PLANTGIFT: AN EFFECTIVE TEACHER WORKSHOP MODEL FOR INCREASING PLANT-BASED LABORATORY EXPERIENCES IN SECONDARY SCIENCE CLASSROOMS

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ABSTRACT

PlantGIFT (Plant Genomics Internships for Teachers) is a weeklong teacher professional development workshop designed to enhance the understanding and utilization of plant-based science in secondary science classrooms. The program establishes an active partnership between teachers and plant genetics researchers, aiming to translate cutting-edge research into a classroom learning experience. The major themes covered in PlantGIFT are genetic mutations, microbiomes through endophytes, drought tolerance, and GMOs. Pre- and post-surveys were used to assess program effectiveness, teacher self-efficacy, and increased awareness of plant awareness disparity. The findings indicated that participants found the workshop enjoyable and reported improvements in their content knowledge and confidence regardless of their baseline knowledge of plant genetics. A post-workshop survey indicated that a majority of respondents incorporated workshop materials into their classroom curricula and found it beneficial for their students. This paper shares an outline of workshop activities, lessons learned, and recommendations for practice and future research.

KEYWORDS

Plant genetics, plant awareness disparity, plant blindness, climate change education, teacher workshop

1. INTRODUCTION

A global survey of individuals highlighted that the most critical questions about plant science revolve around two climate change-related categories, 1) food security and 2) protecting and restoring biodiversity [1]. These are critical issues for the global community and are closely linked to the United Nation's 17 "Sustainable Development Goals" [2]. Over 11,000 scientists worldwide have warned of the impending impact of climate change [3]. Despite the significance of this data, there is skepticism from many politicians and citizens, in part leading to a continuing downward trend of students aspiring to enter careers as botanists and plant scientists [4, 5]. Further, numerous schools shy away from teaching about climate change [6, 7].

An emerging theory suggests that at least some of the perceived apathy toward the aforementioned problems stems from the decline of global plant biodiversity. This brings to light the importance of addressing what is known as Plant Awareness Disparity (PAD), a preferred term replacing the original moniker '*plant blindness'* [8, 9]. Both terms refer to a current problem wherein most people appear to overlook plants and their vital role in supporting all life on Earth [10]. This issue was first noted by Hershey (1993), who described it as a decline and neglect of botanical education in American schools. More recently, it has been identified as a much larger issue, i.e., not just a lack of education but also a failure to appreciate the importance of plants [8]. In the past two decades, these observations have developed into a theory that at least some of the apathy for human-caused climate change and potential corrections for it can be, at least partly, blamed on PAD [10-14]. As dimensions of "awareness disparities" begin to be considered, researchers have also identified Biome Awareness Disparity (BAD; [15]) and Species Awareness Disparity (SAD; [12]) indicating a larger issue with how life science education falls short in connecting classroom content to real-world issues. PAD has been identified in high school and undergraduate students around the world, indicating that it is not just an American phenomenon [12, 16-19].

Although the research on the role of PAD is still emerging, current studies indicate connections between environmental literacy and pro-environmental/conservation behaviors [20-23]. Strong evidence also suggests that when empathy is engaged, people feel more connection to nature and more desire to conserve species [11, 23, 24], and relative to climate change, they can feel more hope and empowerment that their actions can make a difference and bring about change [21, 25]. Secondary science teachers can be effective agents of change [26]. Numerous studies demonstrate that increasing content knowledge has a small or negligible impact on PAD [27, 28], but teachers can significantly inspire students in their understanding of the critical importance of biodiversity and greatly stimulate their interest in related careers [16, 20, 29]. Additionally, PAD is present in vertebrate-centered biology education at all levels, including in the curriculum materials utilized to teach [24, 30]. Therefore, in order to increase plant awareness and scientific literacy in relation to global issues (e.g., climate change, food security, and biodiversity), there is a need to address the need for K-20+ teacher/educator PAD resources and development of curriculum materials to meaningfully engage students in plant studies [22]. Although plant-centered institutions like botanical gardens often offer professional development and student field trips [20], very few teacher workshops specifically address PAD through a lens of engaging education connected to hands-on biotechnology experiences.

When students learn about science content through hands-on research experiences, it can increase not only their content knowledge but also their interest in carrying out future research and their appreciation of current and future botanical studies [31]. This can be taken a step further by framing content in a way in which students learn about issues and actions they can take and are encouraged to discuss and consider their actions, rather than being given a directive of how to act [32]. Within this context, Plant Genomics Internships for Teachers (PlantGIFT) is anchored in studies of climate change, food security (through genetic modification), and biodiversity through hands-on research in which participants make decisions about what to investigate and include embedded discussions of the ethical and societal implications for the work. The aim is that encouraging teachers to include more plant-based science in their curricula will reduce PAD, build pro-environmental behaviors in students, and build more connections between scientific exploration in secondary classrooms and authentic research and industry. The purpose of the current study was to develop and evaluate a workshop for secondary science teachers that framed plants in the context of global issues and biotechnological solutions for global food security.

