention questions. The attitude component includes Positive Affect Toward Plants and Caring for and Investment in Plants, with three and five questions for each factor, respectively. The relative interest component has four questions about Plants Being Better than Animals and three about Animals Being Better than Plants. The final knowledge component has six questions about the Necessity and Importance of Plants. The Likert scale consisted of the following answer options with their corresponding scores in parenthesis: "completely disagree (1)," "somewhat disagree (2)," "somewhat agree (3)," and "completely agree (4)." Lower PAD-I scores indicate a higher level of PAD or a low level of plant appreciation. Higher PAD-I scores indicate a lower level of PAD or a high level of plant appreciation. Questions with negative connotations for plant awareness were scored in reverse. The PAD-I includes a quality-control question that instructs the students to select the answer "somewhat agree." Responses from students who answered this question incorrectly were excluded from the analysis since the student was likely not paying attention while completing the survey. Student responses were paired pre- and post-module and analyzed using a paired t-test for each of the 24 questions with a statistical calculator web application (Statistics Kingdom, 2017).

The PAD-I included four reflection questions in the pre- and post-survey and an additional question only in the post-survey. The reflection questions are:

1) "When you go outdoors, what types of features do you notice about the environment? (For example, what types of organisms do you see, do you notice human-made things, etc.)."
2) "What are your feelings towards plants in general? (For example, do you enjoy being around them, etc.)."
3) "Would you say that you find plants more or less interesting than animals?"
4) "In what ways (if any) do you think plants are important and why?"
5) "Has this course had any effect on your ideas regarding plants? If so, how?"

Student responses to these reflection questions were analyzed using a deductive coding method. This method uses a top-down approach to systematically categorize excerpts from students' responses based on recurring themes and patterns. Two coders read the answers and independently assigned code excerpts to build a codebook. The coders then compared and adjusted their codes to create a mutually agreed-upon qualitative codebook (S3). Frequencies and percentages of students reporting themes were summarized for pre- and post-responses in alignment with the reflection questions (Table 1).

3. RESULTS

3.1 Plant awareness increased after the completion of the module

Based on the responses from 70 students to the PAD-I survey's Likert questions, many students expressed high plant awareness at the beginning of the module, and more students reported plant awareness themes after the completion of the module (Figure 2). However, responses varied across the different PAD-I factors (e.g., Attention Towards Plants, Caring for Plants, Plants Better than Animals, etc.) and between pre- and post-responses. Completely Agree and Agree responses indicate higher plant awareness, while Disagree and Completely Disagree responses indicate lower plant awareness (Figure 2). For the factor Necessity or Importance of Plants (Necessity), 97 to 99% of pre- and post-responses ranged from Completely Agree to Agree. For the factors Positive Affect toward Plants (Affect), Attention toward Plants (Attention), and Caring for or Investment in Plants (Caring), 75% to 87% of the pre- and post-responses fell between Completely Agree and Agree. Lower plant awareness was reported for the factors Plants Better than Animals (Plants) (33-38%) and Animals Better than Plants (Animals) (20-25%). When comparing the sum of percentages of the Completely Agree

and Agree responses, between pre- and post-responses for each factor, plant awareness increased in four of the six factors after students completed the module (Attention by 7.5%, Affect by 1.2%, Plants by 5.4%, and Animals by 4.8%).

Student paired comparisons between pre- and post-responses from 24 of the 25 questions of the PAD-I survey were not significantly different, as well as for paired comparisons for pre- and post-averages from questions per factor (t-test $p > 0.05$). The only exception was a significant positive increase in plant awareness in the paired comparison for the question, "When I go outdoors, I am more likely to notice the individual plants around me than any animals in the environment," which is part of the factor Plants Better than Animals ($t(69) = 2.4$, $p = 0.019$).

3.2 Plants were the most noticeable feature outdoors

Reflection Question: "When you go outdoors, what types of features do you notice about the environment? (For example, what types of organisms do you see, do you notice human-made things, etc.)."

When 64 students were surveyed pre- and post-module about what environmental features they noticed outdoors, their responses included seeing organisms, human-made structures, and various aspects of the environment. Before the module, plants were the most frequently mentioned organism at 92.2%, and 3.1% of students noticed plants only after the module (Figure 3). Several students referenced noticing plants because of their striking features, such as bright, colorful flowers, leaves of trees, and unusual shapes. Animals (excluding humans) were the second most noted organism (57.8%), with 15.6% of students including animals only in their post-responses.

Students also commented on human-made structures and buildings and how they interacted with the natural environment. This theme had the third-highest number of students responding, with 45.3% doing so before the module. Fifteen students (23.4%) who had not previously reported taking note of human-made structures did so after completing the module. A few students remarked on how plants could enhance architecture and living spaces.

Students noticed various aspects of the environment—weather, sky, air, water, and land. Environmental concerns (e.g., litter, smog, and habitat destruction) and how humans and animals interact with nature were listed. Statements about the environment accounted for 34.4% of pre-responses, and even more students (15.6%) referred to the environment after the module.

3.3. Students have mainly positive feelings toward plants

Reflection Question: "What are your feelings towards plants in general? (For example, do you enjoy being around them, etc.)."

An analysis of 65 pre- and post-responses revealed that most students felt that plants were enjoyable. Before the module, 89.2% of students had positive feelings, and three (4.6%) students who initially felt neutral developed positive feelings after completing the module. Many students did not explicitly state why they had positive feelings toward plants. Themes extracted from the remaining positive responses included plants being calming, aesthetically pleasing, and pleasant to smell and touch. Students also enjoyed growing plants and recognized their importance to the environment and society. Some students found plants interesting to study. Several students enjoyed plants but were cautious of poisonous plants, insects, and allergy-causing plants. The largest subthemes before the module were Calming (23.1%) and Beautiful (21.5%) (Figure 4). The subthemes ‘Interesting to study’ (16.9%) and ‘Importance of plants’ (15.4%) were the next highest and only differed by one response. Several students reported subthemes after the module that they had not mentioned previously. The ‘Importance of plants’ subtheme had the greatest number of these responses, with twelve students (18.5%) recognizing the importance of plants in the environment (e.g., ecosystem, oxygen) and for food, medicine, and other resources only after completing the module. Also, 12.3% of students expressed interest in growing plants only after the module.

The number of students with neutral feelings, meaning they neither liked nor disliked plants, or negative feelings toward plants was low. Three students who initially reported neutral feelings toward plants had positive attitudes after the module. Only two students had negative feelings toward plants both before and after the module. Ultimately, more students stated that after completing the module they enjoyed plants and learned about their importance.

3.4 Students stated that animals are generally more interesting than plants

Reflection Question: “Would you say that you find plants more or less interesting than animals?”

Pre- and post-responses from 64 students regarding their perceptions of whether plants were more or less interesting than animals were categorized into three major themes: 1) plants are more interesting, 2) animals are more interesting, and 3) plants and animals are equally interesting. Several subthemes were identified within each theme. Before the module, 17.2% of

students expressed that plants were more interesting than animals (Figure 5). The most prominent subtheme (6.3% pre-module) highlighted the importance of plants for the environment (e.g., survival) and resources (e.g., medicine). Students also thought plants were interesting to learn about and were diverse and complex.

Many students (65.6%) stated that animals were more interesting than plants. An animal's ability to interact through movement and interactions with humans and the ability to think and have personalities and emotions were the top two reasons animals were more interesting to students. 'Interactivity,' the highest subtheme, accounted for 35.9% of pre-responses, and 26.6% of students listed interactivity exclusively in their post-module responses. Complexity was mentioned in 20.3% of pre-responses, with additional responses (18.8%) after completion of the module. Some students were interested in studying animals and considered future careers related to them. A few students (4.7%) acknowledged the importance of studying plants even though they thought animals were more important before the activity, and even more students (7.8%) did afterward. A new subtheme, 'Animals are similar to humans,' emerged only after the module, where 6.3% of students related animals to themselves.

Plants and animals were equally interesting to 17.2% of students. Despite these students having an equal interest in plants and animals, a few preferred animals or plants. Students also stated plants and animals were interesting in distinct ways because of the differences in how plants and animals interact with the environment and the uses and complexity of plants. One student recognized the importance of plants and animals pre-module, and four more students did so after the module. Before the module, 4.7% of students appreciated that plants and animals were interesting to study, and more students (4.7%) commented similarly in only the post-responses. After completing the module, 20.3% of students changed their preference regarding whether they were more interested in plants, animals, or found plants and animals were equally interesting. One student initially interested in animals changed their preference to plants after completing the module, and four students switched from being solely interested in animals to finding both plants and animals equally interesting.

