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Broadening the impact of plant science through innovative, integrative, and inclusive outreach

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Abbreviations: ABRCMS, Annual Biomedical Research Conference for Minority Students; AFRI, Agricultural and Food Research Initiative; AISL, Advancing Informal STEM Learning; ANNHI, Alaska Native-serving institution or a Native Hawaiian-serving institution; ART-21, Arabidopsis Research and Training for the 21st Century; ATE, Advanced Technology Education; BPSF, Berkeley Public Schools Fund; BUSD, Berkeley Unified Public-School District; CADRE, Community for Advancing Discovery Research in Education; CC, Creative Commons; CLEAR, Communication, Literacy and Education for Agricultural Research; CRS, Community Resources for Science; DEI, Diversity, Equity and Inclusion; DOE, U.S. Department of Energy; DOI, Digital Object Identifier; EDSIN, Environmental Data Science Inclusion Network; ESSA, Every Student Succeeds Act; EWD, Education and Workforce Development Program; FASEB, Federation of American Societies for Experimental Biology; FFA, Future Farmers of America; GMO, Genetically Modified Organism; GRC, Gordon Research Conference; HBCU, Historically Black College or University; HHE, High Hispanic Enrollment Institution; HHMI, Howard Hughes Medical Institute; HSI, Hispanic Serving Institution; ICAR, International Conference on Arabidopsis Research; IHE, Institutes of Higher Education; ISP, Institute for School Partnership; ITEST, Innovative Technology Experiences for Students and Teachers; K-12, Grades of primary education from kindergarten to 12th grade; K-14, Kindergarten to associate degree; LGU, Land Grant University; MANRRS, Minorities in Agriculture, National Resources and Related Sciences; NAASC, North American Arabidopsis Steering Committee; NANTI, Native American-serving nontribal institution; NCSU, North Carolina State University; NGSS, Next Generation Science Standards; NIH, National Institutes of Health; NSDL, National STEM Education Distributed Learning; NSF, National Science Foundation; PBI, Predominantly Black Institution; PDAL, Professional Development for Agricultural Literacy; PR, Public Relations; PreK-12, K-12 grades with preschool; PWI, Primarily White Institutions; RCN, Research Coordination Network; RET, Research Experiences for Teachers; REU, Research Experiences for Undergraduates; SAPS, Science and Plants for School; STEM, Science Technology, Engineering and Math; TCU, Tribal Colleges and Universities; UCB, University of California, Berkeley; USDA, United States Department of Agriculture.

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Abstract

Population growth and climate change will impact food security and potentially exacerbate the environmental toll that agriculture has taken on our planet. These existential concerns demand that a passionate, interdisciplinary, and diverse community of plant science professionals is trained during the 21st century. Furthermore, societal trends that question the importance of science and expert knowledge highlight the need to better communicate the value of rigorous fundamental scientific exploration. Engaging students and the general public in the wonder of plants, and science in general, requires renewed efforts that take advantage of advances in technology and new models of funding and knowledge dissemination. In November 2018, funded by the National Science Foundation through the Arabidopsis Research and Training for the 21st century (ART 21) research coordination network, a symposium and workshop were held that included a diverse panel of students, scientists, educators, and administrators from across the US. The purpose of the workshop was to re-envision how outreach programs are funded, evaluated, acknowledged, and shared within the plant science community. One key objective was to generate a roadmap for future efforts. We hope that this document will serve as such, by providing a comprehensive resource for students and young faculty interested in developing effective outreach programs. We also anticipate that this document will guide the formation of community partnerships to scale up currently successful outreach programs, and lead to the design of future programs that effectively engage with a more diverse student body and citizenry.

1 | INTRODUCTION

Science is under attack and the United States of America represents a frontline in mutiple anti-fact and anti-scientific method movements (Attacks on Science, 2020). These efforts violate the basic reasoning behind societal changes needed to slow climate change, and more recently, to allow for a coherent response to the COVID-19 pandemic. We believe that as plant scientists working in the United States, we need to be more innovative, inclusive, and integrative in how we engage with students and the public to reverse these worrying trends (Figure 1). We define students here to be those individuals that dedicate part or full time to their education through a formal program offered by K-12 or institutes of higher education. Greater effort is needed to inspire wonder at the magnificence of plants, and to train the next generation of scientists who will leverage the power of plants to ensure long-term sustainability and health of our global society (see Box 1). This pressing challenge requires plant scientists to question the standard approaches we currently use to engage students and the public at large.

This document is an effort to shift our academic culture towards greater public engagement and service through outreach, which we define as those activities aimed at engaging members of the public, both nationally and internationally, that are outside of the immediate professional community (see Box 2). We holistically evaluate how plant science outreach programs are designed, implemented and shared and identify six major challenges in broadening their impact that also define the organization of this document.

Section 2: Overview of the major challenges in plant science outreach. We first discuss the challenges in outreach that are specific to plant science as a field.

Section 3: Understanding context-specific challenges to outreach and engagement of students in plant science. Whatever the area of science, student needs vary widely across different educational contexts and we explore a range of challenges and opportunities that exist specifically in the US.

Section 4: Current state-of-the-art in plant science outreach—case studies. We provide an overview of the current state of the art in plant science outreach programs and delve deeper into a few programs that have proven to be effective.

Section 5: Funding outreach—How are outreach programs financially supported? Outreach programs usually require external funds

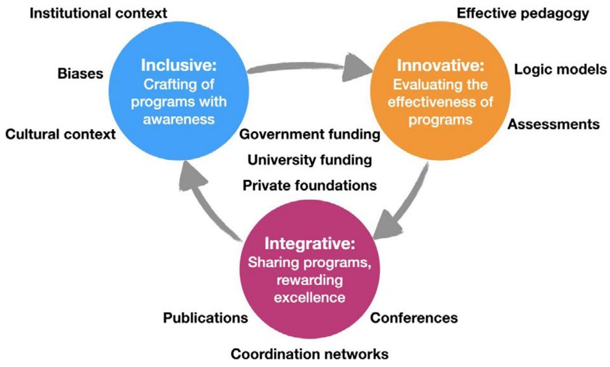

FIGURE 1 Advancing outreach in plant science through Inclusion, Innovation and Integration. Successful outreach programs thrive when a holistic approach is taken. Inclusive programs are crafted with awareness of the demographic, cultural and institutional contexts they exist in. Innovative programs use the state of the art organizational models in their design and devise a means of evaluating their effectiveness through assessments appropriate to their scale. Integrative programs communicate their outreach efforts across labs and institutes to disseminate and share what works. All of these activities need to be supported by an ecosystem of funding from the government, universities and private foundations that recognize excellence across these areas

BOX 1 Questions we address in this document.

Innovative: How do we create, evaluate, reward and share outreach activities that work in plant science?
Inclusive: How do we excite the imagination of a broader section of our society to appreciate and focus attention on plant science?
Integrative: How do we better integrate the members of our diverse community to ensure we are more than the sum of our parts?

BOX 2 What do we mean by outreach?

Outreach encompasses those activities aimed at engaging members of the public that are outside of the immediate professional community. Public engagement includes communication of professional activities and new research findings to the general public, or specifically to students and educators at all levels, government organizations and business entities. In this document, we highlight activities in the K-16 grade range, though engagement with the public outside of an academic setting is also addressed.

to have a broad impact and we describe the current relevant funding sources and suggest new potential mechanisms to support this important work.

Section 6: Evaluating outreach—How do we know if a program works? Evaluating the efficacy of outreach programs is integral to making funding decisions and ensuring that needs and objectives are met. We describe useful metrics and mechanisms to evaluate the breadth and depth of the programs enacted.

Section 7: Disseminating outreach—How do we scale up and reward programs that work? Finally, if a program is innovative, inclusive, and integrative, there may be opportunities to scale it up or share it with others to provide a model for future innovation and adaptation. We discuss current and future ways that such programs can be disseminated and how leaders in the development of these programs can be rewarded for their excellence.

1.1 | How to use this guide

This guide is meant as a starting point for advancing the success of science outreach. If you are a science professional or educator initiating an outreach program, this guide provides a comprehensive roadmap of the various contexts, considerations, and resources available that will help you in crafting your program and getting it funded. For those who are experienced in science outreach, this guide can help to identify areas where you can innovate and increase the impact of your program. For leaders in the field, this guide will provide a reference to train others in effective outreach. Whether you are at the beginning of this journey, or are well versed in outreach, we thank you for the passion you bring to your efforts and the desire to pair this passion with rigorous planning and implementation.

2 | OVERVIEW OF THE MAJOR CHALLENGES IN PLANT SCIENCE OUTREACH

> "It's not easy being green."

Kermit the Frog.

Plants are ubiquitous. In addition to their essential role in providing sustenance, they are symbols of beauty, have inspired mathematicians, represent gifts from gods in many cultures, and were pivotal in the establishment of human civilization around the world. We give them as gifts, wear them, burn them for warmth, discover and develop their medicinal and therapeutic uses, and rest under their shady branches. As major players in the carbon cycle, they are key in the fight against climate change. In short, our ability to survive and thrive on this planet is inexorably linked to their success and our understanding of their unique biology.

While history shows that knowledge of plants was a cornerstone of the advancement of civilization, further advancing our knowledge of plants will be ever more important. Climate change will affect the stability of crop yields and other plant ecosystems (Lobell et al., 2014). By 2050 predictions are that global demand for plant-derived calories and protein will at least double with respect to

2005 levels (Tilman et al., 2011). A significant increase in crop productivity, quality, or innovative land-use approaches will be needed to match the demand for food expected from population growth (Godfray et al., 2010). However, yield trend projections suggest that current rates of increase will not satisfy future needs (Figure 2a; Ray et al., 2013). Predicted increases in CO_2 levels, higher temperatures and more extreme weather, and decreases in water and nutrient availability will all impact crop production and add additional uncertainty to our ability to maintain food security (Hatfield et al., 2011). These challenges will require efforts to increase productivity and nutritional quality beyond current practices, including through improvements in crop water-use efficiency (Gago et al., 2014; Martignago et al., 2020) and enhanced crop photosynthetic efficiency (Ort et al., 2015), to name just two approaches. Knowledge of plant biodiversity and methods to discover metabolic innovations in plants will be needed to expand the sources of food, medicines, and other products that maintain and enhance quality of life.

To tackle these challenges, a talented, passionate, and diverse community of plant scientists will be needed. Unfortunately, the current training pipeline cannot ensure the availability of this type of workforce. As a recent commentary states (Jones, 2014), the number of PhD degrees in biomedical sciences awarded in the US in the last two decades has increased at an unsustainable rate, even triggering warnings from members of the National Academy of Sciences (Alberts et al., 2014). In comparison, plant science doctoral degrees, both fundamental biology and agronomy-related, have remained stagnant during this time period (Figure 2b; Jones, 2014). This is in contrast with the 4.12% projected annual increase in jobs for Soil and Plant Scientists (Career Outlook & Job Vacancies for Soil & Plant Scientists, 2021). Clearly, renewed and innovative outreach efforts to transform public perception of careers in plant science are necessary to meet future challenges and workforce demands. Furthermore, we must shift the outdated narrative of a rigid career "pipeline" to a flexible "pathway" that reflects the reality that people today move in and out of educational systems and take different routes in their careers. The concept of an ordered, rigid, step-by-step career path is less frequently applicable to 21st century science careers; such a shift requires that all relevant entities make adjustments to framing outreach, mentoring, training, and professional development (Friesner et al., 2017; Henkhaus et al., 2018).

2.1 | Lack of plant awareness

Recruitment of a diverse, talented and driven workforce to plant research is plagued by a general lack of plant awareness. This concept, introduced as plant blindness by Wandersee and Schussler, is defined as the failure of individuals to "see or notice the plants in one's own environment, leading to the inability to recognize the importance of plants in the biosphere and in human affairs or to appreciate the aesthetic and unique biological features of the life forms belonging to the Plant Kingdom; and the misguided, anthropocentric ranking of plants as inferior to animals, leading to the erroneous conclusion that they are unworthy of human consideration" (Wandersee & Schussler, 2001). Such views consequently discourage interest and engagement by the public and students at all levels (Knapp, 2019; Ro, 2019). Note that a more contemporary and less ableist phrase is "plant awareness disparity." Furthermore, the inherent nature of plants, wherein they appear to only respond to stimuli slowly through growth and development, can lead many to view them as less complex, less sophisticated, and therefore less intriguing to study than other forms of life.