2. METHODS

2.1. Study Type and Setting

This descriptive study utilized a pre/post survey design to investigate teachers' perceptions of a professional development (PD) workshop. The focus was on perceived workshop effectiveness, self-efficacy, and content-knowledge shifts that could be translated into changes in classroom practice. The workshops spanned five consecutive days in a functional research lab within the University of Alabama at Birmingham's (UAB) Biology Department. All methods were approved by the University's Institutional Review Board and informed consent was obtained from all participants.

2.2. Recruitment of Teachers

Participants for the PlantGIFT workshop were recruited using an existing network of prior workshop participants, field trip participants and administrators with whom the UAB Center for Community Outreach Development (CORD) had previously interacted. Moreover, emails had been sent directly to middle and high school life science, biology, environmental science, and AP biology/environmental science teachers. Participants were given a stipend for completing the workshop, credit hours that could be used towards their annual certificate renewal, with the option to earn graduate biology hours. The target annual enrollment for the workshop was 12-15 teachers from diverse schools with at least 50% being Title I schools. Following this model of recruitment, PlantGIFT aimed to bring together the resources of outstanding university researchers and the expertise from CORD to introduce a diverse group of teachers to the most up-to-date research in plant science.

2.3. Participants

Registration for the 2023 cohort was restricted to 15 participants because of the size of the laboratory used. Out of the 15 registrations, a total of 9 individuals attended the workshop. The cohort (n = 9) averaged 10-15 years of experience, with one teacher having just completed their first year and two with over 20 years of experience. The cohort represented urban, suburban, and rural districts, with 55% of the cohort teaching at Title 1 schools.

2.4. Workshop Model

This workshop was conducted in partnership with UAB CORD, which has a 25-year-long history of offering high-quality professional development programs to Alabama K-12 teachers. CORD's long-running "BioTeach" workshop was used as a model for PlantGIFT[33, 34]. Following this successful model, PlantGIFT was modified to a weeklong credit-bearing workshop with a main focus on the genetics of plant biology. Darling-Hammond et al. (2017) have identified seven themes that contribute towards effective PD: (1) focused content, (2) incorporation of active learning, (3) environment of collaboration, (4) the use of effective practice models, (5) providing coaching and expert support, (6) offering feedback and reflection, and (7) sustained duration[35]. CORD has used this model in its previous workshop designs[33, 36]. To facilitate adoption by other institutions, a detailed daily workshop schedule—based on the PlantGIFT structure described in Bedgood et al.—has been previously provided. [37].

2.5. Workshop Design

PlantGIFT was created in response to the growing need for plant education and as an opportunity to inspire students through hands-on biotechnology experiences. Following the COVID-19 pandemic, a large number of school teachers were under increased time pressure during the summer and were forced to limit their time participating in professional development and/or research internships. Moreover, plant-based research is simple, straightforward, safe and affordable to undertake in middle and high schools. To address these priorities, we designed a one-week intensive course that would introduce participants to a range of important plant/botanical topics paired with cutting-edge biotechnology labs that could be deployed in middle and high school settings. Each day of the workshop included an interactive lecture from a content field expert, hands-on labs, opportunities to debrief and plan with peers, and group discussions of real-world issues and possible solutions. Following the conclusion of the workshop, participants were encouraged to implement the newly learned skills in their classrooms. To facilitate this, the teachers were offered the use of loaner lab equipment, free reagents for gel electrophoresis, and ongoing support from workshop leaders.

2.6. Daily Activity Schedule of the Workshop

Table 1: Daily activities of PlantGIFT Workshop

Day	Topic	Laboratory	NGSS Alignment
1	Botanical Interdependence; Plant Immunity	Inoculate plants for pathogen assay. Design and set up heat stress assay (observations of plants made daily).	HS-LS1-3 HS-LS4-3
2	Plant Anatomy; Plant-Microbial Interactions	Lily dissection; Endophyte isolation	HS-LS1-2 HS-LS4-6 HS-LS4-3
3	PCR Identification of Genetically Modified Organisms T-DNA Insertion and Application	Micropipette practice; GMO detection via agarose gel electrophoresis	HS-LS1-1 HS-LS2-7 HS-LS3-1 HS-LS2-2 HS-LS3-2 HS-LS4-5
4	Plant Immunity, *continued;* Climate Change and Human Health	Vegevaders game; Is climate change making us sick?	HS-ESS3-4
5	Bioinformatics tutorial; Data collection and presentation	Practice BLAST search; Collect and report final data from week-long experiments	HS-LS1-3 HS-LS2-7