3.5 Students indicate that plants are most important as a food and oxygen source.

Reflection Question: "In what ways (if any) do you think plants are important and why?"

Major themes identified by 64 students pre- and post-responses about the importance of plants are environment, uses, research, and beauty (Figure 6). Most students emphasized the importance of plants to the environment, particularly for photosynthesis, survival of the planet

and humans, the ecosystem, and climate change. The 'Environment' theme had the most pre-responses (90.6%), with photosynthesis (e.g., oxygen production) accounting for 56.3% of total pre-responses (Figure 6). Within the 'Environment' theme, several students reported environmental subthemes for the first time after completing the module. Over 20% of students who had not previously mentioned 'Survival' stated that plants were essential for survival post-module.

Students also commented that plants were useful because they provided food, medicine, shelter (e.g., habitat), and resources (e.g., materials). The 'Use' theme constituted approximately 72% of pre-responses, with food (62.5%) identified as the most recognized use of plants and the primary reason why plants are important. Many statements included references to the food web and energy transfer. Twenty-two students (34.3%) listed plants as a food source only after completing their projects. Before the module, 31.3% of students recognized that many medicines were derived from plants, and an additional 20.3% did after the module.

The themes 'Research' and 'Beauty' had the fewest responses. Only one student mentioned the importance of plant research before the module, but two more students did after the module. After completing the module, additional students stated that plants make the world beautiful.

3.6 Students change their ideas about plants in a positive way

Reflection Question: "Has this course had any effect on your ideas regarding plants? If so, how?"

Responses from 75 students indicated that 65.3% of the students positively changed their ideas about plants after completing the module, while 34.7% reported no change (Table 2). These changes included increased plant knowledge (38.7%) and understanding of their importance (22.7%). Some students (9.3%) realized the importance of plants for the ecosystem, including the need for plant conservation. Students (9.3%) discovered that plants had more uses (e.g., food, medicine, research) than they originally considered. Students also learned more about plants, including the structure and complexity of the plants (14.7%), different types of plants, and how to care for plants. Students also gained a new appreciation for plants (12%) and were inspired to start their own garden. One student even learned how research at the DDPSC affects food security. Nearly all the students who did not change their ideas about plants did not give a reason. A few students already appreciated and understood the impact of plants on the environment. Four students gained additional knowledge but did not alter their opinions about plants.

Feedback from students included:

"This course has allowed me to grow in my love and knowledge of plants and how they impact what humans eat. I did not previously know that the Danforth Center did so much for making sure food supply was efficient, both in qualitative and quantitative ways."

"This course made me realized that plants are literally everywhere you look. When you're watching a soccer game, the grass that they play on have a use and a reason why it is there. No matter how small or ignorable the plants are at times, they always have an important use to society and research."

4. DISCUSSION

4.1 Plant Awareness

This study investigated the impact of a STEAM+Ag® learning module on high school students' plant awareness. The module involved the creation of 3D plant models using a STEAM framework for integrating plant science, art, design, and technology. This approach combined a project-based approach with instructors as facilitators and students working in collaborative teams where students learn by doing. To assess the impact of this module on plant awareness, we used the PAD-I survey, which examines student quantitative and qualitative responses to the six factors that represent the four PAD components: attention, attitude, relative interest, and knowledge (Parsley et al., 2022).

Student positive responses to the PAD-I survey (Completely Agree and Agree), before and after the module's implementation, indicated that many students had a high plant awareness at the beginning of the module. Many more students reported plant awareness themes after completing the module. Considering the individual PAD-I factors, 75 to 95% of the students reported positive statements for Attention Toward Plants (Attention), Positive Affect Toward Plants (Attitude), Caring for or investment in Plants (Attitude), and Necessity or Importance of Plants (Knowledge) before the implementation of the module. After completing the module, another one to eight percent of the students only reported positive statements for these factors. Student responses to reflection questions supported these results.

Attention: According to the Likert questions, students acknowledged that they notice plants where they live, walk, in wooded areas, and generally as part of the environment. Also, plants were the most noticeable feature outdoors based on the reflection questions. This study found

that students have high attention to plants, which contrasts with other studies reporting low attention to plants (Balas & Momsen, 2014; Parsley et al., 2022; Prokop & Fančovičová, 2023). Further discussions on the reasons for attention to plants is detailed under the Relative Interest component.

Attitude: Most students had positive attitudes toward plants as they acknowledged finding joy and happiness among plants, having good memories about plants, and finding them interesting based on the Likert questions. The reasons provided by the students for positive feelings toward plants based on their reflections include that plants are a source of beauty and calming effects, they are essential, you can grow and care for them, and they are interesting to study. The ideas of beauty, calming effects, and growing plants align with previous studies that acknowledge the positive impact on humans' mental and physical health of forest environments and gardening (Dünser et al., 2024; Karjalainen et al., 2010). The theme 'Plants are interesting to study' is novel and has not reported or included in assessment tools about attitudes toward plants (Amprazis & Papadopoulou, 2024; Dünser et al., 2024; Kubiatko et al., 2021). The rising popularity of plant-based AREs and other hands-on instructional approaches may explain why students are more open and interested in studying plants (Arango-Caro et al., 2024).

Relative interest: Contrasting results were found when comparing pre- and post-responses for the factors Plants are Better than Animals and Animals are Better than Plants. These two factors evaluate the idea that there is more interest in plants than animals without diminishing student interest in animals (Parsley, 2020). Based on the Likert scale questions, more students reported that plants were better than animals, and more students felt this way after completing the module. Additionally, among students who reported that animals were better than plants, the number of Completely Agree responses decreased after completing the module. To our knowledge, this outcome of plant awareness has not yet been reported in the literature. We are uncertain if the participating students' preference for plants over animals was influenced by their academic and/or personal experiences. Instructors who chose to implement this module may have already been interested in plants and were promoting plant awareness among their students. Some of these instructors are agricultural teachers who are required to teach a plant component in their courses. A few students acknowledged the importance of plants, even if they preferred animals. Other studies have found that connecting plants with animals can develop more interest in plants (Amprazis & Papadopoulou, 2024; Prokop & Fančovičová, 2023).

On the other hand, the reflection questions revealed that more students found animals more interesting than plants. Student explanations for why they preferred animals included animals' ability to move, interact with humans, and behave similarly to humans, which align with findings

from several authors. Less attention to plants has been attributed to lack of movement (Guerra et al., 2024; Pany et al., 2022; Stagg & Dillon, 2022) and predisposition of people for relating to more human-like animals (Lindemann-Matthies, 2005; Pany et al., 2022; Stagg & Dillon, 2022), which has been suggested to have some genetic basis (Lindemann-Matthies, 2005; Pany et al., 2022). Other factors that have been attributed to the preference of animals over plants are culture and traditions (Balding & Williams, 2016; Lindemann-Matthies, 2005), the popularity of anthropomorphic animals presented on social media, and the emphasis on conservation initiatives that use animals as flagship species (Lindemann-Matthies, 2005). Preference for animals over plants has also been attributed to implicit bias against plants in teaching from kindergarten through college, as instructors unconsciously provide more examples about animals than plants and or teach curricula that underrepresent plants (Balas & Momsen, 2014; Brownlee et al., 2023; Pany et al., 2022). Contrasting results between the responses to the Likert questions and the reflection questions are attributed to the differences among the types of questions. The Likert questions presented specific statements about various aspects of plants and animals in terms of finding them more practical, interesting to learn about, caring for them, or noticing outdoors. In contrast, the reflection question was open-ended, “Do you find plants more or less interesting than animals? Why?”.

Knowledge: For the factor Necessity or Importance of Plants, almost all students acknowledge the importance of plants before the module. Students indicate that plants are essential to humans (e.g., food, medicine, shelter) and the ecosystem (e.g., photosynthesis, climate change). Students have a high level of understanding of the importance of plants, which was also evident in another study with students of comparable ages (Dünser et al., 2024). However, many studies have reported a general lack of knowledge about the necessity or importance of plants among different types of populations (Pany et al., 2022).