Contemporary research questions in plant sciences do not permeate our teaching curriculum at the K-12 or university level to the extent that reflects their importance. This is due to both structural and cultural factors at our institutions. The lack of plant awareness

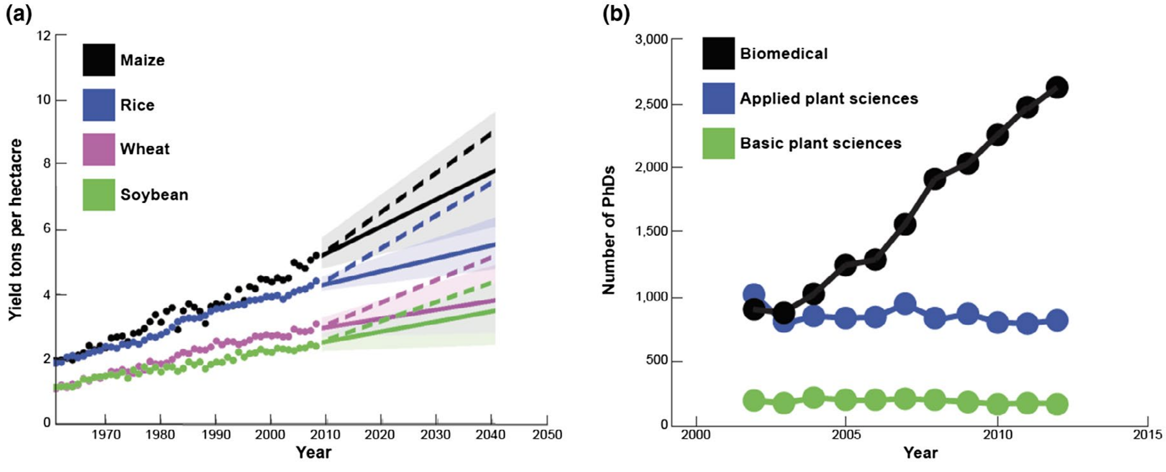

FIGURE 2 Trends in global food demand and number of PhDs awarded in biomedical and plant science fields. (a) Current yield trends are insufficient to address food demands by 2050. Global projection of yield trends indicates a deficit to achieve the needed doubling in crop production by 2050. Closed circles indicate measured yield for the four main global crops until 2008. Solid lines are the projections following the measured trends, and the dashed lines show the yield increase needed to double production in each crop by 2050 without adding additional land. Data regraphed and adapted from Ray et al., (2013). (b) The number of PhDs in applied and basic plant science has not kept up with trends in other disciplines. Data regraphed and adapted from Jones (2014)

affects those most removed from agricultural and natural environments, such as students in urban K-12 schools and institutions of higher learning (Wandersee & Schussler, 2001). Within higher learning institutions, non-biology majors may not be exposed to plant science at all. Within biology majors, introductory and intermediate courses often provide little significant exposure to plant science research and there are few specialized plant courses at colleges and universities. This both limits access to information about plants and to contemporary plant science research. Furthermore, plant science faculty not in plant-specific or agricultural departments are often a minority within a department or university/college and thus have limited influence on curriculum decisions.

The lack of coursework in plants profoundly impacts early stage undergraduates who are making choices about what courses to take, which major to choose, or which career path to pursue. For example in 2020, Stanford University, one of the leading universities in the US, offered only two courses that mentioned the term "plant biology" in Autumn 2020, while over 27 mentioned "cancer." This deficit at the undergraduate level impacts later cohorts as incoming graduate students may be unfamiliar with the leading edge of plant research and thus may not be interested in considering plant research. If they do engage in plant research, they may need to spend a disproportionate amount of time "catching up."

Especially at institutions without majors in the plant sciences, career counseling centers and other networking and support organizations may be unaware of the many viable career paths available to plant scientists. These challenges result in students failing to make the vital connections between plant science and societal and global challenges that are needed right now. Outreach activities by plant scientists serve to directly inform others about the importance of plants and close this disconnect by actively promoting the value of plant science and its relevance to other sciences and daily life (Moscoe & Hanes, 2019).

2.2 | Scientists typically lack training in how to translate plant research into effective outreach programs

Plant scientists, though eager to participate and deliver outreach activities, often face their own challenges to create and implement effective outreach activities. Many aspire to develop high quality, broad-reaching, long-term, sustainable programs that are institutionalized and community-wide. Given that training to deliver such endeavors are not typically required components of PhD training programs, developing and coordinating the logistics of such activities can be daunting for new faculty members. Although enthusiastic early career scientists can often connect well with students, these efforts may be viewed as peripheral to their immediate career goals by institutional and departmental evaluators. Faculty peers and university administrators may not value or support outreach efforts, when, for example, metrics of success are weighted more heavily toward scholarship and grant funding.

2.3 | Effective outreach requires resources that are frequently limited

Outreach efforts may require several types of resources, such as trained personnel, meaningful activities that are planned and pretested, spaces for work and engagement, equipment, reusable and disposable materials, and sometimes, giveaways. All of these are likely to require funding. Federal funding for outreach activities through NSF is typically tied to a specific research project which may run on two, three or five-year funding cycles that require renewal applications for expansion and sustainability. Thus, the likelihood of an outreach activity being supported is typically dependent on an associated research component. Thus, even grant applications with extremely well-conceived outreach activities can be turned down if the research component does not rank highly enough during review. Academic institutions may support development of outreach activities through their office for education and outreach, which typically provides resources for connecting with K-12 educators, science coordinators and outreach experts. However, these offices are often under-funded and under-staffed, making it a challenge to provide sufficient support for those seeking to initiate outreach activities that are not tied to a federally funded research program.

2.4 | Implicit biases limit the effective scope of an outreach program

All scientists should receive implicit bias training in order to recognize unconscious prejudice and accompanying behaviors that might reduce or negatively influence their outreach efforts. During outreach events, volunteers must take care not to inadvertently cause subtle discrimination (Brownstein, 2017). Microaggressions, which are subtle intentional or unintentional actions that affect a historically marginalized group, can deter students from participating in future outreach events and from science in general (Harrison & Tanner, 2018). There may be a socioeconomic gap between outreach volunteers and community members, which can lead to the feeling of "We don't understand them, they don't understand us." As another example, a volunteer might say to a female participant or a person of color, "It's great that you're interested in plant science! Are you the first person in your family to consider going into science/going to college?" While the intent of the volunteer may have been to cultivate enthusiasm and express encouragement, the message conveyed is that the recipient should feel that its unusual, even unexpected, that someone "like them" shows interest in science or higher education, and consequently that they do not "belong" in science. People who regularly receive these subtle messages may be discouraged from pursuing science; if they do persevere to the college level, they are more likely to leave university degree programs than peers of comparable talent (Harrison & Tanner, 2018).

3 | UNDERSTANDING CONTEXT-SPECIFIC CHALLENGES TO OUTREACH AND ENGAGEMENT OF STUDENTS IN PLANT SCIENCE

> "For me context is the key – from that comes the understanding of everything."

Kenneth Noland, abstract painter.

The types of educational institutes available to students are increasingly diverse, as are the student populations they serve. Outreach programs need to be tailored to meet specific contextual challenges (Varner, 2014; Wandersman, 2003). The general lack of persons of color in academia make it more likely that racial and cultural differences must be bridged to gain the attention and trust of a diverse audience. Furthermore, there is still a significant cost to persons of color in entering primarily white institutions (PWIs) and academic spaces that have associated implicit or explicit expectations that compel people of color to shed their cultural identities as they enter. We must go beyond a focus to increase diversity through recruitment alone, and shift to supporting retention and persistence through "inclusive diversity." Inclusive diversity centers on institution-centered approaches that will change the culture of science and education so that students feel that they belong and that the system expects them to be successful (Asai, 2020).

3.1 | K-12

Ensuring access and opportunity for K-12 students to explore their interest and ability in science is an issue nationwide. Local, state, and federal support for public schools can vary widely. Data from 2018, adjusted for variations in regional costs, showed Vermont and Alaska to have the highest expenditures per pupil at $20,795 and $20,640 while Utah spends the least at $7,207; the national average per pupil is $12,526 (Education Week Research Center, 2018). Much of federal and state funding is tied to results from standardized tests focused on reading and math. The Every Student Succeeds Act (ESSA) formerly known as *No Child Left Behind* seeks to improve educational equity and outcomes by providing federal funds to school districts serving low-income students. ESSA requires annual testing in reading and math for grades 3–8 and once in high school. States must also test students in science once each in elementary, middle, and high school (Education Post, 2020).

Due to the dominant focus on reading and math in K-8 assessment, teachers in this grade range frequently lack training in the sciences (National Academy of Sciences, National Academy of Engineering, & Institute of Medicine, 2007). Considering that implementing hands-on inquiry-based activities in the classroom is particularly challenging, the quantity and quality of elementary and secondary science education can differ markedly. The development of the Next Generation Science Standards (NGSS; https://www.nextgenscience.org), released in April 2013, with subsequent adoption by states, sought to update science education by redefining core ideas in science and scientific practice.

Despite these efforts to develop more meaningful education goals around science education, a focus on plant science at the K-12 level still lags far behind that of other sciences (Anderson et al., 2014; Krosnick et al., 2018). This means that plant-based outreach efforts outside of the core K-12 curricula are even more critical. Disparities in science education are particularly evident in more rural and lower-income urban areas; in the former students may come from farming environments, yet have few outreach options available to them due to distance from universities and other institutions that offer such programs. Many urban school systems in economically depressed locales have faced significant funding cuts for decades; simultaneously, urban schools with higher concentrations of URM students receive fewer resources than predominantly white and affluent urban schools. Combined, these fiscal challenges result in unequal education and access to in-school and after-school science opportunities in lower income urban communities (Smedley et al., 2001). Overcoming these challenges requires increased commitment to include plant science in the core K-12 curriculum and increased training opportunities for K-12 teachers via plant-focused summer Research Experiences for Teachers (RET) programs, and funding for students to travel to outreach activities.

3.2 | R1 (non-land grant)

The Carnegie Classification of Institutions of Higher Education defines R1 institutions as those that emphasize research, offer extensive baccalaureate and graduate programs, and award 50 or more doctoral degrees each year. These institutions receive at least $40 million or more in federal funding and are considered by many to be "the pinnacle of higher education." R1 universities (including land grant institutions) accounted for 37% of science and engineering (SE) bachelors degrees in the USA in 2015 and 72% of doctorates (Science & Engineering Indicators, 2018).

The majority of life science faculty at non-land grant R1 institutions are typically focused on biomedical research, with funding for life sciences research coming from NIH rather than NSF and USDA. These institutions are often associated with medical schools, and if so, include clinical as well as basic research. At these institutions, life science students generally begin their undergraduate career highly focused on biomedical careers, with the large majority hoping to enter medical school. Knowledge of alternative career paths is minimal unless the institution actively engages in career counseling that includes non-medical tracks. Most undergraduates do not enter these universities with a strong background or interest in plant science, thus recruiting them into plant science courses and laboratories is a challenge. Without a critical mass of faculty with expertise in plant science these topics get left out of the introductory biology curriculum. Even when knowledgeable faculty are available to teach plant-specific courses, they often must be taught at an introductory level, due to lack of preparation in lower level courses. The lack of advanced undergraduate courses in plant science makes such institutions less attractive to students that might have an interest in plant science, creating a self-reinforcing cycle. Faculty performing research in plant science at these institutions can recruit undergraduate researchers, but may find it difficult to identify students that are motivated by an interest in research, as opposed to a primary objective to secure a letter of recommendation for medical school.

3.3 | R1 land grant universities

Established by the federal land-grant law in 1862, land-grant universities (LGU) are public institutions whose original mission was to train students in agriculture, classical studies, mechanics, and military fields, but have since evolved to teach a wide variety of additional disciplines, including business, education, veterinary medicine, design, and social sciences, to name a few (Council & National Research, 1995). University guidelines or state laws often mandate that LGU serve the needs of individual states and thus predominantly take local students, with quotas allocated to specific counties (e.g., by law the University of North Carolina system can enroll no more than 18% of freshmen from out of state (Pennington, 2016)). Nonetheless, the make-up of the undergraduate student body of LGU is usually more diverse than non-land grant R1 institutions in terms of family income levels and ethnicity, and includes students that are from underrepresented groups, first-generation college attendees, Pell Grant eligible students, as well as transfer and international students. In some states, imposing quotas on local attendees translates into admitting to LGU a greater percentage of students from rural areas. Consequently, a significant proportion of students are interested in agriculture and life science majors, including plant science. In contrast to private institutions, at many LGU, a diverse body of plant sciences faculty are available with expertise in basic plant science, horticulture, crop sciences, plant pathology, forestry, and/or ecology.

One unique aspect of LGU is the availability of University-affiliated extension specialists that work directly with farmers, growers, and other local interest groups to communicate the research that takes place at the universities to the stakeholder communities, to make immediate impacts on local agriculture. Students at LGUs thus have numerous opportunities to participate in translational research, as well as lead local Future Farmers of America (FFA) and 4-H groups, and participate in other outreach activities. Faculty and students at LGUs are fortunate to also have access to research stations that make field-based experimentation on plants a realistic endeavor, and frequently benefit from the availability of botanical gardens, university student farms, and herbarium collections that enhance training in plant systematics.

Despite these advantages, LGUs face many of the same challenges as other types of academic institutions when it comes to student plant science engagement. Again, plant science-related majors compete for students against the more popular biomedical career paths. With plant science funding being far lower, and the career route being more obscure than that of health-related majors, plant science programs often struggle with recruiting talented students. This is further exacerbated by the growing trend of plant science content being cut from general biology curricula, leaving a large proportion of biology students without any exposure to plants throughout their collegiate experience. Other disturbing trends are that, in an effort to save money, some LGUs chose to cut extension positions (Administrator, 2002; O'Leary, 2015), while others take the opposite stance and reduce the number of fundamental plant scientists' positions and thus shift the emphasis towards more applied areas of plant science at the expense of foundational disciplines.