Each day of the workshop included 45–60-minute didactic interactive lectures presented by UAB instructors and hands-on laboratory activities using *Arabidopsis thaliana* as a model organism, as shown in Table 1. Table 1 describes an overview of the workshop activities and alignment to Next Generation Science Standards (NGSS). Major topics addressed included climate change, genetic modification of organisms, microbiomes, endophyte isolation, and bioinformatics. Biotechnology lab skills and practices introduced through the workshop included experimental design, microscopy, micropipetting, bacterial streaking, Polymerase Chain Reaction (PCR), and DNA identification through agarose gel electrophoresis.

2.7. The Role of Instructors During PlantGIFT Workshop

The daily didactic lectures were delivered by both faculty members and graduate students. Lecture themes were expanded on during hands-on laboratory experiments. The details of these activities are shown in Table 2.

Table 2: Didactics and the Role of Instructors During PlantGIFT Workshop.

Speaker Role	Lecture Topic	Connected Lab/Activity
Principal Investigator/Research Professor	Connections between Plants and Climate Change	Plant Heat Stress and Pathogen Assay; "Is Climate Change Making Us Sick?"
Graduate Student	T-DNA Insertion and Application	GMO Detection by Agarose Gel Electrophoresis
Graduate Student	PCR Identification of Genetically Modified Organisms	GMO Detection by Agarose Gel Electrophoresis
Graduate Student	Plant Immunity	"VegEvaders" Game to Model Plant Immune Response
Principal Investigator/Research Professor	Microbial Interactions with Plants	Endophyte Extraction and Isolation
Graduate Student	Bioinformatics Tutorial	Practice Searching BLAST Database; Pathogen Assay

2.8. Development of Teachers into Scientists

Another goal of PlantGIFT was to assist participants in envisioning themselves as scientists. According to Rushton & Reiss (2019), teacher scientists display five key elements : (1) undertake authentic research with students, (2) continuously develop their subject knowledge base through discussing current, peer-reviewed research with their students, (3) enhance and develop and their own laboratory skills and those of their students through training and interaction with research scientists, (4) provide opportunities for students to build community with a network of professional scientists, and (5) encourage their students to disseminate their research at a range of activities[38]. *The science identity* of teachers is linked to both their content area and community of practice[38, 39], although it can also remain somewhat separate from pedagogy and praxis[40]. Opportunities to work with other science teachers and scientific researchers can help to develop teachers' science identity[38]. A study by Faber et al. (2014) found that collaborations between teachers and scientists can improve teachers' comprehension of inquiry and research and increase their confidence in teaching inquiry-based science[41]. For teachers to implement all of these elements, they must themselves have access to a scientific community and have adequate confidence in their ability to teach and discuss science beyond what is found in a textbook or laboratory manual. Professional development opportunities like PlantGIFT can help strengthen both self-efficacy and the professional community.

Peer learning in professional development settings offers an additional layer of engagement and innovation[42]. Teacher-participants were able to exchange ideas, strategies, and best practices as well as collaborate with their peers to plan lessons and share resources. Experienced participants served as mentors for newer educators, providing guidance, support, and practical advice. Further, learning from peers with diverse backgrounds and experiences, such as educators from rural and Title I schools, helped all teachers better understand the diverse needs of their students and contributed to the development of cultural competence in the classroom.

2.9. Use of Arabidopsis Thaliana as a Model Organism

The majority of lab work described here centered around *Arabidopsis thaliana,* further referred to as Arabidopsis, a model plant organism useful for genetic experiments because of its small size, short generation time, compact genome and prolific seed production through self-pollination[43]. Arabidopsis is a mustard family plant, related to the Wisconsin Fast Plant that is popular in K-12 classrooms and many common crops including cabbage, cauliflower, radish, Brussels sprouts and turnip, kohlrabi, and broccoli. However, scientists have made more genetic discoveries on Arabidopsis than any other flowering plant and thus have produced robust databases of information that can be used by the general public[44]. Over 11,000 researchers and 4,000 organizations spanning the globe have made contributions to the field which developed into a database composed of rich diversity and quantity of information and materials that is available publicly through a comprehensive online resource known as The Arabidopsis Information Resource (TAIR)[44]. This can give K-12 students an opportunity to act as authentic participatory scientists, learning from and contributing to the existing body of knowledge for this model organism.