4.2 A STEAM+Ag® module to promote plant awareness

Our 3D plant modeling module used a project-based approach integrating art and design with plant science and technology, providing a unique experience that benefits students in numerous ways. First, students could access plant specimens, interact with scientists, and visit the DDPSC facilities to investigate the biology, uses, and importance of plants researched at the DDPSC. Students increased their understanding of the role of plants in agriculture and gained valuable research skills. Students also improved their scientific literacy, which is crucial for citizens to make informed decisions that could affect national policies on plant conservation, climate change, and other environmental issues. Second, students learned 3D modeling and

experienced plant-related AVR immersive experiences, which helped them understand the practical application of these technologies in the real world. Using emergent technologies in science education is a relatively novel tool that has effectively engaged students in STEM learning and sparked interest in STEM careers (Leavy et al., 2023). Students learned to use these technologies and how to effectively work in groups and communicate their results. These 21st-century skills are essential to navigating the current challenges of a technology-driven world where teamwork and communication are crucial (Perignat & Katz-Buonincontro, 2019).

Several authors have reported different strategies to promote plant awareness, many of which have been incorporated in our module. Early life experiences, inspiration from teachers, active learning, and exposure to plants enhance students' appreciation of plants (Fančovičová & Prokop, 2011; Jose et al., 2019; Kubiatko et al., 2021; Lindemann-Matthies, 2005). Out-of-school activities, such as community gardens and trips to botanical gardens can positively influence students' attitudes toward plants and increase scientific literacy (Bell et al., 2009; Lindemann-Matthies, 2005). Frequent interaction with plants that are directly relevant to students' lives and the use of digital tools during extracurricular activities have been shown to promote plant awareness (Kissi & Dreesmann, 2018; Stagg & Dillon, 2022). Additionally, Batke et al. proposed six key areas that need to be developed in school and university environments to improve plant awareness among students (2020). Our module addresses six of these areas: improving educators' awareness, emphasizing plant applications, increasing contact with plants (theory versus practice), teaching more about the applications and uses of plants, and introducing more career content and student involvement in research.

Our module offered various opportunities to improve plant awareness through innovative pedagogical strategies. Sixteen teachers implemented this module in classrooms and informal settings for more than 250 students. These students came from diverse educational backgrounds (e.g., rural and urban schools, public and private institutions) and socio-economic status and ethnic groups (underserved African Americans and Hispanic students). Although most of the participating students in this module showed a high level of plant awareness, not all students responded the same way to questions and reported on the same themes of plant awareness. Many students reported some themes of plant awareness for the first time after completing their projects, suggesting that the module effectively broadened their understanding of plant awareness or made them aware of plants.

4.3. Limitations

Self-reported surveys, where individuals respond with a scale indicating their level of agreement, can have inherent response bias due to social norms and other factors. In this study, teachers may have influenced students when promoting the 3D plant module, potentially introducing bias. Some responses might have been biased because students simply wanted to please the teachers. The timing of when the students completed the pre-PAD-I survey could have introduced bias toward higher plant awareness. Some schools completed the survey after the project was presented by EROL researchers rather than before. The student population for this study consisted of high school students (grades 9-12) from both informal and formal educational settings (e.g., public and private) and locations (e.g., rural and urban). Including rural and urban schools could have introduced additional bias because students from rural areas are exposed to plants more in their local environment than students from cities. For example, a study comparing Midwestern rural and inner-city high school students' knowledge of agriculture and food revealed that rural students knew more about plants than their urban counterparts (Frick et al., 1995).

A strength of our module was its flexibility in implementation. Educators could implement the module within a timeframe ranging from three weeks to a full academic year. Depending on students' familiarity with 3D modeling software, they could choose which software to use. Students picked their plant species with unique complexities for 3D design. Not all students were able to visit the DDPSC or participate in immersive AVR experiences. This flexibility also meant that institutions varied on how they implemented the module to some extent. Working with educational institutions from different environments (e.g., rural, urban, public, private, formal, informal) may influence the outcomes of plant awareness. Future analysis, including data collected from additional students, will allow us to explore how plant awareness factors may vary based on institutional differences and implementation strategies.

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AUTHOR CONTRIBUTION

T.L. and S.A. analyzed data and wrote the manuscript. K.Y. coded the qualitative reflection questions. K.C. helped with data analysis and oversaw the project. All authors reviewed and approved the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

638 **References**

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640 Aguilera, D., & Ortiz-Revilla, J. (2021). STEM vs. STEAM education and student creativity: A
641 systematic literature review. *Education Sciences*, *11*(7), 331.
642 https://doi.org/10.3390/educsci11070331
643 Amprazis, A., & Papadopoulou, P. (2018). Primary school curriculum contributing to plant
644 blindness: Assessment through the biodiversity perspective. *Advances in Ecological and*
645 *Environmental Research*, *3*(11), 238–256.
646 Amprazis, A., & Papadopoulou, P. (2024). Plant blindness intensity throughout the school and
647 university years: A cross-age study. In K. Korfiatis, M. Grace, & M. Hammann (Eds.),
648 *Shaping the Future of Biological Education Research* (pp. 137–146). Springer
649 International Publishing. https://doi.org/10.1007/978-3-031-44792-1_10
650 Ananda, L. R., Rahmawati, Y., & Khairi, F. (2023). Critical thinking skills of chemistry students
651 by integrating design thinking with STEAM-PjBL. *Journal of Technology and Science*
652 *Education*, *13*(1), 352. https://doi.org/10.3926/jotse.1938
653 Antonelli, A., Fry, C., Smith, R., Eden, J., & Govaerts, RHA. (2023). *State of the world's plants*
654 *and fungi 2023* (pp. 1–90). Royal Botanic Gardens, Kew. https://doi.org/10.34885/wnwn-
655 6s63
656 Arango-Caro, S., Ying, K., Lee, I., Parsley, K., & Callis-Duehl, K. (2024). A model of science,
657 technology, engineering, and mathematics remote research-based learning: High school
658 independent authentic research experiences from home. *The American Biology*
659 *Teacher*, *86*(1), 24–29. https://doi.org/10.1525/abt.2024.86.1.24
660 Autodesk Inc. (2023). *Tinkercad* [Web application]. https://www.tinkercad.com
661 Autodesk Inc. (2023). *Fusion 360* [Web application]. https://www.autodesk.com/products/fusion-
662 360/
663 Balas, B., & Momsen, J. L. (2014). Attention "blinks" differently for plants and animals. *CBE—*
664 *Life Sciences Education*, *13*(3), 437–443. https://doi.org/10.1187/cbe.14-05-0080
665 Balding, M., & Williams, K. (2016). Plant blindness and the implications for plant conservation.
666 *Conservation Biology*, *30*(6), 1192–1199. https://doi.org/10.1111/cobi.12738
667 Barman, C. R., Stein, M., Barman, N. S., & McNair, S. (2003). Elementary teachers respond to
668 a study involving students' perceptions of plants. *Science and Children*, *41*, 46–51.
669 https://doi.org/10.33225/jbse/23.22.799

Batke, S., Dallimore, T., & Bostock, J. (2020). Understanding plant blindness—Students' inherent interest of plants in higher education. *Journal of Plant Sciences*, *8*, 98–105. https://doi.org/10.11648/j.jps.20200804.14

Bell, P., Lewesnstein, B., Shouse, A. W., & Feder, M. A. (2009). *Learning Science in Informal Environments: People, Places, and Pursuits* (p. 12190). National Academies Press. https://doi.org/10.17226/12190

Bertrand, M. G., & Namukasa, I. K. (2020). STEAM education: Student learning and transferable skills. *Journal of Research in Innovative Teaching & Learning*, *13*(1), 43–56. https://doi.org/10.1108/JRIT-01-2020-0003

Bozniak, E. (1994). Challenges facing plant biology teaching programs. *Plant Science Bulletin*, *40*(2). https://botany.org/psbarchive/issue/1994-v40-no-2.html

Brownlee, K., Parsley, K. M., & Sabel, J. L. (2023). An analysis of plant awareness disparity within introductory biology textbook images. *Journal of Biological Education*, *57*(2), 422–431. https://doi.org/10.1080/00219266.2021.1920301

Çil, E., & Yanmaz, D. (2017). Determination of pre-service teachers' awareness of plants. *International Electronic Journal of Environmental Education*, *7*, 84–93.