3.4 | Non-R1, elite liberal arts, comprehensives

Non-R1 four-year universities and colleges awarded a larger number of science and engineering bachelor degrees than R1 universities (63% versus. 37%) in 2015, thus representing a major source of students entering PhD programs at R1 universities (Science & Engineering Indicators, 2018). However, most of these institutions do not have PhD programs in the life sciences and receive very modest amounts of funding to support research; students thus have more limited opportunities to engage in authentic research experiences compared to students from R1 institutions. As with the non-land grant R1 institutions, a significant challenge faced by many non-R1 universities and liberal arts colleges is a lack of faculty members with expertise in plant science, making it difficult to cover plant science topics in introductory biology courses, and especially difficult to offer research opportunities in plant science. Students at these institutions thus may receive limited to no exposure to plant science research, and may not gain an appreciation of the significance of plants to human wellbeing. Addressing this contextual challenge largely depends on University/College commitments to hiring faculty and lecturers with expertise in plant science.

3.5 | Minority serving institutions

Minority Serving Institutions (MSI), as defined by the Higher Education Act of 1965, are a federally recognized category of colleges and universities that serve students from underrepresented groups. There are seven categories of MSIs and their enrollment constitutes almost 30% percent of all undergraduates enrolled in higher education institutions in the US (Espinosa et al., 2017). Historically Black Colleges and Universities (HBCUs) are MSIs established prior to 1964, whose principal mission is the education of African Americans/Blacks. These include the public HBCU LGUs in the Southern US that were established through Congressional legislation in 1,890 in response to the LGUs established in 1862, which were restricted to whites only. HBCUs were established first in the North, and after the civil war, in the southern USA. They expanded in the Jim Crow south to meet the letter of the law to provide access to higher education for African Americans/Blacks. These segregationist policies included the serious underfunding of these institutions; still today, HBCUs receive less funding than required by federal law due to failure by individual states to provide adequate support (John Michael Lee & Samaad Wes Keys, 2013).

There are 102 HBCUs across the nation and in 2015, they awarded 16% of the 54,000 science and engineering bachelor degrees earned by black U.S. citizens and permanent residents and represent the baccalaureate origin institution for nearly 30% of black science and engineering doctorate recipients from U.S. universities (Science & Engineering Indicators, 2018). Despite their track record in training African American/Black students in fields such as agricultural sciences and biological sciences, few of their students pursue advanced degrees in plant sciences, largely due to the lack of plant-centric undergraduate and graduate curricula and faculty who specialize in plant sciences Women, Minorities, & Persons with Disabilities in Science & Engineering, 2017).

Hispanic serving institutions (HSIs) educate a rapidly growing demographic group and have grown as this population has expanded (Hispanic Association of Colleges & Universities, 2019). Between 2000 and 2015, the share of bachelor's degrees awarded to Hispanics among U.S. citizens and permanent residents increased from 7% to 13% in science and engineering (Women, Minorities, & Persons with Disabilities in Science & Engineering, 2017), while the proportion of Hispanics in the US who are between the ages of 20 and 24 in 2015 was 22% (Science & Engineering Indicators, 2018), suggesting that Hispanics are significantly underrepresented in higher education. More than one-third of Hispanic doctorate recipients earned their bachelor's degree from a High Hispanic Enrollment (HHE) institution (Women, Minorities, & Persons with Disabilities in Science & Engineering, 2017), thus these institutions play an important role in training undergraduates that then pursue advanced degrees.

One of the biggest challenges to participating in a research experience in the plant sciences for students at HBCUs, HSIs, and other MSIs is the lack of exposure to labs conducting plant science research. Faculty recruitment at these institutions is rarely committed to specifically hiring those with expertise in plant science. In addition, structural problems often exist whereby resources to complete research in general, and in plant sciences specifically, are limited due to systemic, persistent undervaluing and under-resourcing of institutions whose missions focus on educating people from historically underrepresented groups. There are a number of summer REU programs and bridging programs between MSI and predominantly white institutions (PWIs) that provide students from MSI with rewarding research opportunities at majority serving institutions (Whittaker & Montgomery, 2014). However, the capacity of these programs is insufficient to serve all students at MSIs who might be interested in research in plant science. As the nation becomes increasingly diverse, the need to address disparities in funding and support for programs at MSIs, which train and serve the bulk of students from underrepresented groups, becomes more urgent.

3.6 | Community colleges

Community colleges are accessible and affordable, serve an increasingly diverse population, and offer a great variety of degree programs and pathways for high-skill to mid-skill level jobs. Community colleges play a substantial role in addressing workforce needs and in developing the talent pool of students who may pursue a science degree. The demographic profiles of community college students share some characteristics that distinguish them from four-year college students. Community college students are more likely to be members of under-represented minority groups or to be single parents. They are often older, include a greater proportion of first-generation students and are more likely to take developmental (also known as remedial or basic-skills) courses than their peers entering four-year institutions. For example, in California, eight out of ten community college students are first enrolled in developmental courses before taking courses that can be applied towards a degree (Preparing Students for Success in California's Community Colleges, 2016). Community colleges are popular destinations for students due to their lower cost, increased accessibility (The College Board, 2014), and proximity to students' homes, relative to 4-year institutions.

Community colleges are often criticized for low student graduation rates. Although individual estimates of community college graduation rates vary, some suggest that less than 30 percent of those who enter community college will graduate with an associate degree within two to four years. For the U.S. overall, 13.3% of all students who started at a community college had completed a bachelor's degree at any four-year institution within six years. This completion rate was 9.0 percent for lower income students and 19.6% for higher income students (Shapiro et al., 2017).

3.7 | Online educational resources

Online courses in plant science that are offered at no cost have the potential to reach a broad population of users and are increasingly important due to COVID19 restrictions. However, a challenge to effectively reaching a diversity of students is that the content has to be reimagined into short, engaging segments with content appropriate for students at various educational levels. Converting an online course into short modules requires time and expertise, such as videographers, video and sound editors, and technology support. Additionally, personalization for a broad spectrum of skill levels is difficult since prerequisites are typically not required. Unfortunately, access to online education is limited to those with access to the internet with sufficient bandwidth. If the internet is not affordable or not available in certain geographic locations, online courses may need to be formatted for mobile devices. Another challenge to long-term sustainability is archiving the material and ensuring the content remains updated.

3.8 | Addressing context-specific challenges

To meet the challenges outlined in the preceding sections, university committees that oversee educational curriculum must recognize that plant science should be a core component of introductory biology coursework as well as coursework for non-majors. To teach these topics/courses, it is important for all universities to include a critical mass of plant scientists among their tenure-track faculty. Such faculty, along with their laboratory personnel, enable outreach opportunities to the community on plant-related topics. In this way, and when implemented across the range of institutional types, plant science becomes a core, equitable and supported component of undergraduate biology education that can readily, and sustainably, attract students. For example, medicinal or therapeutic usage of plants, food security and safety, social justice and food access, and traditional plant knowledge are several topics that may engage more diverse, or non-traditional, students with plant science. These courses or seminars can also be developed through collaborations with relevant departments outside the traditional plant science or botany departments, such as food science, Native American/Indigenous studies, or political science. Established programs like pre-college summer experiences, summer Research Experiences for Undergraduates (REU) programs, and paid research assistant positions in the labs of plant faculty can also serve as effective recruitment tools that have the power to shift how undergraduates view plant-related careers and make non-medical paths an attractive, clearly laid-out alternative for biology undergraduates.

4 | CURRENT STATE-OF-THE-ART IN PLANT SCIENCE OUTREACH—CASE STUDIES

> "If we don't plant the right things, we will reap the wrong things. It goes without saying."

Maya Angelou.

While outreach activities can never replace the necessary plant science instruction provided by educational institutions, they do provide powerful opportunities to reach people who would otherwise miss the importance of plants and plant science to their lives. It is also increasingly important that plant scientists, and indeed all scientists, share with the general public the passion that they have for their profession and relate their activities to shared societal benefits. "Outreach" is the broad category under which scientists and the science-passionate do the work of engaging members of the public around scientific topics—but in practice this term can mean many things. Here we define "Outreach" as any activity that invites members of the public to interact and engage with science through interactions with practicing scientists (see Box 3). Irrespective of whether outreach is outside of, enriches, or is essential to one's professional activities, outreach is typically meant to be enjoyable or fun—a way for science novices to experience the joy of science and discovery, which is ultimately what will keep an audience engaged, and what will motivate scientists to continue to put in the hard work necessary for a successful program.

Within STEM and science outreach, plant science provides a user-friendly, accessible and universally-relevant entry point (see Box 4). Volunteer participants often gain experience in communication, teaching, mentorship and policy that fosters empathy and understanding of lay persons' perspectives on scientific topics of concern such as GMOs (Genetically Modified Organisms). Once students are introduced to the value of, and gain an appreciation of, outreach, they often continue these efforts throughout their careers. In addition, graduate students or postdocs sometimes discover a passion for teaching or policy, thus forging new career paths. Here we highlight current case studies in plant science outreach that successfully take kinesthetic, auditory, reading/writing, and visual approaches to outreach (Table S1).

BOX 3 Plant science outreach programs vary in terms of program goals, participants, intended audiences and methods of conducting outreach.

Program goals may communicate knowledge such as the skills needed to become a scientist, knowledge in both general and specific scientific topics, passion and joy of scientific discovery, and what it is like to be a practicing scientist.

Program participants/intended audiences may include K-12 students, teachers, and parents, university or college students, local community including parents of kids, K-12 teachers, government, and policy makers. Programs can be tailored to or involve a specific audience or set of audiences or it can be relatively undefined. Outreach can also take place in traditional educational settings—such as classrooms or alternative venues like museums, farmers markers, etc. where you have expectations about the types of attendees but where significant variability may exist. With podcasts or public online social media you might have an initial audience you have in mind—but nearly anyone can listen, with consideration for those individuals with limited access to internet technology. Outreach activities can focus on particular demographics—underserved—underrepresented in general—women/girls, member of an under-represented group in STEM, rural or urban. Numbers of involved participants can also vary dramatically and programs can scale differently depending on their activity/platform.

The methods of conducting outreach include in-person and virtual activities. For example, school classrooms or after school programs; a community setting such as a museum, farmers market, gatherings in community spaces, zoos or botanical gardens. Digital and online resources may be developed for use by teachers and educators as well as non-traditional educational resources such as podcasts.

4.1 | Case study for K-12 outreach – *Be A Scientist* partnership

One example of an in-class scientific program adopted by a public-school district is *Be A Scientist*—a partnership between the University

BOX 4 Outreach experiences, audiences and goals.

Possible Experiences:

- In person "one-off" events: Public lectures, Science fairs, Guided nature hikes, Campus visits
- Activities integrated into school curricula: Classroom activities with active scientist participation, Enrichment programs designed with scientists, Scientists teaching in class
- Informal science: Science or technology museums, Art exhibits with scientific content
- Digital Media: Documentaries or science videos, Podcasts, Science websites, Webinars & Q&As, Social media

Possible Audiences:

- General public (can be all ages or more adult focused)
- School children (some level in K-12)
- Undergraduate students
- Smaller groups based upon access or background such as members of under-represented groups in STEM or people with disabilities

Possible Goals:

- Science learning & literacy
- Fostering interest in science
- Fostering interest in pursuing science as a career
- Nurturing scientific curiosity or wonder
- Seeing oneself as a scientist
- Promoting an increased appreciation/value in the work of scientists
- Promoting trust in scientists

of California Berkeley, the Berkeley Unified Public-School District (BUSD), Community Resources for Science (CRS), a local science education non-profit, and the non-profit Berkeley Public Schools Fund, which helps catalyze and fund programs that enhance excellence and equal opportunity in the Berkeley Public Schools.

The *Be A Scientist* program, which has operated for over 5 years, is a six-week module taught in each BUSD middle school. Berkeley middle schools are economically, ethnically and racially diverse; 55% of the students are members of underrepresented groups in STEM (19% African-American, 24% Hispanic, and 12% mixed race) and 45% are from low income families. The program recruits UC Berkeley STEM graduate students and postdocs as volunteers that mentor small groups of 7th graders to design, conduct, and present an independent research project of their own design.

Students are taught important scientific concepts like controlled experiments and replication, which allow students to assess the validity of their results themselves. The program allows for individualized guidance and support to students and is designed to provide equal access to science instruction and resources for all BUSD seventh graders; in the past, this type of scientific project was performed by a few students working after school-hours on science fair projects. This design supports the school district in implementing the statewide Next Generation Science Standards (NGSS), which emphasize scientific skills and concepts that cut across disciplines. The learning outcomes include: igniting an interest in science, developing the skills of a scientist and first-hand knowledge of the process of scientific inquiry, developing confidence in their scientific ability, and normalizing scientists as people like them. Long-term goals of the program are to help develop the next generation of diverse scientists and to help create an educated citizenry that is familiar with the scientific process.