2.10. Role and Inclusion of Graduate Students and Faculty Members

A central part of the workshop design was the inclusion of university faculty members and graduate students who provided collaborative lectures and assisted in laboratory experiments. Their expertise and enthusiasm for plant topics help make PlantGIFT an enjoyable and meaningful experience for the teachers. The relationships established between the faculty, graduate students and teachers can lead to long-term partnerships between the university's Biology Department and local schools. Once a teacher completes the workshop, they have the opportunity to invite the graduate students into their classrooms to demonstrate and conduct experiments. The faculty of PlantGIFT is also available to host lectures in the classrooms of the participants. A long-term goal of this project is to foster these relationships so that the greater community benefits from this network of science educators and science communicators.

2.11. Assessment

2.11.1. Research Questions

This study investigated the impact of participation in a professional development workshop using a curriculum based on incorporating the core concepts of Plant Awareness Disparity to assist secondary science teachers in the implementation of plant biology-related concepts into their curricula. This effort is divided into three components: (a) Did the teachers' knowledge of plants and the importance of plants in science increase after the completion of the workshop? (b) Are teachers comfortable conducting new plant biology research projects in their classrooms? (c) Did participating in the workshop translate to inclusion of workshop content/ implementation of workshop lessons and lab activities?

The main research questions for this study are: (RQ1): How has the teachers' confidence in their knowledge of plants and the importance of plants in current science research increased after completion of the workshop? And (RQ2): How has participation in PlantGIFT changed the teachers' familiarity with essential concepts in plant biology? RQ1 was assessed by four domains: (i) teaching plant anatomy and physiology, (ii) the challenge of using science to solve problems, (iii) student motivation, and (iv) the importance of implementing current scientific research in their class. RQ2 assessed (i) PAD, (ii) gel electrophoresis, (iii) endophytes, and (iv) plant anatomy and physiology.

2.11.2. Survey Instruments

The surveys included 4 and 5-point Likert-scale questions with 2-3 open-response questions. The survey questions intended to measure self-efficacy were modified from a popular survey instrument the Science Teaching Efficacy Belief Instrument or STEBI[45]. For this study, the focus of the questions changed from general science to plant biology to specifically address the content of this workshop. Questions addressing workshop design and content relevance were modeled from a survey for the North Carolina Race to the Top (RttT) professional development plan conducted by the Consortium of Education Research and Evaluation-North Carolina[46]. However, the 4-point Likert scale used in that study was modified to a 5-point likert scale to include a neutral option as a choice for participants. To address issues of validity and reliability, statements like "most of my students" were given an accompanying estimated percentage (80% or more) and scales of agreement had strong, somewhat, and neutral agreement/disagreement. When asking teachers, perhaps particularly science teachers about their knowledge and skills related to laboratory activities, there can be a feeling of defensiveness or fear of being perceived as unknowledgeable. Survey items did ask teachers to rate their knowledge and comfort of skills related to workshop content. These questions were framed with the understanding that workshop facilitators wanted to know how to best meet the participants at their current skill level. Although reported skill level was not formally compared to demonstrated skill in lab, observations of participants in lab reflected their reported familiarity. The surveys were analyzed with the goal of determining whether the teachers' interest in teaching plant biology increased by participating in the workshop. In addition to studying the teachers' interest in plants, the open-ended questions were designed to investigate the workshop's effectiveness and the role the workshop plays in establishing long-lasting mentee-mentor relationships between the teachers, UAB faculty and graduate students.

2.11.3. Research Design

Participant data was collected via anonymous pre/post survey instrument. In the pre-survey, participants were asked to indicate agreement or familiarity using a 5-point Likert scale with topics relating to self-efficacy, science content knowledge, and student engagement. They were also asked about the inclusion of workshop content in their current lessons, goals they hoped the workshop would address, and anything they find difficult about teaching science. The post-survey used the same Likert questions but changed questions about the current curriculum to include workshop content in future lessons. It also added questions focused on workshop evaluation, asking for feedback about workshop elements, whether goals were met, and what participants enjoyed, as well as solicited constructive feedback for shaping future sessions.

2.11.4. Statistical Analysis

Pre- and Post-surveys were sent as Qualtrics links. All data was de-identified through anonymous links in Qualtrics. Quantitative data was analyzed using Welch's T-test which is a two-sample t-test assuming unequal variances known and tested via ordinal logistic regression where applicable. A Welch's t-test is a two-sample test that is used to determine if the null hypothesis that two populations have equal means is true and this test allows for standard deviations to be different and is almost as powerful as the Student's t-test[47]. Ordinal logistic regression can explore the relationship between variables while retaining some of the nuances in a Likert scale that would be lost in simple comparison of means or performing a standard regression[48, 49]. Appropriate analysis of Likert-type data is widely debated, but a range of analyses shows that while descriptive statistics show the clearest picture, parametric tests can be performed and yield reliable interpretations of trends and significance in the data set [50].