Colon, J., Tiernan, N., Oliphant, S., Shirajee, A., Flickinger, J., Liu, H., Francisco-Ortega, J., & McCartney, M. (2020). Bringing botany into focus: Addressing plant blindness in undergraduates through an immersive botanical experience. *BioScience*, *70*, 887–900. https://doi.org/10.1093/biosci/biaa089

Donald Danforth Plant Science Center. (2024, May 16). *Education Technology Program*. https://www.danforthcenter.org/our-work/education-outreach/education-technology-program/

Dünser, B., Möller, A., Fondriest, V., Boeckle, M., Lampert, P., & Pany, P. (2024). Attitudes towards plants – exploring the role of plants' ecosystem services. *Journal of Biological Education*, 1–15. https://doi.org/10.1080/00219266.2024.2308293

Fančovičová, J., & Prokop, P. (2011). Plants have a chance: Outdoor educational programmes alter students' knowledge and attitudes towards plants. *Environmental Education Research*, *17*, 537–551. https://doi.org/10.1080/13504622.2010.545874

Fiel'ardh, K., Fardhani, I., & Fujii, H. (2023). Integrating perspectives from education for sustainable development to foster plant awareness among trainee science teachers: A mixed methods study. *Sustainability*, *15*(9), 7395. https://doi.org/10.3390/su15097395

Frick, M. J., Birkenholz, R. J., Gardner, H., & Machtmes, K. (1995). Rural and urban inner-city high school student knowledge and perception of agriculture. *Journal of Agricultural Education*, *36*(4), 1–9. https://doi.org/10.5032/jae.1995.04001

Gatt, S., Tunnicliffe, S. D., Borg, K., & Lautier, K. (2007). Young Maltese children's ideas about plants. *Journal of Biological Education*, *41*(3), 117. https://doi.org/10.1080/00219266.2007.9656080

Guerra, S., Betti, S., Sartori, L., Zani, G., & Castiello, U. (2024). Plant awareness in the hand. *Journal of Environmental Psychology*, *94*, 102246. https://doi.org/10.1016/j.jenvp.2024.102246

Guyotte, K., Sochacka, N., Costantino, T., Walther, J., & Kellam, N. (2014). STEAM as social practice: Cultivating creativity in transdisciplinary spaces. *Art Education*, *67*, 12–19. https://doi.org/10.1080/00043125.2014.11519293

Havens, K., Kramer, A. T., & Guerrant, E. O. (2014). Getting plant conservation right (or Not): The case of the United States. *International Journal of Plant Sciences*, *175*(1), 3–10. https://doi.org/10.1086/674103

Henriksen, D., Mehta, R., & Mehta, S. (2019). Design thinking gives STEAM to teaching: A framework that breaks disciplinary boundaries. In M. S. Khine & S. Areepattamannil (Eds.), *STEAM Education* (pp. 57–78). Springer International Publishing. https://doi.org/10.1007/978-3-030-04003-1_4

Hershey, D. R. (1996). A historical perspective on problems in botany teaching. *The American Biology Teacher*, *58*(6), 340–347. https://doi.org/10.2307/4450174

İri, F. G., & Çil, E. (2020). Attitudes toward plants: Comparing the impact of instruction through writing & through a botanical garden trip. *The American Biology Teacher*, *82*(4), 218–226. https://doi.org/10.1525/abt.2020.82.4.218

Janni, M., Maestri, E., Gullì, M., Marmiroli, M., & Marmiroli, N. (2024). Plant responses to climate change, how global warming may impact on food security: A critical review. *Frontiers in Plant Science*, *14*, 1297569. https://doi.org/10.3389/fpls.2023.1297569

Jose, S. B., Wu, C.-H., & Kamoun, S. (2019). Overcoming plant blindness in science, education, and society. *Plants, People, Planet*, *1*(3), 169–172. https://doi.org/10.1002/ppp3.51

Karjalainen, E., Sarjala, T., & Raitio, H. (2010). Promoting human health through forests: Overview and major challenges. *Environmental Health and Preventive Medicine*, *15*(1), 1–8. https://doi.org/10.1007/s12199-008-0069-2

734 Kinchin, I. M. (1999). Investigating secondary-school girls' preferences for animals or plants: A
735 simple 'head-to-head' comparison using two unfamiliar organisms. *Journal of Biological*
736 *Education*, *33*(2), 95–99.
737 Kissi, L., & Dreesmann, D. (2018). Plant visibility through mobile learning? Implementation and
738 evaluation of an interactive flower hunt in a botanic garden. *Journal of Biological*
739 *Education*, *52*(4), 344–363. https://doi.org/10.1080/00219266.2017.1385506
740 Kose, E. (2011). Number of animal and plant species identified by biology students. *Energy*
741 *Education Science and Technology Part B: Social and Educational Studies*, *3*, 245–252.
742 Krishnan, S., Moreau, T., Kuehny, J., Novy, A., Greene, S. L., & Khoury, C. K. (2019). Resetting
743 the table for people and plants: Botanic gardens and research organizations collaborate
744 to address food and agricultural plant blindness. *Plants, People, Planet*, *1*(3), 157–163.
745 https://doi.org/10.1002/ppp3.34
746 Krosnick, S., Ramey, K., & Baker, J. (2018). The Pet Plant Project: Treating plant blindness by
747 making plants personal. *The American Biology Teacher*, *80*.
748 https://doi.org/10.1525/abt.2018.80.5.339
749 Kubiatko, M., Fančovičová, J., & Prokop, P. (2021). Factual knowledge of students about plants
750 is associated with attitudes and interest in botany. *International Journal of Science*
751 *Education*, *43*(9), 1426–1440. https://doi.org/10.1080/09500693.2021.1917790
752 Land, M. H. (2013). Full STEAM ahead: The benefits of integrating the arts into STEM. *Procedia*
753 *Computer Science*, *20*, 547–552. https://doi.org/10.1016/j.procs.2013.09.317
754 Leavy, A., Dick, L., Meletiou-Mavrotheris, M., Paparistodemou, E., & Stylianou, E. (2023). The
755 prevalence and use of emerging technologies in STEAM education: A systematic review
756 of the literature. *Journal of Computer Assisted Learning*, *39*(4), 1061–1082.
757 https://doi.org/10.1111/jcal.12806
758 Liao, C. (2016). From interdisciplinary to transdisciplinary: An arts-integrated approach to
759 STEAM education. *Art Education*, *69*, 44–49.
760 https://doi.org/10.1080/00043125.2016.1224873
761 Lin, C.-L., & Tsai, C.-Y. (2021). The effect of a pedagogical STEAM model on students' project
762 competence and learning motivation. *Journal of Science Education and Technology*,
763 *30*(1), 112–124. https://doi.org/10.1007/s10956-020-09885-x
764 Lindemann-Matthies, P. (2005). "Loveable" mammals and "lifeless" plants: How children's
765 interest in common local organisms can be enhanced through observation of nature.
766 *International Journal of Science Education*, *27*, 655–677.
767 https://doi.org/10.1080/09500690500038116