The *Be A Scientist* program outcomes are assessed from the perspectives of the ~700 participating 7th grade students, the seven involved classroom teachers, and the ~140 UC Berkeley STEM mentors. Overall, teachers have welcomed the individual support their students receive, and are enthusiastic about the opportunity to have students meet and engage with a wide range of diverse scientists and engineers. Students have indicated strong enjoyment in picking their own experiments, working on their own questions, and having a "cool" scientist mentor. Pre- and post-project evaluation scores indicate increased student understanding of the purpose and process of scientific research, slightly increased interest in science career pathways, and increased awareness of the importance of science in everyday life.

4.2 | Case study for new media – The Taproot podcast

Over the past decade, access to new media—defined here as mechanisms for communication and education that make use of existing digital platforms—have made new types of outreach possible (see Table S2). These tools typically have a low barrier for entry as they can be accessed online from anywhere in the world, and can be used for education, recruitment and retention. In addition, the young communities that scientists are typically trying to reach are frequently familiar with, and excited about, new media. Novelty can be a powerful attraction, but can be a barrier when those creating content are unfamiliar with the latest and most popular platforms. Examples of new media include Slack, Facebook groups/pages, Twitter, Instagram, YouTube Videos, Online Courses, TikTok, Twitch, and Podcasts. Hashtags like "#PhDLife", "#plantbiology" "#BlackBotanistsWeek" or "#iambotanist" can help identify posts of interest on Twitter or Instagram. Below, we highlight the use of podcasts as a case study for the use of new media.

Podcasts are essentially digital magazines that deliver audio content to a subscriber on a regular basis (often, weekly). In general, podcasts provide a conversational and personalized entry into challenging scientific or other content. A major advantage is the ease of production—all that is required are recording equipment (computer, digital recorder, microphone, and headphones), editing software (ex. Audacity, Hindenburg Journalist, or Adobe Audition), and a podcasting host site (ex. Soundcloud) for online distribution. Similarly, there are few barriers to access content; in fact 40% of people over the age of 12 have listened to a podcast (Demographics of Social Media Users & Adoption in the United States, 2019). Studies suggest that podcast audiences are racially diverse (Making the Connection Between Podcast Fans & Their Purchase Behavior, 2017), though information on the gender and economic status of audiences are still missing. Recruiting, supporting and promoting diverse podcast producers and hosts as well as diverse audiences is a challenge for the future.

Podcasts can easily provide information, mentoring, and a sense of community to geographically or socially isolated individuals. About 1,000 science podcasts are currently active (MacKenzie, 2019). Several examples of podcasts related to plant science are listed in Table S2. Podcasts have different outreach, retention, or inclusion goals. They can be used to deliver scientific information to the public (e.g., In Defense of Plants) to discuss recent results and methods for the plant science research community (e.g., Plants and Pipets), or help build and broaden communities (e.g., GradCast, the Taproot). The latter type, in particular, can help normalize the challenges and experiences of trainees and reduce the sense of isolation that can be part of the academic experience.

In early 2017, Ivan Baxter and Elizabeth Haswell started *The Taproot* Podcast (tagline: "We tell the story behind the science") with support from the American Society of Plant Biologists (ASPB), Plantae, and NSF. In each episode, the co-hosts discuss the publication of a paper with one of its authors, addressing those narratives that are not represented in a final manuscript—such as technology development, work-life balance, career gaps, gender discrimination, racism, and student mental health. Ultimately, the goal of *The Taproot* is to foster a sense of belonging, agency and community among plant science trainees, thereby improving diversity and inclusion.

To date, 32 episodes over five seasons have been broadcast and were downloaded over 81,000 times. According to a survey in the summer of 2018, 46% of the listeners identify as female, over 50% are PhD students and postdocs, and 85% are in North America or Europe. The active @taprootpodcast Twitter account (>1900 followers) serves to advertise new episodes, foster discussion, and solicit feedback—and to reach as broad an audience as possible. The podcast has been well-received by the community, and has been covered on public radio (2 St. Louis Plant Scientists Use Podcast to Dig Deep into the Struggles of Research, 2018) and in Nature Careers (Kwok, 2019).

4.3 | Case study for community outreach: *CLEAR*

In the arena of community outreach, it is important to build common ground, to take other people's concerns seriously, to listen, to empathize, and to speak in language they can understand. In a program established at UC Berkeley called *CLEAR* (Communication, Literacy and Education for Agricultural Research, https://clear-project.org, Figure 3) student researchers are mentored to reach out as scientists to the public to introduce them to scientific research on plants and other topics.

The overarching goal of *CLEAR* is to encourage and empower undergraduates, graduate students and postdoctoral fellows to communicate with the public regarding what scientists do and why they do it, with a particular emphasis on plant and microbial biology. Since its inception in 2015, the *CLEAR* program has attracted increasing numbers of students with interests in engaging with the public. But the largest increase in interest occurred following the 2016 election, when students became especially concerned about the dangers of science denial and

FIGURE 3 *CLEAR* outreach program. *CLEAR* members (a) isolating DNA from veggies at Bay Area Science Festival (b) talking about food waste at Downtown Berkeley's Farmers' Market (c) talking about citrus diversity at Downtown Berkeley Farmers' Market (d) teaching in a CRISPR-in-the-Classroom high school class. (e) *CLEAR* PubScience event featuring a UC Berkeley astrophysicist talking about extraterrestrial intelligence

"fake news" relating to science. The impact of climate change on the world's poorest people is also of concern to much of the *CLEAR* project's organizers, whether it is as agricultural economists, conservation researchers, plant biologists or microbial geneticists. More recently, addressing misinformation surrounding SARs-CoV2 and COVID19 has become increasingly important in discussions with the public.

CLEAR activities fall into four general categories: *CLEAR* in the Community, *CLEAR* in the Classroom, *CLEAR* on Campus, and *CLEAR* in the Capital. In the most active program, *CLEAR* in the Community, *CLEAR* Fellows and their peers set up tables at Farmers' Markets with new themes each month, featuring activities for kids and information for adults on diverse topics. At these events, students have discussions in lay language on their own research, climate change and GMOs. Another monthly event, PubScience, involves off-campus gatherings to engage with the public about varying science topics such as paleobotany and astrobiology. In the face of the Covid-19 pandemic these activities have ceased and organizers must find new ways, through webinars, blogs and other social media venues to try to reach the general public.

CLEAR is a voluntary program run by practicing laboratory research scientists, carried out in their spare time, with no formal training in science communication (Figure 3). Thus, activities need to fall in line with their own interests, where they can invest their creativity in developing and engaging in activities that they develop and about which they get excited. One element that is key to the success of such a program is the establishment of mentorship resources for student volunteers. An experienced mentor provides guidance and support to empower students to effectively follow their own interests in developing outreach activities.

4.4 | Case study for outreach at the intersection of science with other disciplines: the SciArt movement

Through the 19th century, art and science were commonly intertwined; some of the most prominent scientists were also incredible artists, and vice-versa. This can be seen in the work of Leonardo Da Vinci, the beautiful illustrations of Ernst Haeckel (Sierzputowski, 2017), the writings of the philosopher and poet Johann Wolfgang von Goethe (Coen, 2001), or the exquisite glass models of Leopold and Rudolf Blaschka, (Brown et al., 2020). With the specialization of modern sciences in the 20th century came an increasing dichotomy between science and art. However, life sciences have retained a strong artistic component: observational drawing remains an integral part of the learning process.

Over the last 30 years, with the development of modern imaging techniques (e.g., microscopy, CT scan, X-rays), biological research has generated a tremendous number of images and videos. These have not only helped solve many scientific questions, many of them are also aesthetically striking and have the potential to spark the interest of an audience much broader than the scientific community. Microscopy competitions like the Nikon's Small World (2021) or Olympus Bioscapes (Bioscapes Gallery, 2021) and scientific imaging contests like the FASEB BioArt (2021) or the Royal Photographic Society's International Images for Science (The Royal Photographic Society's International Images For Science Exhibition, 2021) have gathered a lot of attention in mainstream media and often involve plants as the subjects of the art pieces. There has also been a renewal of interest in the intersection of science and art—or SciArt (BioArt in the case of biology)—both from artists whose work is inspired by science, and from scientists whose work is in part driven by aesthetics.

A small but growing SciArt movement is bringing together artists and scientists through social media, publications (Editors, 2016; Plasma, 2021; SCIART MAGAZINE, 2021), artist residencies in laboratories (RESIDENCIES, 2021), public talks, and exhibitions. These collaborations between artists and scientists bring new perspectives on scientific questions, and can have a positive influence on research (Hoel, 2018). SciArt can also be used to bring scientific questions to the attention of the general public. The Digital Nature public exhibitions at the Los Angeles County Arboretum, for instance, showcase botany-inspired digital artworks (Digital Nature, 2019). SciArt can also be specifically designed in collaboration between artists and scientists to share the beauty of the natural world with the general public (Hangarter, 2000). Art has long been used to communicate about science and retains a great potential for outreach in the future.

5 | FUNDING OUTREACH—HOW ARE OUTREACH PROGRAMS FINANCIALLY SUPPORTED?

> "Fundraising is the gentle art of teaching the joy of giving."

Henry A. (Hank) Rosso, a founder of the Center on Philanthropy and founding director of The FundRaising School at the Center.

A variety of funding options for outreach programs are available and vary in scope, scale and intended audience (Table S4). The funding available to start up a new creative program is often different from that available to sustain an already established program. For instance, an outreach program may be initiated as part of a research project funded by a 3-year NSF Broader Impact aim and then transition to a stand-alone independent program, perhaps from support by a private foundation. Of course, some programs may run their course and need to be replaced or substantially modernized.

5.1 | Funding available at the federal and state level

NSF grant applications must include a "Broader Impacts" section, which often describe the design, development and delivery of activities that facilitate meaningful sharing of scientific research with the public. This mechanism for funding is available to NSF-funded investigators to support any STEM education outreach activities and programs. Stand-alone funding for outreach is also available. For example, NSF's Advancing Informal STEM Learning (AISL) program supports outreach programs that provide pathways for broadening access and engagement with STEM learning experiences in informal environments.

Specific NSF funding schemes are also available to provide either direct (from NSF) or indirect (from an awardee institution) funding for improving student learning through science curricula development, training or retention. The NSF's Innovative Technology Experiences for Students and Teachers (ITEST) program is a research and development program that supports projects that promote PreK-12 student interests and capacities to participate in STEM using information and communications technology. It supports the design, development, implementation, and selective spread of innovative strategies for engaging students in technology-rich experiences that: (a) increase student awareness of STEM occupations; (b) motivate students to pursue educational paths to STEM occupations; or (c) develop disciplinary-based knowledge, and promote critical thinking and communication skills needed for STEM occupations. ITEST supports projects that broaden participation of students from underrepresented groups in STEM fields.

The NSF's Advanced Technological Education (ATE) program in Biotechnology, Biology, Chemistry emphasizes learning in two-year Institutions of Higher Education (IHEs), and involves partnerships between academic institutions (grades 7–12, IHEs) and industry to promote education of science and engineering technical staff at the undergraduate and secondary school levels. ATE supports curriculum development, professional development of college faculty and secondary school teachers, mentoring in career pathways and other activities. The NSF's National STEM Education Distributed Learning (NSDL) program aims to establish a national network of learning environments and resources for STEM education at all levels. Two tracks, Pathways I and II, serve communities of learners by supporting educational and outreach opportunities for undergraduate students, graduate students, and K-12 educators.

Outreach activities that involve enrichment and training opportunities for teachers may receive funding from the NSF's Robert Noyce Teacher Scholarship program or through Research Experiences for Teachers (RET) supplements to existing NSF research grant awardees. Within the NSF's Directorate for Education and Human Resources, STEM education researchers may find support through the Community for Advancing Discovery Research in Education (CADRE) and the Discovery Research PreK-12 (DRK-12) program. The DRK-12 program invites proposals that address immediate challenges in preK-12 STEM education as well as those that aim to test different structures of preK-12 teaching and learning. The NSF's S-STEM program supports collaborations among different types of partners: STEM faculty and institutional, educational, and social science researchers as well as partnerships among IHEs and local business and industry, if appropriate, to increase the number of low-income academically talented students obtaining degrees in STEM and entering the workforce or graduate programs in STEM. The program also supports projects that generate knowledge to advance understanding of how factors or curricular and co-curricular activities affect the success, retention, transfer, academic/career pathways and graduation rates in STEM of low-income students. The S-STEM program particularly encourages proposals from 2-year institutions, Minority Serving Institutions (MSIs), Historically Black Colleges and Universities (HBCUs), Hispanic Serving Institutions (HSIs), Tribal Colleges and Universities (TCUs), and urban public and rural institutions.