3. RESULTS

All nine participants completed the pre-survey, with eight completing the post-survey. Prior to completing the post-survey, participants were strongly encouraged to give constructive feedback to shape future iterations of the workshop.

3.1. Participants' Self-Efficacy and Workshop Perceptions

Table 3: Pre (n = 9) Post (n = 8) Test Differences on the *agreement* with statements regarding teacher self-efficacy and workshop interest.

Statement	Mean Pre	Mean Post	Difference
I feel confident teaching a module covering plant anatomy and physiology	3.44	4.57*	1.13*
The challenge of solving problems using science appeals to me	4.89	4.75	-.14
I can motivate my students to be interested in science	4.67	4.75	.08
Implementing current scientific research in my class is important	4.44	4.63	.19
Workshops are an effective way to learn new science content to be implemented in the classroom	5.00	5.00	0
I would attend additional science workshops like this one if given the opportunity	4.78	5.00	.22
I am interested in UAB faculty/ graduate students being guest lecturers in my class	4.67	4.88	.21
I am comfortable teaching a lab where I do not know the outcome	3.89	4.63	.74

Note: 5 Strongly agree, 4 Somewhat agree, 3 Neither agree nor disagree, 2 Somewhat disagree, 1 Strongly disagree

Prior to the start of the workshop, participants indicated agreement with statements about workshops being effective, desire to attend additional workshops, and have university faculty and graduate students guest lecture in their classrooms (Table 3). After completing the workshop, agreement regarding attending a similar workshop remained at 100% strong agreement, with interest in guest speakers and agreement about general workshop effectiveness moving up to 100% strong agreement and 63% strong agreement respectively. Although the change was not statistically significant, agreement about comfort teaching a lab where the teacher does not know the outcome shifted from 33% not agreeing to 100% of participants indicating some or strong agreement. Improvement in confidence about teaching a plant anatomy and physiology module was statistically significant at $p<.05$ using both ordinal logistic regression ($\chi^2 = 5.791$, df = 1, n = 8, p = .016) and a Welch's t-test for unequal variances ($t(11) = 0.003$, $p<.05$). The results showed an insignificant decrease in the agreement with the statement that the challenge of solving problems using science appeals to me. The statements I can motivate my students to be interested in science and implementing current science in my class is important had a slight increase in agreement upon completion of the workshop; however, the increase was not found to be significant (Table 3).

3.2. Participants' Familiarity with Plant Topics

Table 4: Pre-Post test descriptive statistics on familiarity with workshop content.

Field	Min	Max	Median		Mean		Std. Deviation	
			Pre	Post	Pre	Post	Pre	Post
Plant Awareness Disparity (PAD)	1.00	2.00	1.00	2.0	1.11	2.00*	0.31	0.87
Gel Electrophoresis	2.00	5.00	3.00	4.0	3.33	3.88	0.94	0.60
Endophytes	1.00	3.00	1.00	3.5	1.56	3.50*	0.68	0.50
Plant Anatomy and Physiology	2.00	4.00	3.00	4.0	2.89	3.88*	0.57	0.60

Note: 5 Extremely familiar, 4 Somewhat familiar, 3 Moderately familiar, 2 Slightly familiar, 1 Not familiar at all. Significance at $p<.05$ is indicated with *.

Familiarity with workshop content significantly increased for several topics. Prior to the workshop, 88% of participants indicated no familiarity with PAD, 44% were very familiar or extremely familiar with Gel Electrophoresis, 56% had no familiarity with Endophytes, and 66% indicated moderate familiarity with plant anatomy and physiology. After the workshop, there was a statistically significant increase as shown by a Welch's t-test in the familiarity with plant contents including PAD($t(9) = 0.030$, $p<.05$), endophytes ($t(15) = 0.00001$, $p<.05$), and plant anatomy and physiology ($t(14) = 0.006$, $p<.05$) as shown in Table 4. The increase in PAD, though significant, was smaller than expected. The workshop facilitators informally discussed this finding with all workshop participants, who said that they understood the concept and had made significant knowledge gains, but had not realized until the facilitators specifically asked them the connection between the content knowledge gained and the definition of Plant Awareness Disparity.

3.3. Prior Experience Teaching Plant and Biotechnology Content and Intent to Include in Future

Table 5: Post-test descriptive statistics on interest in including workshop topics in future curriculum.