768 Link-Pérez, M., Dollo, V., Weber, K., & Schussler, E. (2010). What's in a Name: Differential
769 labelling of plant and animal photographs in two nationally syndicated elementary
770 science textbook series. *International Journal of Science Education*, *32*, 1227–1242.
771 https://doi.org/10.1080/09500690903002818
772 Oculus. (2023). https://www.meta.com/quest/
773 Pany, P., Meier, F., Dünser, B., Yanagida, T., Kiehn, M., & Möller, A. (2022). Measuring
774 students' plant awareness: A prerequisite for effective botany education. *Journal of*
775 *Biological Education*, 1–14. https://doi.org/10.1080/00219266.2022.2159491
776 Parsley, K. M. (2020). Plant awareness disparity: A case for renaming plant blindness. *Plants,*
777 *People, Planet*, *2*(6), 598–601. https://doi.org/10.1002/ppp3.10153
778 Parsley, K. M., Daigle, B. J., & Sabel, J. L. (2022). Initial development and validation of the plant
779 awareness disparity index. *CBE Life Sciences Education*, *21*(4), ar64.
780 https://doi.org/10.1187/cbe.20-12-0275
781 Patrick, P., & Tunnicliffe, S. (2011). What plants and animals do early childhood and primary
782 students' name? Where do they see them? *Journal of Science Education and*
783 *Technology*, *20*, 630–642. https://doi.org/10.1007/s10956-011-9290-7
784 Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative
785 literature review. *Thinking Skills and Creativity*, *31*, 31–43.
786 https://doi.org/10.1016/j.tsc.2018.10.002
787 Prokop, P., & Fančovičová, J. (2023). Enhancing attention and interest in plants to mitigate plant
788 awareness disparity. *Plants*, *12*(11), 2201. https://doi.org/10.3390/plants12112201
789 *Qualtrics*^{XM}. (2023). [Web application]. Provo, UT. *Qualtrics*^{XM}. https://www.qualtrics.com
790 Schussler, E. E., & Olzak, L. A. (2008). It's not easy being green: Student recall of plant and
791 animal images. *Journal of Biological Education*, *42*(3), 112–119.
792 https://doi.org/10.1080/00219266.2008.9656123
793 Schussler, E., Link-Pérez, M., Weber, K., & Dollo, V. (2010). Exploring plant and animal content
794 in elementary science textbooks. *Journal of Biological Education*, *Summer 2010*, 123–
795 128. https://doi.org/10.1080/00219266.2010.9656208
796 Sidoti, B. J., Walsh, L. L., Parsley, K. M., Callis-Duehl, K., Hove, A. A., Liu, H., Uzcategui, M.,
797 Ospina, D., Bruce-Opris, H., Gonzalez, R., Baraloto, C., & McCartney, M. (2023).
798 Characterizing the landscape of plant science careers in the United States I:
799 Government and private sector perspectives. *Plants, People, Planet*, 1–20.
800 https://doi.org/10.1002/ppp3.10375

Stagg, B., & Dillon, J. (2022). Plant awareness is linked to plant relevance: A review of educational and ethnobiological literature (1998–2020). *Plants, People, Planet*, *4*. https://doi.org/10.1002/ppp3.10323

Statistics Kingdom. (2017). *Paired t-test Calculator* [Web application]. Statistics Calculators. https://www.statskingdom.com/paired-t-test-calculator.html

Taljaard, J. (2016). A review of multi-sensory techniques in a Science, Technology, Engineering, Arts and Mathematics (STEAM) classroom. *Journal of Learning Design*, *9*(2), 46–55. https://doi.org/10.5204/jld.v9i2.274

Wahyuningsih, S., Nurjanah, N. E., Rasmani, U. E. E., Hafidah, R., Pudyaningtyas, A. R., & Syamsuddin, M. M. (2020). STEAM learning in early childhood education: A literature review. *International Journal of Pedagogy and Teacher Education*, *4*(1), 33–44. https://doi.org/10.20961/ijpte.v4i1.39855

Walsh, L., Parsley, K., Sidoti, B., Callis-Duehl, K., Hove, A., Liu, H., Bruce-Opris, H., Gonzalez, R., Ospina, D., Uzcategui, M., Baraloto, C., & McCartney, M. (2023). Characterizing the landscape of plant science careers in the United States II: Academic perspectives. *Plant, People, and Planet*, 1–16. https://doi.org/10.1002/ppp3.10374

Wandersee, J. H. (1986). Plants or animals—Which do junior high school students prefer to study? *Journal of Research in Science Teaching*, *23*(5), 415–426. https://doi.org/10.1002/tea.3660230504

Wandersee, J. H., & Schussler, E. (2001). Toward a theory of plant blindness. *Plant Science Bulletin*, *47*(1), 2–9.

Wandersee, J. H., & Schussler, E. E. (1999). Preventing plant blindness. *The American Biology Teacher*, *61*(2), 82–86. https://doi.org/10.2307/4450624

zSpace. (2024). https://zspace.com/

826 **TABLE 1** Qualitative survey questions, associated codes, and student quotes.

Survey Question	PAD-I Component	Theme	Code	Example
1. When you go outdoors, what types of features do you notice about the environment? (For example, what types of organisms do you see, do you notice human-made things, etc.). (Pre/Post)	Attention	Animals	1.1.1.	"I notice animals more frequently, especially if they run past or interact with me."
		Plants	1.1.2.	"I tend to notice plants that have flowers rather than just plain shrubs or trees. Plants that look "more interesting" like those with flowers or those that are beautiful or very tall catch my attention more easily."
		Other organisms	1.1.3. and 1.1.4.	"I do notice organisms as well- usually bugs or insects around me."
		People	1.1.5.	"People walking"
		Environment	1.2.	"I always take interest in what the weather looks like that day. I love fresh air."
		Human-made	1.3.	"I look at architecture and buildings, cars and roads"
2. What are your feelings toward plants in general? (For example, do you enjoy being around them, etc.) (Pre/Post)	Attitude	**General positive feelings**	2.1	"I love plants and love being around them."
		Calming	2.1.1.	"They provide me with a sense of tranquility that I cannot get anywhere else. I feel connected to the world around me when I am walking in a forest, because it is calming and serene."
		Beautiful	2.1.2.	"Plants are pleasantly to look at as they can vary to different colors and shapes."
		Growing plants	2.1.3.	"I've always found it fascinating to see how plants grow, from seed to a strong system that bears fruits of its labor."

		Importance	2.1.4.	“I enjoy being around plants, and I think they're extremely important for the environment and for human survival.”
		Interesting to study	2.1.5.	“Plants are pretty cool to study and learn about.”
		Enjoys plants but not poisonous ones, insects, allergies	2.1.6. and 2.1.7.	“I like plants. I don't mind being around them unless they attract lots of bugs. I do enjoy nature and plants but bugs creep me out and I prefer to stay away from bugs.”
		Neutral feelings	2.2.	“I don't mind being around them but I don't necessarily enjoy being around them.”
		Negative feelings	2.3.	“I feel grossed out by them and don't like to be around them.”
3. Would you say you find plants more or less interesting than animals? Why? (Pre/Post)	Relative Interest	**Generally, plants are more interesting**	3.1.	“I think I find them more interesting than animals because they are everywhere.”
		Important and useful	3.1.1.	“I would say they are more interesting because they are sources of medicine. Also, without plants animals can not live, therefore they are more important and interesting.”
		More diverse and complex	3.1.2.	“I say they are more interesting because they have more variety.”
		Interesting to study	3.1.3.	“Yes, because I feel like there is more research to be done about plants that can make a bigger difference in the world.”
		Generally, animals are more interesting	3.2.	“I would say less interesting because i like animals more.”
		More complex	3.2.1.	“I think animals are more intricate and have a lot more components to study than plants.”

Interactive	3.2.2.	“I think animals are more interesting because they are interactive and have personalities.”
More diverse	3.2.3.	“Probably less interesting than animals because I see more variations in animals and their biology.”
Interesting to study	3.2.4.	“I find plants less interesting because animals are more exciting to me to discover new animals would be a lot fun to figure out what they eat or need to survive.”
Future area of study/career pursuit	3.2.4.1.	“Less intersting personally, just because my career is more focused around animal health.”
Animals are interesting, but learning about plants is important	3.2.5.	“Although I find animals to be more complex, I would rather learn about plants because I have always been fascinated by soil, hydroponics, and how climate affects the botanical world.”
Similar to humans	3.2.6.	“I find plants less interesting than animals because animals are more closely related to humans“
Generally, plant and animals are equally interesting	3.3.	“I don't really find either one more interesting. They're both very interesting to me and it's hard to choose which one is more interesting.”
Equally interesting but prefers animals	3.3.1.	“I find both of them interesting but I do prefer animals more than plants. The reason why is because I grew up living with animals”
Equally interesting but prefers plants	3.3.2.	I think that both are interesting but I'm more interested in learning about plants than animals.”
Interesting in different ways	3.3.3.	“I don't think I really find plants or animals more interesting than the other because they each have their unique properties.”