The United States Department of Agriculture (USDA) National Institute for Food and Agriculture (NIFA) has many programs that provide support for plant science and agriculture education. The Agriculture and Food Research Initiative (AFRI) focuses on developing the next generation of research, education, and extension professionals in the food and agricultural sciences. The AFRI Education and Workforce Development Program (EWD) addresses projected shortfalls of qualified graduates in the agricultural, food, and renewable natural resources sectors of the U.S. economy. AFRI EWD has three main goals: (a) Enhancing agricultural literacy through institutional grants for in-service training, which will provide K-14 (referring to K-12 and vocational training) teachers and administrators with increased knowledge of food and agricultural science disciplines and career opportunities, and help them develop improved curricula to enhance plant science and agricultural literacy, (b) Developing career pathways by promoting research and extension learning experiences for undergraduates, and (c) Advancing science through graduate and postdoctoral fellowships to cultivate future leaders who are able to solve emerging agricultural challenges of the 21st century. The Professional Development for Agricultural Literacy (PDAL) program, formerly known as PD-STEP (Professional Development Opportunities for Secondary Teachers), supports opportunities for K-14 teacher enrichment in plant science and agriculture.

Another federal agency that supports STEM education is the U.S. Department of Energy (DOE), which funds plant research related to bioenergy. At the state level, partnerships developed with state Departments of Agriculture, Conservation, Natural Resources, etc. may provide funding support from the state government for programs that align with their public education initiatives. Teaming up with state offices that support 4-H, FFA, and other youth development groups have also been fruitful.

5.2 | University level

Many IHEs have outreach offices that can assist in establishing collaborations and seeking funding for outreach efforts. University Offices of Community Interaction/Public Communications will likely have information on pre-existing programs as well as contacts for community resources. The Office of the Provost for fundraising may have specific engagement or outreach officers who can provide information on community contacts, funding opportunities, and pre-existing efforts. Notably, university faculty likely will have limited access to contacts that are reserved for university development activities. Therefore, alternative sources of funding must be sought. The Office of Education within a university or college is a place to find local K-12 teachers with established connections to the institution through student teacher programs. This office will also have information on special training that may be required to work with young people. Some institutions have existing dedicated student/postdoc groups focused on outreach. We highlight several such programs in the "Case Studies" section of this report.

5.3 | Private and public foundations

There are numerous private, public and corporate foundations in the United States that support STEM outreach. A private foundation is a nongovernmental, nonprofit organization that derives its funding from a family, an individual, or a corporation. Many large corporations establish a private foundation to direct its philanthropic activities. The principal fund of a private foundation is managed by its trustees or board of directors, who award grants to other nonprofit organizations. A grantmaking public charity, sometimes referred to as a public foundation, derives its support from diverse sources which may include other foundations, individuals, and governmental agencies. Most community foundations fall into this latter category.

One place to search for funding opportunities in individual states is Stemfinity (STEM Grants, 2021). Private foundations may not always maintain a website, so a useful site for getting information on outreach support is also the Foundation Directory Online (2021). In this searchable site (which requires a membership fee), keywords can be used to narrow down the scope to a reasonable number of potential grantmakers with shared visions. A wide range of funding opportunities can be found with information on grantmaker profiles, recipient profiles, decision makers and leaders, grant requirements, as well as types of grants being made and amounts given. Often, local, regional and state foundations have higher rates of funding of outreach support or program sponsorship than federal or state agencies.

The Howard Hughes Medical Institute (HHMI) is a leader in biomedical research. The HHMI's grants program enhances science education at all levels, from early grade levels through postdoctoral training, and HHMI sponsors workshops available to teachers. In 2011, the HHMI, in collaboration with the Gordon and Betty Moore Foundation, began supporting investigators working in plant science. Scholarships are available to undergraduate through graduate students. Plant science-related outreach materials can be found on the HHMI Biointeractive website (BIointeractive, 2021). Outreach efforts also involve the field-testing of materials for classrooms. The development of plant science educational materials of high quality that could potentially be disseminated by the HHMI would be a worthy endeavor for the plant science research and education community to address the public's lack of "plant awareness".

In addition to foundation support, funding from private donors with a keen interest in science and STEM education can also be quite successful (Cramer, 2020). Various professional societies including the American Society of Plant Biologists (ASPB Education & Outreach, 2021) and the Botanical Society of America (BSA Education & Outreach, 2021) offer awards, programs and other outreach resources.

5.4 | Case study for sustainable funding: the Institute for School Partnerships, Washington University in St. Louis

Funding to support University-K-12 school partnerships is a constant and pressing concern for universities. Diminishing donor bases, donor fatigue and short-term state and federal government funding are squeezing charitable giving, leaving fledgling outreach programs vulnerable to shifts in funding and challenged to implement a strategic long-term vision. Most funding opportunities that support "broader impact" programs provide seed money for the development of the program, but are non-renewable. Often, just when the program is reaching a high level of success with implementation, the funding cycle ends, and the resources to support personnel and activities are no longer available. This is extremely disappointing to both program participants and designers, and can diminish the original intent of the effort.

The Institute for School Partnership (ISP) at Washington University in St. Louis, founded by Sarah Elgin, Professor in Biology, and led by Victoria May, Executive Director and Assistant Dean in Arts & Sciences, has faced this funding challenge for the past 30 years. Successful strategies have been opportunistic and worked synergistically through partnerships with influential individuals and diversified funding sources. This case study illustrates the necessity for concentrated and sustained time, energy and personnel to maintain a consistent and stable funding stream for broader impact activities by writing grants, cultivating relationships with corporate and foundation representatives, school administrators and teachers, conducting focus groups with school district leadership and teachers to assess needs and financial capacity, and focused stewardship and communication with all funders.

In the 1990s, during the early days of the ISP outreach center, May partnered with scientists to develop proposals to submit to the NIH Science Education Partnership Award, the HHMI, and the NSF Mathematics and Science Partnership Awards. At this stage, ninety-five percent of the outreach budget was grant-funded, with in-kind space and services, and the remaining five percent of the budget was contributed by the University. The University faculty were key to the establishment of the outreach models; providing experience and skills in grant writing, as well as scientific expertise and credibility to establishing the importance of this work for the University. The ISP staff developed strong relationships with local school district leaders and teachers, co-taught with science faculty in workshops and courses for teachers, developed curricular materials to fill identified gaps, and assisted in writing and supporting broader impact activities. This pattern of funding and programming continued for approximately 12 years at which time the government grant funding options were exhausted and the ISP was no longer eligible to apply for the same funds. Unlike grant funding for scientific research, funding for partnership work is limited to one or possibly two rounds of funding even if the efforts are high quality and show significant impact.

After 12 years, both the faculty and the university administration understood the benefits of an established infrastructure for community engagement in broader impact activities and strengthening science education in local schools. Therefore, the administration agreed to provide university funds to support the Institute's director and an assistant. Eventually the University agreed to offer the courses at a reduced rate for teachers at partner schools. Next, the organizers began meeting with local corporations and foundation leaders to discuss the needs in the region and to build relationships. They continued meeting regularly and established a local consortium of funders interested in STEM, branded as STEMpact (STEMpact - Preparing. Connecting. Impacting, 2021). STEMpact currently funds four of the cornerstone professional development programs of the Institute and represents approximately one third of its funding.

To ensure the Institute's activities remained relevant, the organizers worked closely with the district teachers and administrators to better understand what the districts could, or could not, fund themselves, and outlined a science program to best meet these needs. This led to the mySci program, which serves over 100,000 students locally every year through books, exploratory science curriculum and materials, and on-going professional development for teachers and administrators. This fee-for-service program leases hands-on science kit materials and provides on-going professional development for school districts, and constitutes about one third of the institute's budget.

6 | EVALUATING OUTREACH—HOW DO WE KNOW IF A PROGRAM WORKS?

> "Everything must be taken into account. If the fact will not fit the theory—let the theory go."

Agatha Christie, *The Mysterious Affair at Styles*.

An essential step in the development of any outreach program is the establishment of specific goals and achievement milestones. Having these objectives clearly defined from the beginning allows program organizers, participants, and funding agencies to evaluate the success of the program and, if needed, to adjust approaches. In that regard, scientists should consider their outreach efforts to require some of the same management practices as their scientific research such as establishing goals and evaluating how well they are achieved. After all, science professionals put an effort into rationalizing the purpose of their research projects, setting and achieving realistic goals, and measuring the impact of their discoveries. Similar criteria apply when developing educational and outreach programs: Why should the work be done, what are the short- and long-term goals, and how well is the program meeting these objectives? Finally, program sustainability and scalability/transferability should be considered in the design and evaluation of the program.

Program evaluation serves several goals and is typically carried out by its administrators, participants, external stakeholders (e.g., funding agencies), and/or paid professionals. A first goal is as an assessment. A second important goal is to build a record of how the program evolves and, ideally, improves over time. The third reason is to provide the content for educational publications and reports that will be appraised by external evaluators such as museum coordinators, private donors, school officials, university administrators, or granting agencies.

6.1 | Using logic models to define program structure and goals

In the development of evaluation strategies, logic models are often employed to clearly define program structure and goals (Taylor-Powell & Henert, 2008). Serving as a graphical representation of a program, logic models allow for more effective program planning, implementation and evaluation, and are often required by funding agencies. Logic models may be thought of as a series of "If…Then" relationships (Figure 4) that can help to uncover gaps in logic, clarify assumptions, and connect investments to results. Logic models assist with planning (recognition of needed investments, key audiences, activities) and identification of expected outcomes. The use of logic models is an iterative process that can lead to improvements through evaluation of steps throughout the process, and may make a program more scalable and transferable. A simplified guide (whose modifications can be used as a starting template for any program) is shown in Figure 4.

6.2 | Successfully implementing your program

Beyond the scientific details of the program, there are logistics that should be considered well in advance, for example when booking venues. Considering venue accessibility, as well as the type of equipment required for the event, will ensure the best environment for the outreach activity. Email campaigns, virtual or physical flyers, and social media dissemination are valuable avenues for advertising and communicating to prospective participants. Prior to the event, volunteers should be well-versed on their assignments and provided all vital details, such as time and location of the activity, and encouraged to participate in question and answer sessions to ensure that the objectives of the activity are clear, that the process and outcomes have been discussed, that concerns and questions are addressed, and that contact information for activity leaders is shared and contingency plans are set in place, if last-minute challenges arise. If transportation is necessary, carpooling or public transportation coordination could be arranged by the organizer to ensure all volunteers arrive on time to the designated location. If volunteers require training, background checks, fingerprinting, or Tuberculosis (TB) tests (typically required when working with children), a longer timeline will be needed in advance of the event. Providing food or small incentives may also increase volunteer commitment and recognize their important contributions.

Consider collaborating with other relevant groups to expand the scope of the project, potentially increase the budget, and to engage additional volunteers. Sharing outcomes, successes, and

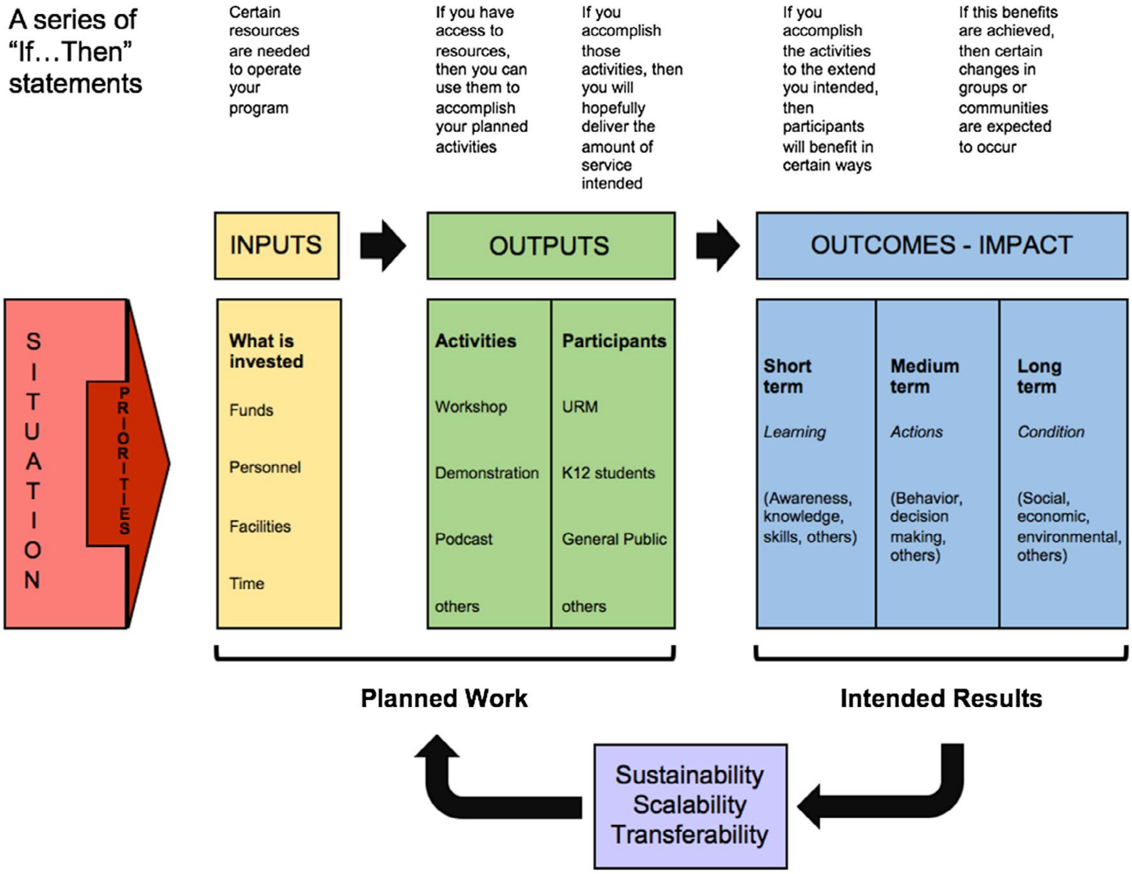

FIGURE 4 A logic model tool to aid in the planning and evaluation of the impact of outreach activities. A logic model is a hypothesized road map that presents the cause-effect relationships among the resources, activities, outputs, outcomes, and impact for a program. While it can be in the form of a narrative, it was commonly represented graphically to show the connection between the program's activities and its intended effects using a series of "if/then" statements. URM, Underrepresented Minority. Modified from (Taylor-Powell & Henert, 2008). While "URM'' is a commonly used term to indicate members of under-represented groups in STEM, as language evolves, new terms arise, including by members of the groups being referenced. Two more recent terms include "minoritized" (Minority vs. Minoritized, 2016) and "Persons Excluded because of their Ethnicity or Race" (PEER; Asai, 2020)

impacts, and "Thank You" notes immediately following the event are effective ways to retain members and encourage volunteers to attend the next event. Sharing pictures from the event is usually well-received; however, it is vital to obtain in advance consent from all participants to have their picture taken and shared. To be fully transparent, consider drafting an email or document that states whether the volunteer consents to their picture being taken and/or shared; sometimes, people consent to their image being taken in a group, but not alone.