Field	Min	Max	Median	Mean	Std. Deviation
Plant Awareness Disparity (PAD)	1.00	4.00	3.00	2.88	1.05
Gel Electrophoresis	3.00	4.00	4.00	3.75	0.43
Endophytes	2.00	4.00	4.00	3.50	0.71
Plant Anatomy and Physiology	4.00	4.00	4.00	4.00	0.00

Note: 4 Yes, planning to include, 3 Interested but unsure about future inclusion of content, 2 Unsure, 1 No, would not include.

None of the participants had prior experience with PAD. Only one teacher had previously used gel electrophoresis in their classroom, none of the participants had included endophytes, and only one participant was currently teaching plant anatomy and physiology in their classes at the time of the workshop. At the conclusion of the workshop (Table 5), 75% (n = 6) of participants wanted to include gel electrophoresis in their curriculum and 25% (n = 2) wanted to include gel electrophoresis but were unsure of how to implement it in their current. After learning about the importance of endophytes 62.5% of the participants were planning to include endophytes in the upcoming school year. After completing the workshop 100% of the participants were planning to include plant anatomy and physiology in the curriculum. After learning about the importance of endophytes 62.5% of the participants were planning to include endophytes in the upcoming school year. After completing the workshop 100% of the participants were planning to include plant anatomy and physiology in the curriculum.

3.4. Teachers' Feedback at the Conclusion of the Workshop

In the post-test, 100% of participants rated all workshop components (duration, daily meeting time, hands-on labs, speakers, and science content) as "just right." Prior to the workshop participants' goals for participation centered around themes of learning more hands-on labs to take back to their classrooms, increasing student engagement, and increasing the plant content in their classrooms. Post-test responses indicated that these goals were met. When asked about challenges teaching, participant themes centered around labs being difficult because of inadequate time and materials, as well as difficulties with student motivation and engagement. When asked about what they valued in the workshop, participants noted the opportunity to collaborate with other teachers as well as to meet and work with the graduate students and faculty. They also enjoyed the hands-on labs. Representative feedback is included in Table 6.

Table 6: Representative Statements of Participant Feedback of Valued Workshop Components.

Theme	Participant Quote
Collaboration	[I valued] Collaboration with teachers and scientists
Hands-On Labs	I enjoyed the hands-on lab activities. It was engaging and student-centered. Great selection of topics and student friendly laboratories. Overall I'm very happy about what I learned, and excited to apply in the classroom
Science Content	The combination of building content from the lectures and application of learned skills during labs.

3.5. Follow-Up on Incorporation of Workshop Materials into Classrooms

Following the fall school semester, approximately 4 months after the conclusion of the workshop, year 1 and year 2 participants were asked to complete a second survey about implementation of workshop materials in their classrooms. The follow-up survey had 52% response rate, with 11 of 21 year 1 and year 2 participants responding. Of these respondents (n = 11), 73% (n = 8) indicated that they had incorporated PlantGIFT workshop material into their classes. Participants reported incorporating all major workshop content including Gel Electrophoresis, Genetic Modification of Organisms, Endophytes, Climate Change, and Plant Anatomy and Physiology. Three participants utilized additional workshop supports offered including visiting the Principal Investigator's lab on a field trip, having PlantGIFT facilitators visit, and guest teach, and borrowing laboratory equipment. All (n = 8) participants agreed that participating in the workshop influenced their decision to include the content in their classrooms. Most agreed that their students enjoyed doing PlantGIFT-related labs and lessons, with one participant indicating disagreement but noting that they would still do the lab again in the future. All participants agreed that they would include the PlantGIFT-related content in their future instruction. These data are presented in Table 7. Participants who indicated that they had not included PlantGIFT workshop content in their classes were asked to select one or more of the following reasons: (i) Did not fit into my pacing, (ii) Did not align with my standards, (iii) Did not seem valuable to include, (iv) Did not feel like I knew it well enough yet, (v) Other (please describe). Of the three who indicated that they had not included content, two said it was due to pacing, with one having moved to teaching undergraduate students, and one selected "Other," indicating that they did not have a way to conduct the lab activities in their classroom. All participants were asked on the survey if they had encountered any difficulties when implementing lab activities; no one indicated problems. When asked about what additional supports they would like, two said they'd like to borrow equipment and others indicated that they would reach out if they needed anything from the PlantGIFT facilitators.