		Both important	3.3.4.	"I find them equally interesting because they both play important roles in our society."
		Both interesting to study	3.3.5.	"I find them equally interesting because I love learning about them both."
4. In what ways (if any) do you think plants are important and why? (Pre/Post)	Knowledge	Environment	4.1.1. and 4.1.1.3.	"Plants are vital to the environment."
		Ecosystem	4.1.1.1.	"Plants are important because they form the foundation of ecosystems"
		Climate change	4.1.1.2.	"Plants are important because they help reduce climate change"
		Photosynthesis	4.1.1.4.	"Through photosynthesis, they provide oxygen for animals to breathe."
		Survival	4.1.1.5.	"I think plants are the backbone of the environment, and are very important to the survival of many organisms such as humans."
		Food source	4.1.2.1.	"Without plants, there would be no food. Everything we eat, including meat from animals."
		Shelter	4.1.2.2.	"They also provide shelter for many animals"
		Medicine and health	4.1.2.3.	"they have certain properties that humans can use in medicine."
		Resources	4.1.2.4.	"Providing goods"
		Research	4.1.3.	"Plants...help us learn about foundational science concepts through research."
		Beauty	4.1.4.	"Plants offer beauty and wonder to our world."
5. Has this course had any effect on your ideas regarding		**Changed ideas about plants**		
		Changed idea but no reason given	5.1.	"Yes, plants are very intresting."

plants? If so, how? (Post)		Importance of plants	5.1.1.	“Yes, plants are very important in ways I never even thought of before”
		Ecosystem	5.1.1.1.	“It helped me learn more about prairie ecosystems and the importance of plant conservation.”
		Uses of plants	5.1.1.2.	“No matter how small or ignorable the plants are at times, they always have an important use to society and research.”
		Learning more about plants	5.1.3.	“This course has allowed me to grow in my love and knowledge of plants”
		Different types of plants	5.1.3.1.	“Yes totally! I not only learned about different plants in the world”
		Caring for plants	5.1.3.2.	“Yes, a lot. Right now I know how to plant a plant... and also I know what season are going to plant what plant.”
		Structure and complexity of plants	5.1.3.3.	“I think plants are way more complex than I had initially thought. Creating 3D models of the plants made me realize the complexity of their structures.”
		New appreciation for plants	5.1.4.	“This course made me realized that plants are literally everywhere you look.”
		Learning about DDPSC	5.1.5.	“I did not previously know that the Danforth Center did so much for making sure food supply was efficient, both in qualitative and quantitative ways.”
		No change		
		No change but no reason given	5.2.	“No, not really”
		Already knew plant importance to the environment	5.2.1.	“No, because I have always known how important plants are”

		Already had an appreciation and understanding of plants	5.2.2.	“Not really, I already had a good understanding and respect towards plants and if anything this course just strengthened that bond.”
		More knowledge than before but didn't change thoughts about plants	5.2.3.	“I like plants about the same, I just know more about them.”

828 **TABLE 2.** Student responses to the post-question, “Has this course had any effect on your
829 ideas regarding plants?”.

	Students	
Themes	**No.**	**%†**
Changed ideas about plants	**49**	**65.3**
Changed idea but no reason given	1	1.3
Importance of plants	3	4
Ecosystem	7	9.3
Uses of plants	7	9.3
Learning more about plants	9	12
Structure and complexity of plants	11	14.7
Different types of plants	8	10.7
Caring for plants	3	4
New appreciation for plants	12	16
Learning about DDPSC	1	1.3
No change	**26**	**34.7**
No change but no reason given	16	21.3
Already knew plant importance to the environment	1	1.3
Already had an appreciation and understanding of plants	5	6.7
More knowledge than before but didn't change thoughts about plants	4	5.3

830 †Percentages are calculated with respect to a total of 75 students. Percentages per column do
831 not add to one hundred since some students provided responses for more than one theme.
832

Figure Legends

FIGURE 1. PAD-I six-factor model with the four components of PAD. This figure was reprinted from Parsley et al. 2020 under the Creative Commons License.

FIGURE 2. The percentage of pre- and post-responses for each of the factors of the PAD-I survey. Necessity – Necessity or importance of plants, Affect – Affect towards plants, Attention – Attention towards plants, Caring – Caring for or investment in plants, Plants – Plants better than animals, Animals – Animals better than plants. Completely Agree shows the highest plant awareness and Completely Disagree the lowest plant awareness.

FIGURE 3. The percentage of students who had a response for a theme only before the module, before and after the module, and only after the module for the question, "When you go outdoors, what types of features do you notice about the environment?". Percentages are calculated with respect to a total of 64 students. Percentages do not add to one hundred since some students provided responses for more than one theme.

FIGURE 4. The percentage of students who had a response for a theme only before the module, before and after the module, and only after the module for the question, "What are your feelings towards plants in general?". Percentages are calculated with respect to a total of 65 students. Percentages do not add to one hundred since some students provided responses for more than one theme.

FIGURE 5. The percentage of students who had a response for a theme only before the module, before and after the module, and only after the module for the question, "Would you say that you find plants more or less interesting than animals? Why?". Percentages are calculated with respect to a total of 64 students. Percentages do not add to one hundred since some students provided responses for more than one theme.

FIGURE 6. The number and percentage of students who responded to a theme only before the module, before and after the module, and only after the module for the question, “In what ways (if any) do you think plants are important and why?”. Percentages are calculated with respect to a total of 64 students. Percentages do not add to one hundred since some students provided responses for more than one theme.

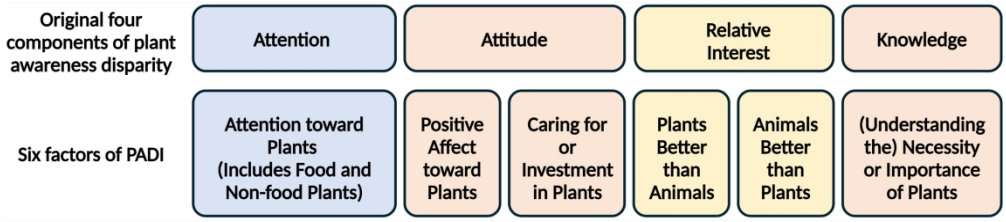

FIGURE 1. PAD-I six-factor model with the four components of PAD. This figure was reprinted from Parsley et al. 2020 under the Creative Commons License.