In large-scale programs, such as those involving an academic institution and local school district, widespread buy-in is critical to the success of the project. First and foremost, consider it a priority to understand how and whether the project fits into the mission and values of the institution. If there is congruence, the next step is to seek and obtain written commitments (letters of support) from institutional leaders (President, Provost, Deans, Chairs and other appropriate administrators); this institutional support is key to success. Letters of support should include a statement of the goals of the project and how it fits into the mission of the institution and, ideally, a statement of in-kind, or other, often financial, support that the institution will make available to the project. A good practice is for organizers to draft bullet points and highlights of what should be included in the letter of support, to be provided to letter-writers so that they can most efficiently (and accurately) provide letters in a timely manner.

Getting faculty buy-in is just as important as buy-in from leadership. Faculty members are often the "boots-on-the-ground" who will implement the program and sustain it, and they are more likely (than staff, students, or postdoctoral scholars) to have positions of power within the University. They are key if the program is to become institutionalized. Open calls to participate are often ineffective to engage faculty. However, inviting key influencers in relevant departments often helps to break down barriers and encourage broader participation and ownership of large-scale institutional projects. Importantly, the proposed project should have clear benefits ("wins") for all departments involved; consider realistically that faculty members, their departments, and associated staff, tend to be pulled in many directions simultaneously and that the presentation of what one may consider an "opportunity" is often perceived as "a new risk or task" if the mutual benefits aren't clearly articulated and realizable. Be open to their input on activities and approaches; treating them as valued partners may achieve greater results and ensure goodwill and stronger buy-in. Institutional programs often start small, and good ones have a ripple effect that engages more people (students and faculty) into the program. A critical component for success is to engage an evaluator in the earliest stages of proposal development to ensure that there are clear objectives and ways to determine what "success" looks like. An expert in project evaluations can help to keep the project focused, prevent project "drift", and ensure that limited resources (funds, staff) are applied wisely and directed towards activities that achieve the stated objectives.

6.3 | Collecting and analyzing assessment data

Assessment data typically come from administrative databases, surveys and direct measures. Each of these has associated advantages and limitations. For example, administrative data can be comprehensive and provide information on funding allocation, volunteer and participant demographics, venue use demographics, and school enrollment and performance data. However, it is not always easy to access and manage these data.

Surveys are ideal for capturing student feelings about a programmatic activity and provide a point-in-time snapshot, but they often constitute an indirect measure of program outcomes and response rate may be low and subject to self-selection bias (self-exclusion of individuals). One way that survey response rates can be increased is if they are administered as part of the program. Coupled pre- and post-assessments are possible for programs with extended time frames, particularly those that serve student populations in formal venues (classrooms, courses). Surveys need not be qualitative; when well designed, they can also serve as direct measurements of learning outcomes. For example, The Science Learning Applications Lab tools (Table S3) for assessing scientific sensemaking provide examples that include a short description of, and the context for, a research question followed by multiple choice questions that test the ability to formulate a testable scientific question, design a controlled experiment, and assess and interpret evidence. In addition, the Applications Lab and other resources provide survey tools to (semi)-quantitatively assess the degree to which outreach participants are fascinated by science, value science, and feel science-competent (Table S3).

Direct measurements constitute one of the most important sources of assessment data; however, direct measurements are not always possible and require time to design, collect and evaluate. Direct measurements can include administrative data (e.g., undergraduate student grades in particular courses, retention in science fields, graduation rates, venue attendance rates, program participant levels), carefully designed surveys (discussed above), or other outputs. Direct measurements of outcome and impact can also be measured by external adoption and/or funding of outreach programs (e.g., by public schools). Finally, pictures may be 'worth a thousand words'. For example, a picture showing a booth with artifacts and students gathered around it can capture activities, interest level, and crowd size (Figure 5). In the case of the *Plants4Kids* outreach program (see case study below), formal evaluation of the success of the program through surveys proved difficult, in part, due to children's inability to write and unwillingness to part with coloring "voting ballots." In contrast, photos taken by volunteers during museum and school demos provide a good "alternative record" (Figure 5). It is important to receive permission from parents of underage minors if photos are to be publicly distributed.

If possible, it is helpful to meet with educational evaluators to assist in assessment development. In some cases, these personnel are associated with a University (e.g., UC Davis Center for Educational Effectiveness). Those without these resources can benefit greatly from online tools developed by educational researchers (Table S3). Alternatively, if funding permits, external assessors can be utilized; a best practice is to include within initial budget requests the appropriate resources to effectively assess and validate proposed programs and their impacts. External program assessment is often required by certain funding agencies and/or for larger outreach programs. For example, the services of Lawrence Hall of Science Research, Evaluation, and Assessment Group (Research, Evaluation, & Assessment, 2021) or independent evaluators (see, for example, American Evaluation Association and their blog can be engaged (AEA365 – A Tip-a-Day by & for Evaluators, 2021).

To perform research that involves human subjects, an Institutional Review Board's (IRB) approval may be necessary. IRBs ensure that the health and welfare of the participants are taken into account and ensure all Federal, State and Institutional guidelines are followed. IRB approval must be obtained before data are collected. Each academic institution will have a process outlined to submit an application for IRB approval through their Research Compliance Office.

6.4 | Challenges and limitations in assessing outreach programs

A successful evaluation entails measuring multiple facets of a program. Hence, without advance establishment of a clear design for evaluation, time allocation for each program component may not be appropriate and may result in an evaluation that does not reflect the program's outcomes. For example, evaluation of plant science-based activities often involves collecting both qualitative stories and quantitative data assessments. Without appropriate time allocated to collecting contextualized and nuanced stories of the impact of the program on participants, and on the community at large, the quantitative data collection, although faster, may be insufficient to adequately gauge impacts. A thorough (but also more time-consuming) program assessment design would appraise multiple aspects of a program:

FIGURE 5 *Plants4Kids* outreach program. Students participating in the "Plants 4 Kids" outreach program in North Carolina (images provided by Anna Stepanova [NCSU]). (a) A welcoming sign at a typical *Plants4Kids* museum demo booth. (b) Three-week-old light-grown pea plants sprouted in recycled yogurt cups: green peas and other legume seeds sold in pound-size bags at most grocery stores are inexpensive and large enough for young kids to handle with ease; museum visitors of all ages plant seeds during hands-on *Plants4Kids* demos and take the cups home to observe plant germination and growth. (c–e) Representative scenes from a Plants4Kids booth at the North Carolina Museum of Natural Sciences demonstrating active public engagement in the hands-on activities the program provides

(1) *Process evaluations* are a measure of the performance or completion of steps taken to achieve desired program outcomes (e.g., number of plant science based activity modules completed, number of classes held in a week, the length of lab sessions, etc.). The evaluation can take place throughout the project cycle allowing the assessment of effectiveness at each step and, if warranted, redesign of the program for maximum effectiveness. The process evaluation, if done at every step, requires a significant commitment of personnel time and of financial resources (that many projects lack), thus limiting the feasibility of such evaluation.

(2) *Output evaluations* are commonly used in lieu of process evaluations to help gauge program's processes (e.g., the number of participating students, of classes held, or of lab modules created from the project, etc.). These types of statistics are straightforward to collect and assess, but do not provide a measure of the quality of these activities.

(3) *Outcome evaluations* take into consideration specific program goals to determine if desired changes to attitudes, behavior, or knowledge of participants have been attained as a result of the program activities. Relevant metrics are collected at the beginning and at the end of a project cycle or program to infer how well the program was able to deliver the objectives set (e.g., whether plant-science-based activities have brought about a more positive outlook on genetic engineering or GMO foods). Output assessments may become difficult to coordinate and consolidate. When multiple similar programs are offered in parallel, biased conclusions may be reached if surveys are done only on a specific ethnic or age group instead of a representative sample of participants, or when extrapolating the data from a single site or several that are not representative of the overall composition of program participants.

(4) *Impact evaluations* seek to isolate a program's impact on participants and communities, while filtering out effects from other potential sources. Impact assessments are mostly experimental in nature where a group participating in a program is compared to a similar group not involved in the program. Major hindrances come from the lack of structured interviews or surveys to assess each participant in a consistent manner and from the lack of proper methods to compare data across individuals, groups, or sites.

Logistically, the implementation of all four types of assessments can become prohibitively time consuming and expensive and it is therefore unrealistic to impose the expectation that small-scale, low-budget programs implement these multi-level types of evaluations. In those cases, it is up to the program administrators to make a decision on the most efficient and cost-effective way of measuring the impact of their projects (Farrell & Mastel, 2016).

6.5 | The challenge of low survey response rates

One major drawback of formal evaluations is the typically low survey response rate and, accordingly, possible bias in who does, or does not, respond. Quality responses through active participation in the evaluation process have been historically low for all types of surveys (Groves & Peytcheva, 2008), including those that assess the impact of outreach programs. Even well established polling groups struggle with low response rates, a phenomenon that drives up the cost of obtaining a meaningful number of respondents. For example, the Huffington Post in 2008 showed that Gallup polling only received a 14% response rate for the US presidential election poll. The American Association of Public Opinion Research (AAPOR) has identified low survey response rate as a critical factor that undermines the value of evaluation reports (A Response Rates - An Overview, 2021). AAPOR concluded that "low cooperation or response rate does more damage in rendering a survey's results questionable than a small sample, because there may be no valid way scientifically of inferring the characteristics of the population represented by non-respondents.

Low survey response rates often stem from an inadequate questionnaire design, cost minimization efforts (mail, e-mail, or online surveys versus in-person questioning), lack of follow-up, and privacy and mistrust issues. Irrespective of the reasons, low response rates prevent effective program evaluations and introduce a bias by the presence of responses by only a small and potentially non-representative subgroup of participants. It is important to emphasize that the barriers to evaluation we highlight are not unique to plant science outreach programs, but are equally applicable to all types of program evaluations.

6.6 | Measuring the long-term impact of outreach programs

Another critical challenge with assessing programs' impacts is measuring long-term benefits to program participants. Given ever shifting demographics, mobile populations, and the fast pace of life, it is currently difficult, if not impossible, to track program participants over time to assess a program's long-term impact. Furthermore, even when tracking program participants is doable in some settings, it is not always possible to demonstrate causality, that is, a direct link between having been involved in a program, such as participation in an outreach activity as a child, and shifts in the mindset (e.g., better appreciation of science in general, or acceptance of GMOs more specifically) or in the career trajectory (e.g., more advanced course load in school, higher grades, a decision in favor of going to college or pursuing a graduate degree, etc.) later in life. Many of the changes in one's attitude or career aspirations are shaped by multiple factors, including family intervention, overall access to resources, involvement of caring teachers and supportive peers, or even chance life encounters like an exciting school field trip, an interesting book or movie, or an intriguing new neighbor. In fact, young people spend far less time in any given outreach or intervention program than with their peers, teachers, family, and friends, and thus are likely to be more affected by their social circle than any single extracurricular educational experience.

6.7 | Special considerations for assessing small-scale programs

A small outreach program might constitute the organization of a single event by an individual or small group. Based on their scale, small programs may best be assessed through tracking the degree to which participants display persistent interest in the program's activities. Self-reflection on the part of the organizers can also be useful, such as asking, "What was positive about the interaction? What worked well?" (Farrell & Mastel, 2016). Small-scale programs are usually simple enough that the organizer(s) can conceive the event only days or weeks ahead of time and still develop a detailed plan to ensure the success of the project. While many small-scale programs assess success informally, there are general approaches that will facilitate a successful activity and enable useful reflection and evaluation. A well thought out plan will clearly outline the goals of the project, define the intended audience(s), and articulate what "success" looks like (i.e., metrics).