Table 7: Follow-Up Survey descriptive statistics on the *agreement* with statements regarding inclusion of workshop content in class

	Min	Max	Median	Mean	Std. Deviation
Participating in the workshop influenced my decision to include the related content in my classroom	4.00	5.00	5.00	4.62	.52
My students enjoyed learning PlantGIFT-related content/ doing labs from the workshop	2.00	5.00	4.50	4.25	1.04
I would include this content again in the future	4.00	5.00	5.00	4.75	.46

Note: 5 Strongly agree, 4 Somewhat agree, 3 Neither agree nor disagree, 2 Somewhat disagree, 1 Strongly disagree

4. DISCUSSION

Similar workshops have been shown to increase teacher interest in science content. Okafor et al.(2021) evaluated the effects of a professional development course in 31 high school biology teachers and found that the interest in teaching biology increased from 23% prior to the course to 91% at the conclusion of the course[26]. Despite coming to the workshop with a range of prior experiences, each PlantGIFT participant indicated that they benefited from attending and reported significant personal growth as an educator. These findings, although preliminary, suggest secondary science teachers are interested in, and receptive to, the incorporation of plant-based science in secondary classrooms through a problem-based learning approach. The data suggests that the participants of PlantGIFT were enthusiastic about the topics of biological sciences, enjoyed learning new skills, and were motivated to learn new skills and convey this knowledge to their students. Although not all of the areas measured showed statistically significant changes, nearly every domain remained strongly positive or increased in positive responses at the conclusion of the workshop. Participants were satisfied with what they had learned in the workshop and they expressed interest in attending additional workshops modeled after PlantGIFT if given the opportunity.

Teacher professional development workshop evaluation often lacks understanding of how the workshop translates to implementation[51, 52]. The follow-up survey indicated that participating in the workshop encouraged teachers to include workshop content into their classrooms and that they would do the lessons again with future groups of students.

Two content areas in which participants indicated significant knowledge gains were in genetic modification of organisms (GMO) and endophytes. Although GMO content knowledge was not specifically measured in this study, it was the basis of the gel electrophoresis labs and lectures and participants had robust discussions during the workshop. Both of these areas are essential for biotechnology and its applications. Endophytes have played a critical role in the evolution of green chemistry[53] and have been successfully applied in agricultural sustainability and environmental conservation[54]. Despite the fact that endophytes have been found to have numerous biotechnological applications (including pigments, bioactive compounds, industrial-use enzymes, production of nanoparticles, biodegradation, and bioremediation)[55, 56], few of the participants were familiar with endophytes prior to the workshop. The authors could not find any published studies on teacher knowledge of endophytes, but it is uncommon for teachers to receive much training on fungi and their microbial interactions[57]. Given that endophyte sampling is a simple and safe research project with many real biotechnological applications, this finding indicates secondary science teachers would benefit from learning about this in more depth. A study asking teens (ages 10-19) about their interest in plants revealed that students were more interested in plants as they related to medicinal and stimulant uses than their uses as foods or spices[58]. Pany's study (2014) did not ask about biotechnological applications or the potential for plant-based technology to address global problems.

Slightly better studied, however, are student views on GMOs. A study of 11th graders found that over 80% had little or no understanding of GMOs or the process of genetic modification, but about 78% expressed negative views and concerns about the use of genetic modifications in plants[59]. This speaks to both the paucity of biotechnology in school curriculum and the susceptibility of students to absorbing opinions based on hearsay, rather than what they have learned through formal instruction. Penn & Ramnarain (2018) also found that students at a school with a more robust science program had higher GMO literacy and this higher literacy corresponded to more favorable attitudes towards GMOs. This is consistent with studies of adult participants, which indicate that those with greater levels of scientific literacy have less opposition to genetic modification of food[60, 61]. In principle, a greater scientific literacy typically corresponds to an increased ability to make more informed decisions about socioscientific issues[62], such as decisions surrounding the genetic modification of organisms. The workshop participants enjoyed having discussions surrounding the genetic modification of food for nutrition and climate-hardiness. While not every participant was in favor of genetic modification of food, all participated in rich and respectful discussions of many possible scientific and ethical considerations. In the scientific community, scientific language and claims are sometimes influenced by ethical, economic, and political claims surrounding the GMO debate[63]. Thus, it is essential for science educators and researchers to consider all angles of a debate and recognize that "best science" doesn't always translate to "best practice", without the inclusion of ethical considerations. By encouraging bioethical discussions in secondary science classrooms, both the value of biotechnological advances like GMOs[64] and the ethical considerations that surround them can be realized and fully appreciated[65].

The importance of labeling and transparency was one topic participants brought up throughout the GMO conversation. Collectively, they suggested that they would like to know what kind of genetic modification has taken place. For example, they would be in favor of genetic modification for drought resistance, but felt hesitant about supporting genetic modification for pesticides. Their considerations are in line with research showing that the public needs more details on GMO labeling[61].