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FIGURE 2

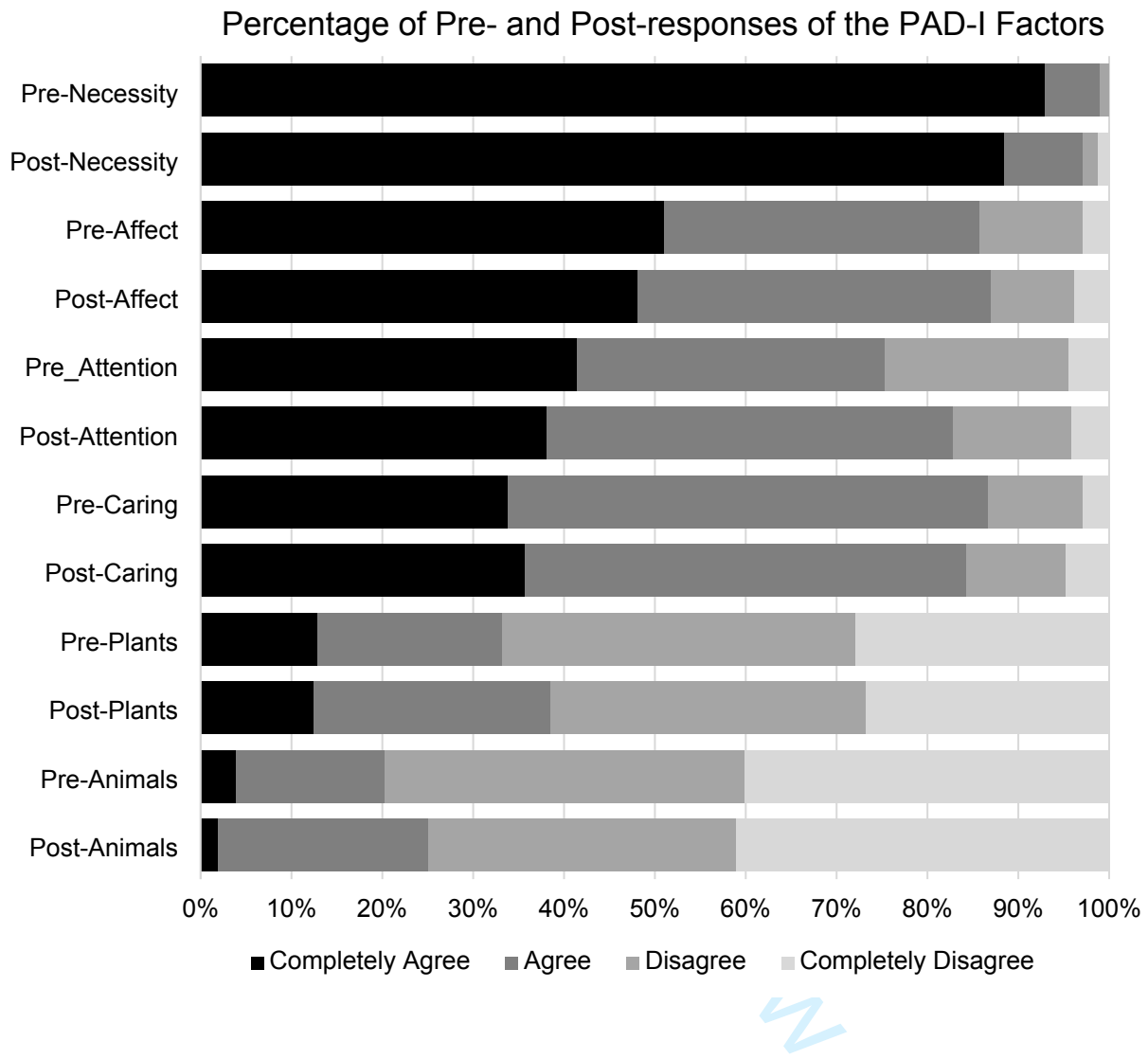

Percentage of Pre- and Post-responses of the PAD-I Factors
Pre-Necessity
Post-Necessity
Pre-Affect
Post-Affect
Pre_Attention
Post-Attention
Pre-Caring
Post-Caring
Pre-Plants
Post-Plants
Pre-Animals
Post-Animals
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Completely Agree
Agree
Disagree
Completely Disagree

FIGURE 3

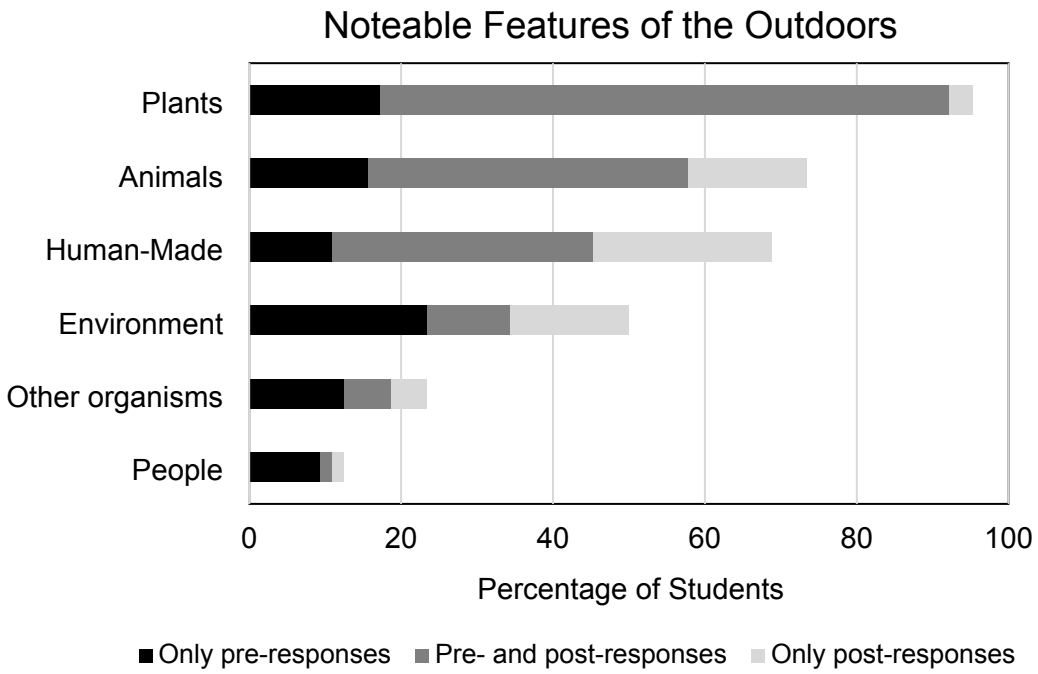


FIGURE 4

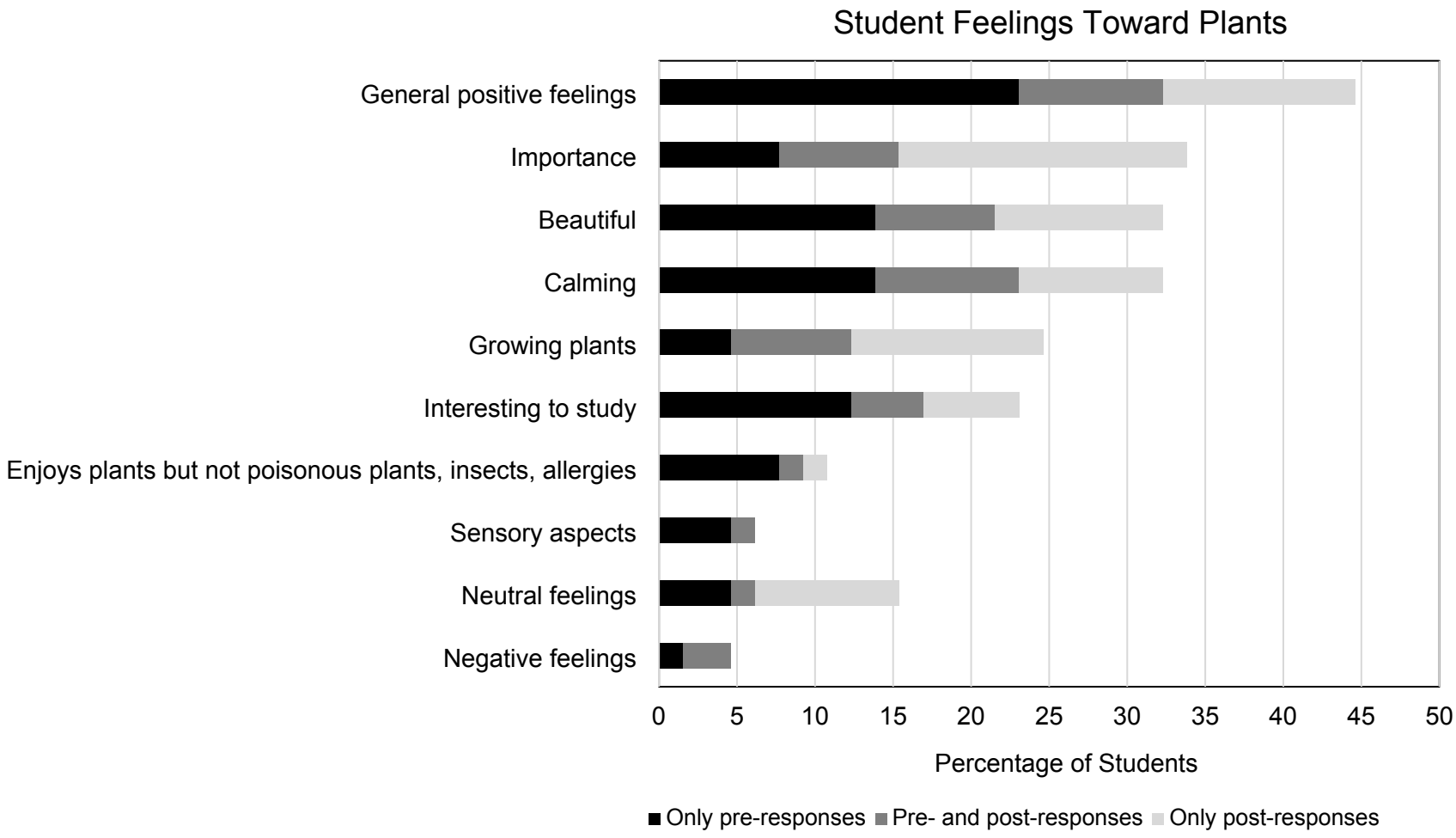

Student Feelings Toward Plants
General positive feelings
Importance
Beautiful
Calming
Growing plants
Interesting to study
Enjoys plants but not poisonous plants, insects, allergies
Sensory aspects
Neutral feelings
Negative feelings
0
5
10
15
20
25
30
35
40
45
50
Percentage of Students
Only pre-responses
Pre- and post-responses
Only post-responses