Following an outreach event, an evaluation should be performed to determine if objectives were met, and to potentially adjust course based on lessons learned. Effective ways of evaluating small projects are to debrief with the members of your team, send out post-event surveys, and compare the results with the original objectives. Typically, small-scale projects are most effective when members feel like they share the values of the group and the event acts as a mechanism for community building. Seek honest input from all who participate, including volunteers, as their efforts are as necessary to success as the planning team, and they will have unique perspectives from being "on the ground" during the event. Their feedback may ultimately be the most useful when assessing and revising activities.

6.8 | General recommendations for assessing outreach programs

We conclude this section with a few general recommendations for developing and evaluating outreach programs. First, having a logic model in place can help with defining a program's objectives, structure and expected deliverables, and make the process of program evaluation and optimization more straightforward. Second, rather than having each research laboratory or organization reinvent the wheel, we encourage plant scientists to seek out programs and surveys that are proven successful and consider adopting (or adapting) those (Clark et al., 2016; Haywood & Besley, 2014). At many institutions, university-level entities and organizations can provide support with developing successful outreach programs in a myriad of ways, from sharing email lists of local biology teachers, helping to recruit volunteers, obtain required permits, provide vital staff support, or provide physical space or equipment for the project. On the other hand, it would be a major benefit to the entire plant science community if organized and resourced bodies or organizations, such as AAAS (American Association for the Advancement of Science), ASPB (American Society of Plant Biologists), HHMI (Howard Hughes Medical Institute), or the like, would take the lead to develop a common repository of program-associated materials (ranging from experimental protocols, to electronic visual aids, to games and coloring activities for kids, to evaluation surveys) to enable folks to share their success stories and/or learn from others who have succeeded. If plant biologists all work together as a community, as opposed to each lab "doing its own little thing," the impact of these programs could be greater.

6.9 | Case Study for using logic models to design and assess outreach programs: *Plants4Kids*

We illustrate the utility of logic models using the *Plants4Kids* program, a plant science outreach program for children (Figure 4). The program was initiated by the lab of José Alonso and Anna Stepanova at North Carolina State University (NCSU) in 2010 and consists of a dedicated bilingual web portal (in English and Spanish) and in-person hands-on demonstrations at local schools, museums, and community events (Plants4Kids Outreach, 2021). The objective of this initiative was to develop a set of simple, easily accessible, inexpensive (ideally, free), highly visual, and entertaining activities for children to spark their curiosity about plants and to teach the concepts underlying basic scientific methods in a fun and engaging way. 14 experimental modules were designed that make use of accessible plants (e.g., leaves and branches of trees), inexpensive seed sources (e.g., beans, lentils or peas from the pantry, seeds from a carved pumpkin or from a fresh cantaloupe, etc.), recycled plastic or paper containers for planting (rinsed yogurt cups, milk cartons, used disposable coffee cups, etc.), soil from outside (soil, mulch, clay, sand, etc.) or indoor paper waste (shredded documents, napkins, newspapers or junk mail) for the planting substrate.

The plants4kids.org website and monthly volunteer-driven demonstrations provide simple instructions on how to set up, run, record and interpret the experiments. Given that all of the materials required are readily available and nearly free, the primary investment (aka INPUT, see Figure 4) from the program organizers is volunteer hours, whereas hosting organizations (such as schools and museums) provide physical space and dedicated time slots at their venues. The OUTPUTS of this program are the activities available in the form of an instructional website (Plants4Kids Outreach, 2021) and recurring hands-on in-person demonstrations at local schools and museums run by NCSU volunteers. The key audience or the primary participants of this program are elementary school children, their caregivers (e.g., parents and teachers), as well as other website users and museum visitors. The short-term outcomes of the program are a greater appreciation of plants and science in general, fueled creativity, and better understanding of research methods and approaches. The desired longer-term outcomes of the program, which are more difficult to measure or attribute to a single program or factor, are greater engagement and performance of the youth in science-related coursework at school and, ultimately, a more diverse STEM workforce and a better educated general public that values science and trusts the body of scientific evidence.

All elements of the logic model (input, activities, output and outcomes, and impact) need to be measured quantitatively and/or qualitatively for use in iteratively refining and optimizing the inputs and activities. Program goals of sustainability and/or scalability also feedback to impact all elements of the logic model. While it is strongly recommended that all outreach programs develop a logic model to frame and define their planned work and intended results, assessments must be tailored to each individual program.

7 | DISSEMINATING OUTREACH—HOW DO WE SCALE UP AND REWARD PROGRAMS THAT WORK?

> "*There is more hunger for love and appreciation in this world than for bread.*"

Mother Teresa.

Recognizing excellence and scaling up a program should be integrated into a system that promotes outreach as a community value. For example, a student who has established a successful plant science outreach activity could be rewarded by the University with a certificate and funds to expand or disseminate the work. Recognition in an academic setting can also be considered a means for dissemination. In a profession where opportunities to speak at research conferences or publish papers is considered a form of professional recognition, opportunities to value and share our efforts in outreach are rich, yet underutilized.

7.1 | Disseminating outreach programs: an overview

Disseminating the outcomes of an outreach program is an important component of any outreach activity. Not only are such mechanisms commonly required for successful funding (e.g., the NSF "Broader Impact" criterion), dissemination affects the success of the outreach program itself and influences the broader scientific community. The goals of dissemination are varied and include knowledge sharing (sharing best practices/state of the art, propagating program ideas), program growth (recruitment of new participants, partnerships and/or funding), gaining recognition for activities, fulfilment of funding requirements, altering the culture of science, and increasing awareness of plant science/STEM. Every mechanism of dissemination may address only one, or some, of the possible dissemination objectives, so the dissemination plan for any outreach activity necessitates thoughtful attention (Colditz & Emmons, 2017; Dissemination Toolkit, 2021). Here we discuss common pathways for dissemination and consider the ways in which each mechanism can address several important considerations: What is the most effective way that this mechanism can support the spread of successful outreach programs? What is the dissemination mechanism best at in terms of dissemination goals? What are the drawbacks/challenges to the mechanism of dissemination? How could we, as a community, do this type of dissemination better? Are there buy-in problems within the community for this mechanism?

7.2 | Publishing papers

There are several types of publications that might arise from outreach activities, including the documentation of teaching pedagogy, citizen science-based results or outcomes from a training activity, among others. The advent of sound-science journals (where the importance of a manuscript is evaluated by the reader, not the editor or reviewers (Elsevier, 2017) provides an excellent opportunity to publish outreach related science projects, which may be more limited in their scope. For instance, plant research-based journals such as *The Plant Cell* offer the option to write short opinion pieces which might include discussion of effective outreach and engagement mechanisms in plant science. Additionally, publication fees from society sound-science journals go to support society activities such as outreach. However, there appears to be a gap between pedagogical journals and repositories where researchers can post unreviewed outreach activities. Filling that gap may require repositories of outreach activities that have been validated or curated so that other researchers can adopt successful research strategies. Another challenge of publications is that they are very time consuming to prepare and may only address some of the dissemination goals of the project. Publications can be useful for getting “credit” or “recognition” for the work of the outreach program in academia, but may fail at reaching a key dissemination audience. For example, if a goal of dissemination is recruitment for a program, likely the audience of the outreach activity is not reading scholarly articles. Additionally, many of the outlets that publish peer-reviewed outreach activities (e.g., CBE Life Sciences Education) are not widely read by the scientific community, meaning that many interested academic colleagues will miss the dissemination.

7.3 | Online resources

The internet has quickly become the primary source for almost every kind of information, and with a quick search most people can find what they need. Therefore, it is obvious that outreach resources should be made available online. However, two important considerations remain: will the outreach materials that the community develops be discoverable, and will the sites that house them persist?

From the point of view of those looking for resources, it makes sense to create structured, searchable repositories of outreach materials. A system for submissions to the repository can be developed that requires the submitters to include keywords and tags. Providing submitters with a DOI or other stable citation can encourage submission and formalize their contributions for *curriculum vitae* and grants. Other considerations include whether the submissions should be formally peer-reviewed or merely vetted for completion, and whether users can rate or evaluate the materials. The author's work can be protected by copyright, including creative-commons (CC) copyrights that allow liberal reuse. Finally, for maximal global impact, the repository can include multilingual resources, and translations of existing resources can be encouraged.

Optimally, curators should be employed to manage submissions, dissemination and digital security of the repository. The curators can also raise awareness of the resources through workshops, social media and newsletters. As an example, SAPS, Science and Plants for School, sends teachers regular newsletters that describe new resources and provides a user forum, and they report a very high rate of readership (Science & Plants for Schools, 2021).

A few such science education/outreach databases currently exist, mainly with an emphasis on education. These include BioSciEdNet's BEN (BiosciEdNet, 2021), spanning across biology and established in 1999, and the Botanical Society of America's PlantED Digital Library (PlantEdDL, 2012). Two sites that choose instead to host the resources (rather than compile a list of links) are CourseSource (2021), which spans the breadth of biology, but has very few plant-based resources, and Science and Plants for Schools (Science & Plants for Schools, 2021). The latter two are actively maintained with more modern, responsive interfaces.

The ASPB has developed an online community for plant scientists, Plantae.org, that already houses many plant outreach resources (ASPB Education & Outreach, 2021; Plantae Outreach, 2021). Plantae has over 10,000 registered users and 8,000 documents, articles and discussions, as well as a full-time community manager/social media specialist. Comments, ratings and discussion features are enabled, and new resources are featured in a weekly email to 30,000 individuals. It's not hard to imagine developing an outreach resource repository on this site.

All of this requires funding and a commitment by an organization or group to the longevity of a repository resource for outreach activities. This is not simple when funding for long-term resources is not a priority for many funding agencies or societies.

7.4 | Social media

Social media, such as Twitter feeds, Instagram or Facebook, is an excellent platform to connect with the “digital native” generation (McClain, 2017). Scientific societies can facilitate social media dissemination of members' outreach activities; not only during annual meetings, but with proactive marketing campaigns throughout the year. To be most effective, social media efforts must be ongoing and updated on a regular basis, which requires dedicated and long-term coordination.

Social media is also powerful for cultivating, highlighting, and connecting diverse communities. For example, there are an increasing number of Twitter feeds and online groups for plant science-related people with diverse identities that wish to communicate and collaborate, and for whom standard networking options are insufficient. One example is the @DiversifyPlants Twitter feed, created by the North American Arabidopsis Steering Committee (NAASC) to increase the visibility and engagement of members of under-represented, marginalized, and minoritized groups in plant science. A related NAASC initiative is the #DiversifyPlantSci online list and database of plant scientists from under-represented groups to reference for invited speakers, reviewers, collaborators, and participants for career or mentorship opportunities (DiversifyPlantSci List, 2021). This tool can be used to expand one's relatively small circle of colleagues and facilitate extending invitations for talks, awards, and jobs to a more diverse and inclusive set of candidates. The most recent NAASC initiative, DiversifyPlantPubs, uses the @ DiversifyPlants twitter feed to amplify scientific articles, including pre-prints, written by scientists who self-identify as plant science researchers with diverse identity(ies). The purpose of this activity is to promote, lift up, and disseminate the research of plant scientists whose identities diversify the community.

7.5 | Research conferences

Although traditional research conferences are an opportunity for researchers to share scientific discoveries, they are also excellent opportunities to present and discuss activities related to broadening impacts and to normalize participation by all members of the scientific community in education and outreach. In fact, there are aspects of education and outreach activities that lend themselves particularly well to research conferences; for example, many conference attendees find that interpersonal interactions, hands-on activities, and interactive discussions are quite valuable and complement the more typical one-way dissemination of information that occurs during research talks. In comparison, outreach activities, by definition, focus on engagement, and education approaches frequently leverage audience participation, such as through breakout groups, discussion panels, or surveys. Depending upon the goals of the researcher, the intended audience, and the type of conference and opportunities for engagement, presenting information about outreach efforts can be surprisingly effective and rewarding at such venues, and presents key opportunities for new collaborations.

Outreach programs impacting undergraduate students, who may already be cultivating a passion for science, often focus on broadening participation of underrepresented individuals through recruitment and retention. Broader, diversity-focused conferences such as the Society for the Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS, 2021), Minorities in Agriculture, Natural Resources and Related Sciences (MANRRS, 2021) or Annual Biomedical Research Conference for Minority Students (ABRCMS, 2021) provide excellent opportunities to share information about outreach and educational opportunities in plant sciences. Not only does this approach facilitate recruitment, it also brings awareness to students from underrepresented groups that the plant science community is making concerted efforts to engage, and values, a more diverse audience at the K-12, undergraduate, graduate level, and beyond.