Studies have shown that students' interest in science starts to decline during late primary school, drops sharply at the primary–secondary transition, and turns into a negative attitude toward science as the students receive further education[66]. However, most biology education research today focuses on the outcomes of undergraduate students who completed a biology course or are majoring in biology. Few studies focus on the K-12 teachers, despite the paramount role they have played in educating these students prior to enrolling in an undergraduate biology course or program. Furthermore, few studies focus on how to best assist K-12 teachers so that their biological content knowledge and didactic toolbox stay current and relevant. As scientific literacy is increased and climate change is addressed, we need to think about how we communicate scientific research with the public[67] and strategically build the next cadre of biology educators who are ready to tackle these challenges. Topics that engage students in real issues and contemporary discussions, and open doors to pathways aimed at developing solutions, such as the topics presented in PlantGIFT, can help build scientific literacy and future career pipelines.

Discipline-based research (DBER) is an emerging field of pedagogical research that investigates teaching and learning in a discipline, such as biology, chemistry or physics, using a wide range of methods that are deeply rooted in the discipline's priorities, practices, knowledge, and worldview. The main goal of DBER is to expand evidence-based knowledge and progress the practices of teaching and learning in the science, technology, engineering, and mathematics (STEM) fields[68, 69]. A distinguishing feature of DBER is deep disciplinary knowledge of what constitutes expertise in a discipline. This knowledge has the potential to guide research focused on the most important concepts in a discipline, thus offering a framework for interpreting findings about learning and which can build on findings from K-12 science education research[70].

The data reported in this study reflects a long-term project coming out of its pilot phase. As such, the data set is still relatively limited and should be viewed as a case study rather than a broadly generalizable trend. Repeating this workshop in other contexts would help to determine if the results are indicative of a wider trend. The workshop facilitators did maintain contact with some teachers following the workshop and were able to learn about some of their inclusion of PlantGIFT content in their classrooms during the subsequent school year. However, the study did not collect student data or conduct a longitudinal analysis of teachers' learning and self-efficacy gains. It will clearly be important to assess the long-term sustainability of this model.

With many schools now desiring career exposure and connections for their secondary students, teacher training such as that provided in the PlantGIFT workshop can offer a viable model for the incorporation of biotechnology skills into science classrooms. Like engineering, biotechnology is a creative field with unlimited room for innovation and growth, making it an exciting option for those who are interested in STEM careers and an engaging application of content for everyone. The PlantGIFT findings indicate that even a short (5-day), intense exposure to research can excite teachers and empower them to include more inquiry-based science in their classrooms. We also noted that the teachers were receptive to the real-world applications of the PlantGIFT alignment to the content which they looked forward to including in their upcoming academic year. PlantGIFT is particularly useful in that it is cost-effective and does not require the safeguards needed for most studies of animal genetics. The lack of classroom inclusion of more recent research appears, in part, due to a lack of teacher knowledge rather than a lack of teacher interest, suggests that the scientific research community should continue to find ways to disseminate their work to the K-12 community in ways that are accessible for teachers and their students.

Future investigations into the long-term relationships formed from the partnership between science teachers and UAB faculty will be evaluated using surveys and interviews. Students of the teachers who successfully completed PlantGIFT should be interviewed, in addition to the graduate students and faculty who facilitated the workshop. We believe there is a bi-directional benefit for both the teachers and the scientists who participated in the workshop.

There is a gap in literature surrounding secondary science teacher knowledge of current biotechnology skills and topics, not unexpected given the very rapid pace of scientific discovery. As these fields continue to advance, they will offer promising careers for solutions to significant global problems to those who are prepared and open to pursuing such directions. Thus, it is imperative to identify what teachers know and design other professional learning opportunities to provide them with the knowledge and tools necessary to prepare their students for active participation in the scientific research community.

5. CONCLUSIONS

PlantGIFT is a unique professional development workshop that brings together plant geneticists and middle and high school teachers to implement current research in the classroom. This approach used hands-on activities and modern laboratory experiments aligned with Alabama and national standards that covered the major emerging themes in genetics. Despite its pilot nature, PlantGIFT had positive impacts providing both content familiarity and confidence to teach core concepts in genetics. Moreover, workshops like this one can be powerful tools to improve science literacy for middle and high school teachers and have the potential for broad dissemination through similar educational institutions.

ACKNOWLEDGEMENTS

This work was funded under NSF Award #IOS-2038872 to MSM and KMP-M; and NIH SEPA award R25 GM132967 to JMW.

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