FIGURE 5

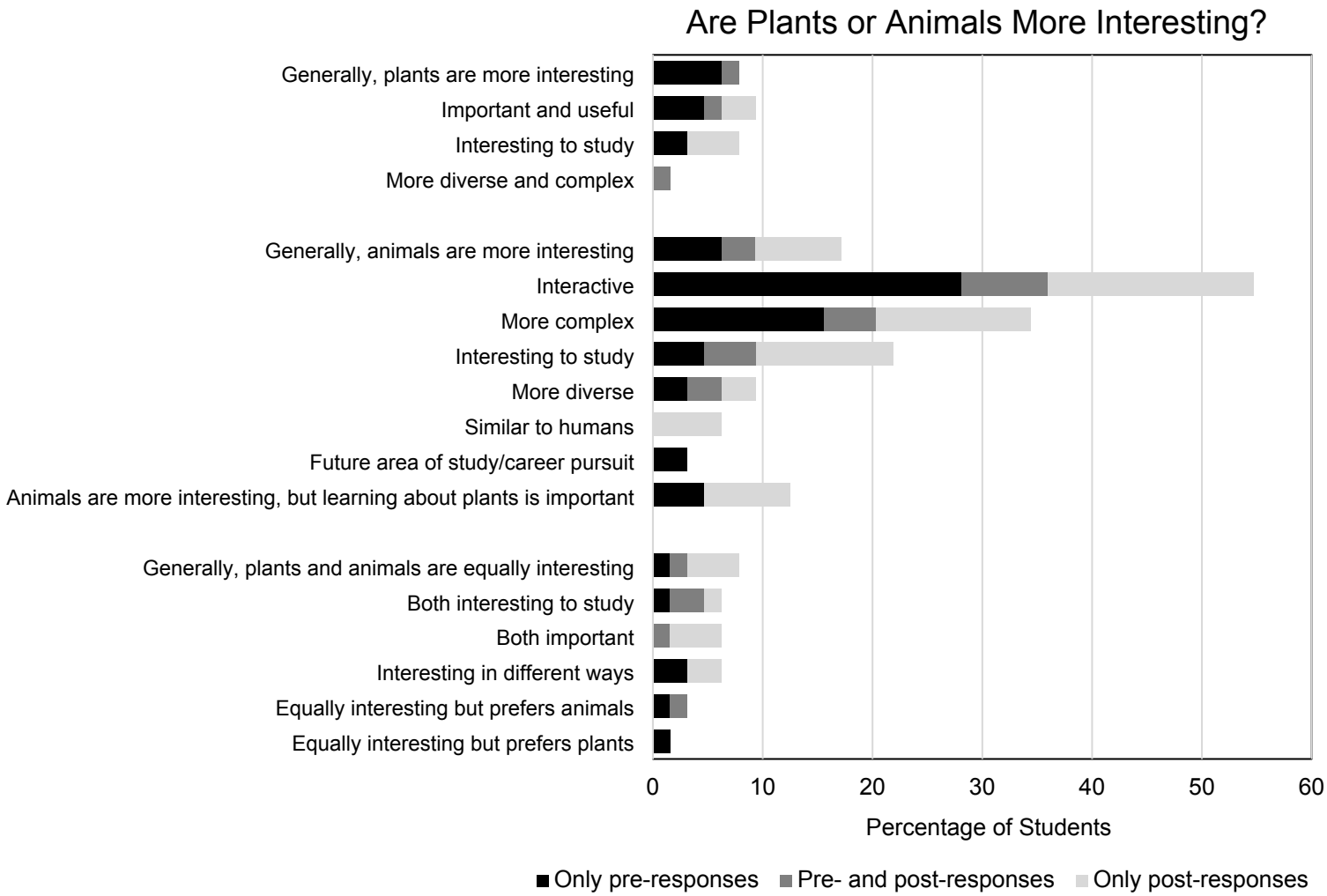
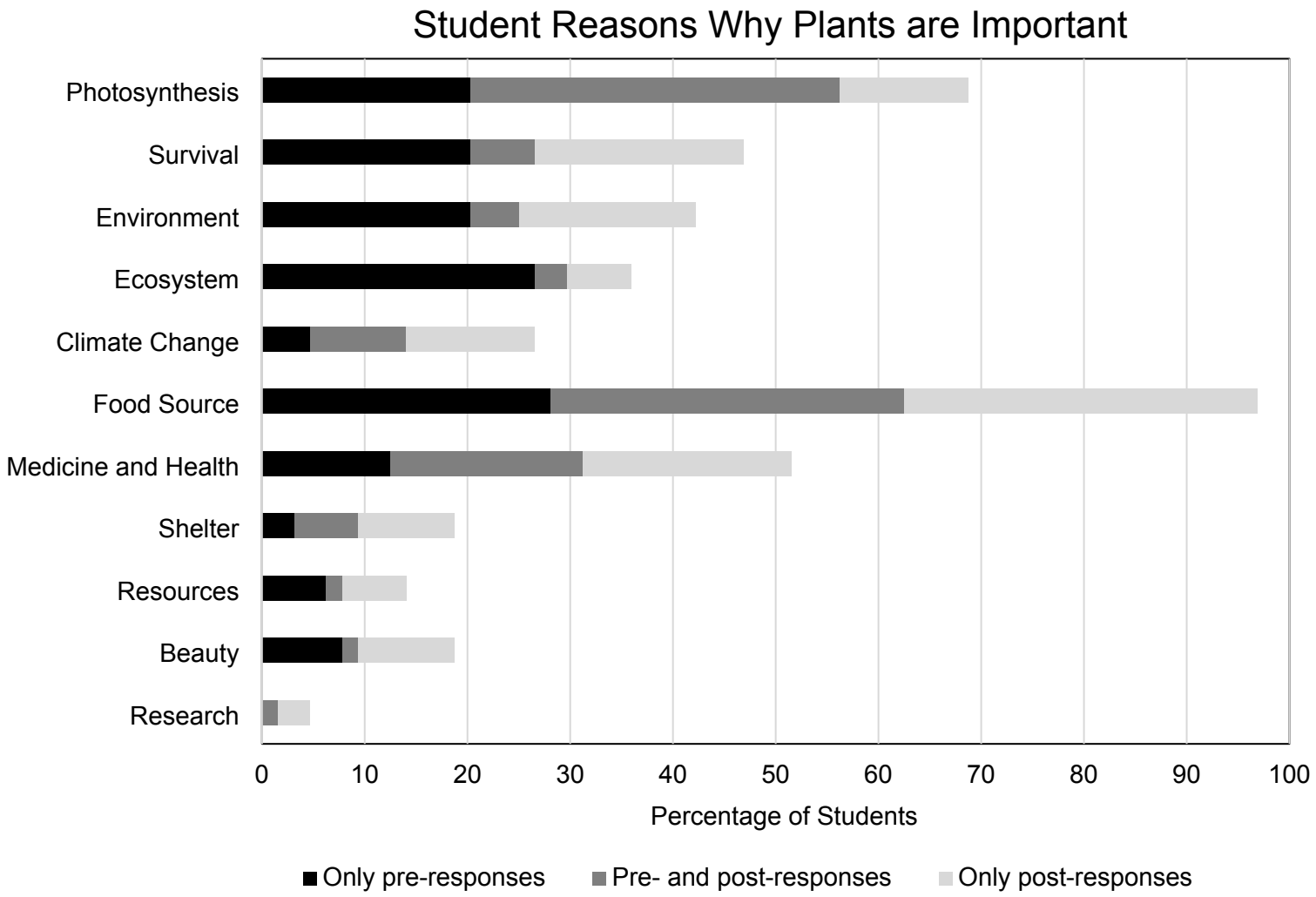

Are Plants or Animals More Interesting?
Generally, plants are more interesting
Important and useful
Interesting to study
More diverse and complex
Generally, animals are more interesting
Interactive
More complex
Interesting to study
More diverse
Similar to humans
Future area of study/career pursuit
Animals are more interesting, but learning about plants is important
Generally, plants and animals are equally interesting
Both interesting to study
Both important
Interesting in different ways
Equally interesting but prefers animals
Equally interesting but prefers plants
0
10
20
30
40
50
60
Percentage of Students
Only pre-responses
Pre- and post-responses
Only post-responses

FIGURE 6


Student Reasons Why Plants are Important
Photosynthesis
Survival
Environment
Ecosystem
Climate Change
Food Source
Medicine and Health
Shelter
Resources
Beauty
Research
0
10
20
30
40
50
60
70
80
90
100
Percentage of Students
Only pre-responses
Pre- and post-responses
Only post-responses