Relatedly, conference "codes of conduct" are becoming increasingly common, even expected at conferences. Often developed initially in response to incidents of sexual harassment or of attendees photographing content without permission, some conferences are now proactively implementing more broad codes of conduct to set clear behavioral expectations for participants, and consequences if they are not met (NAASC, 2021). Such codes may positively affect outreach efforts for groups that have traditionally been minoritized in STEM, for example, women, members of under-represented racial or ethnic groups, LGBT, and early career attendees, as they provide a shared understanding of the specific challenges that members of these groups face in STEM, and clear guidelines and processes to address breaches of the conduct code.

Scientific community and society committees on diversity, equity, and inclusion are active within more broad-based research conferences, such as the International Conference on Arabidopsis Research (ICAR), the Botany Conference of the Botanical Society of America, and the Plant Biology meeting of the ASPB. These scientific society conferences make concerted efforts to recruit and financially support traditionally minoritized and excluded individuals to attend their conferences and thus, can also be highly effective at broadening participation. Disseminating content at these research conferences, including more specialized non-plant specific conferences such as the Gordon Research Conferences (GRC) and Federation of American Societies for Experimental Biology (FASEB) meetings, can also effectively reach out to faculty and expose them to the variety of outreach programs that are successfully engaging students and the general public.

The approaches to disseminate information about outreach efforts at research conferences will depend upon the audience, project goals, the role of the presenter within the conference, and available resources. PIs, postdocs and students who have been invited to give oral presentations have the benefit of a captive audience in this regard. However, even labs that run lauded outreach programs seldom take advantage of these opportunities, perhaps due to time constraints, or simply because there is no real precedence for presenting outreach programs during research talks. One simple and potentially effective approach to disseminate outreach outcomes is to include a slide or two at the end of each scientific talk on the value of disseminating outreach, as well as any specific activities in which you are engaged, or positive outcomes you have realized. In addition, these slides could include invitations for engagement with the presenter's outreach activities, or advertise recruitment opportunities for students and postdocs to join current or future projects. Alternatively, presenters could include links to relevant outreach programs at the end of their abstracts. Another powerful approach is to present a poster on your outreach efforts and outcomes, separate from a presented research talk. Given that speakers often choose not to present a poster on their research abstract, it is advised to check with the conference organizers to request to be allowed to submit two abstracts: one for the research talk, and a second for a poster presentation (some conferences, for example, the 31st International Conference on Arabidopsis Research (ICAR, 2021), have recently adapted their abstract submission process to allow up to two abstracts to be submitted in order to explicitly promote inclusion of education, outreach, or community-support presentations in addition to traditional research presentations). This dual approach could be a powerful and effective way to fundamentally enhance research conferences to broaden impacts and expand outreach and collaborations. If the presenter also highlights this alternative content during their presentation (i.e., within the final two slides, as described), then another benefit may be higher interest and "traffic" at the poster session. Disseminating outreach information at conferences has the added value of informing program directors, who may be in attendance from federal funding agencies such as NSF, NIH and USDA. Disseminating information, products, and outcomes from outreach programs is an important demonstration of our public dollars in action and also reinforces the value, and the approaches that work well, to vital funders.

Another option for disseminating information is to host a booth at a conference. Universities will often pay for booth space at research conferences that serve members of underrepresented and minoritized groups, such as SACNAS, MANRRS, or ABRCMS. It also may be worthwhile to file a request for such a booth at "standard" scientific conferences (e.g., ICAR, Plant Biology), particularly if the requesting entity has a new program that the hosting institution is keen on publicizing broadly. Since booth participation may be expensive, a cost effective route is to send an "Outreach Ambassador" from a lab or department to be present at a booth funded by the university, college, scientific society, or perhaps a research coordination network. At many of these conferences, the organizers have dedicated funding to expand participation and may have partial or full travel scholarships or awards that the "Outreach Ambassador" might apply for in advance to help defray costs. If space at the booth is limited, literature about the specific outreach program can simply be given out at the booth. However, it is important that booth representatives have sufficient information about the outreach program to address questions that may be asked. A lower cost (and lower commitment) option available at many conferences is the use of physical "Community Outreach" bulletin boards or digital message boards to communicate collaboration and outreach opportunities, for example, through the use of fliers with contact information about outreach programs that are readily available to interested students and faculty.

Research conferences are often an excellent way to reach both senior scientists and starting trainees, however the size of the audience reached can vary (generally, limited to whomever visits your talk or table), and requires resources in both time and funding. It can also be difficult to determine if the investment of resources produced a sufficient benefit, for example, it can be challenging to determine if noticed changes, such as an uptick in applicants to an outreach program, come from the presentation you gave at a conference, or some other mechanism of communication. When considering the menu of approaches, it is useful to outline all the options that are available for the conference and to be sure to note all relevant deadlines, including for abstract submission for talks, posters, or to lead/participate in workshops, or to purchase an ad, or reserve an exhibit booth. Typically, information on outreach, advertising and exhibits are listed in a specific "support" section of the meeting website, while opportunities for inclusion in the scientific program are featured elsewhere.

7.6 | Coordination networks

Outreach-focused (or featured) coordination networks provide opportunities for strengthening and disseminating outreach efforts. Coordination networks are a group of stakeholders with common research goals, action projects, and, often, shared resources. Coordination networks also require a commitment of resources and interactions through meetings, events, and online forums to achieve collaborative objectives. Networks can benefit the plant science research community by identifying mechanisms to pool resources and funding, reducing duplication of efforts, piloting new projects, developing assessment criteria, and disseminating resources to stakeholders.

Coordination networks require several resources to be successful. A dedicated coordinator, and project-appropriate level of support staff, are an essential component to maintaining working relationships among network members, enabling regular communications and updates to stakeholders, and successfully achieving objectives. Support for network coordinators and activities may be funded through federal grants or through smaller contributions from network members and other stakeholders. Coordination networks are most effective when dedicated staff or volunteers incorporate regular engagement such as through newsletters, creating robust online databases/repositories, managed online forums, and in-person meetings.

In general, networks may be structured with vertical integration or horizontal integration. Vertical networks include stakeholders from different sectors such as community members, families, K-12 educators, universities, research institutions, and companies. Horizontal networks are stakeholders in the same level across sectors, such as a coalition of universities, trade associations, or research laboratories. A successful outreach-focused network would ideally include a mix of horizontally and vertically integrated organizations. One example is the Environmental Data Science Inclusion Network (EDSIN), launched in 2019 and focuses on examining diversity, equity, and inclusion (DEI) across the environmental and data science fields (https://qubeshub.org/community/groups/edsin/).

Coordination networks are especially valuable when there are stakeholders who have common goals that can only be achieved through contributions from a variety of members, potentially across disciplines, or sectors, or interest groups. The goals of the network should be dynamic and build in regular assessments to react to the needs of the communities, and to enable growth through inclusion of new voices, partners, and perspectives. Goal setting and assessment of achievements is critical for reacting to the needs of the network as the membership expands.

Networks supported by federal grants must also consider the need for the network to be sustained long-term. For instance, the federal grants from the NSF supporting Research Coordination Networks (RCNs) are limited and not eligible for renewals; therefore, it is important for the network to identify whether (a) the need is ongoing and can be directly supported by members, (b) the network goals have changed significantly and thus members may apply for funding on a new project, or (c) the network has accomplished its goals and is no longer necessary. While some coordination networks may find long-term support and form permanent organizations, federal grant support for outreach-focused coordination networks is essential and should continue to be available to promote, share, and amplify evidence-based practices and impact.

Coordination networks are an effective structure for the plant science community to collate outreach efforts, evaluate and innovate across organizations, and facilitate community goal setting and establish strategic plans. Networks facilitate visioning efforts, lead pilot projects, evaluate effectiveness of programs, and ultimately make recommendations for future efforts. For instance, the North American Arabidopsis Steering Committee (NAASC) has utilized NSF support to create the Arabidopsis Research and Training for the 21st century (ART-21) Research Coordination Network (RCN). ART-21 RCN is a multi-year project that has coordinated outreach activities at scientific meetings, engaged community members in genomic and computational training workshops, hosted recruitment events for members of underrepresented groups to promote the plant sciences, and disseminated outreach activity outcomes via publications (NAASC, 2021), including this document. It is notable that the RCN funding vehicle focuses on new research and research communities, and not solely on outreach; however, the ART-21 RCN steering committee included within the original proposal a significant amount of resources and activities aimed at outreach, and broadening participation and impacts. Ideally, funding mechanisms should be established that specifically focus on outreach coordination networks, or, at minimum, that require significant outreach activities (and associated budget) within the research agenda.

To make these efforts as successful as possible, coordination networks must bring together the maximum number of relevant stakeholders while not expanding beyond the capacity of the network to engage in meaningful discussions. In the plant sciences, diverse representation from universities (faculty, staff, and trainees involved in outreach), private industry, K-12 educators, community colleges, non-profits, and government are key to gaining a holistic view of the effectiveness of outreach efforts. Representation at both the practitioner and leadership levels must be included in discussions in order to encourage buy-in and support of network efforts.

In some ways, coordination networks can represent the pinnacle of dissemination processes. They typically have the resources in terms of staff, funding buy-in and recognizability to tackle multiple dissemination goals and dissemination mechanisms. But as mentioned, this is also a fundamental challenge of the network. An effective network requires significant effort in people coordination and management, which requires staff to be funded over the long-term. It also requires that the groups involved remain committed to the same goals and vision of the project even through changing times and priorities.

7.7 | Recognition for outstanding outreach contributions

An important element in encouraging and supporting the spread of successful outreach programs is for institutions to provide recognition awards to individuals who are excelling in outreach efforts. Departments, colleges and universities are encouraged to develop mechanisms for rewarding effective and impactful outreach activities. These awards could be for individuals at multiple levels, such as for outstanding effort by undergraduate, graduate, postdoc, faculty and/or staff. A major current challenge, and future opportunity, in facilitating institutional change in the area of outreach, is to include outreach as criteria for faculty promotion decisions. While "service" and "teaching" (in addition to "scholarship") are criteria written into promotion guidelines, particularly at public institutions, outreach efforts associated with service and/or teaching may be de-emphasized and considered less important among academics themselves when evaluating promotion cases. Connecting outreach efforts to the institution's or department's mission statement can help validate the work. If a mission statement does not exist, community members should work within their administrative structures to help create one. Ultimately, recognition for outreach work needs to be done at departmental, institutional, professional society, and national levels.

8 | CONCLUSIONS AND FUTURE PERSPECTIVES

> "I have discovered in life that there are ways of getting almost anywhere you want to go, if you really want to go."

Langston Hughes.

The academic culture surrounding science outreach can often frame these activities as extensions of our professional roles, rather than intrinsic. Indeed the term "outreach" suggests such a connotation. Why do we see presenting our work at research meetings through posters or talks to be central to the act of being a scientist, but see efforts to bring this work to lay audiences as laudable but hardly essential? Just as there is rigor in giving a stellar scientific talk we also view engaging non-scientists, and communicating the broader importance of the science, as a rigorous endeavor that should be taken equally seriously. As a community, we must convince our leadership, our colleagues, and ourselves that engaging with non-scientists should be part of our training and that these efforts be acknowledged through funding and career advancement opportunities. Only then, when we take the practice of sharing our science seriously, will the public take our call to support science seriously.

8.1 | Things you can do now to improve outreach in your community

1. Lobby your dean to recognize outreach as a valued component of academic excellence. Tenure guidelines for faculty describing expectations for tenure should provide clear guidance for how outreach activities will be evaluated. Letters sent to evaluators of a tenure package should include language stating that the university values outreach and that involvement in public engagement should be explicitly evaluated for all tenure candidates.
2. Add a service requirement component to the curriculum of PhD students. This requirement should not add an additional burden to the already tight timeline of students, but should be integrated into a training program that sees these activities as an opportunity to teach skills in communication, education and project management. Establishing an academic culture where conducting effective outreach is an important career-relevant skill at this early stage that will sow the seeds of lasting change.
3. Talk to the program officers of funding agencies with which you seek funding about your interests in outreach and the value these activities bring. Discuss the criteria each agency views as most important for evaluating outreach programs. Ask for contact information of scientists and educators who have successfully run an outreach program, particularly those that have engaged in evaluation and assessment to objectively measure success.
4. Share your work through social media, with your neighbors or your kids' classrooms. Associate a friendly face and kind voice with the possibilities in plant science.
5. Normalize the communication of outreach activities as an integral part of our professional activities. If you are planning a research conference, symposium or institutional retreat, reserve a part of the program for presentations focusing on outreach. Furthermore, ask all speakers in all sessions to include a slide that talks about their outreach efforts, and encourage them to invite participants and feedback.
6. Get your undergraduate/graduate students and postdoctoral scholars involved. Often, earlier career scientists retain a sense of wonder and excitement about plant sciences, and many have creative and "out of the box" thinking that could be applied to effective outreach and engagement activities.
7. Engage with local outreach opportunities, as well as potential community collaborators, by contacting local SACNAS chapters or other national organizations, such as Expanding Your Horizons (EYH), 4-H, or groups associated with local schools and community groups; your local town may have botany or ecology enthusiasts that provide new opportunities to meet interested members of the public with which to share the wonder and love of plant science with.
8. Share your outreach program with us, the authors of this document. We would like for this document to continue to live on through a curated list of programs and activities that have been developed and successfully implemented.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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