

Reinventing Postgraduate Training in the Plant Sciences

T-Training Defined Through Modularity, Customization, and Distributed Mentorship



Plant Science
Research Network

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Executive Summary

The Plant Science Research Network (PSRN) comprises scientific societies and organizations with a mission to build and communicate a consensus vision of the future of plant science research, education, and training. This report enumerates a set of far-reaching recommendations for postgraduate training that emerged from workshops held in October 2016 and September 2017. These recommendations broaden and deepen the “T-training” concept presented in the *Decadal Vision for Plant Science*, which emphasizes experiential learning beyond the traditional disciplinary focus (Fig. 1) (1). Both workshops used the scenarios developed in *Imagining Science in 2035* as a mechanism to encourage out-of-the-box thinking, an approach that led to the innovative recommendations and solutions described.

Core Principles

At the heart of our recommendations is the empowerment of trainees, who should be enabled to customize and take ownership of their training experiences (Fig. 2). This fundamental concept is embodied in five principles:

- 1. Trainees should be provided guidance** and resources needed to define and pursue career objectives within and beyond academia, conferring to them greater independence and responsibility in shaping their own future.
- 2. Learning should be flexible, adaptable, and distributed.** Training should combine traditional and modular coursework to encompass both technical and professional skills. Guidance from diverse mentoring teams will support and tailor training toward diverse, personalized career paths.



Figure 1. T-Training for Diverse Careers. The T-shaped individual develops professional skills and takes part in deep disciplinary training. Skills may vary among disciplines but include transferable as well as technical skillsets. Disciplinary training may be acquired through specific research experiences or degree programs. Modularity, customization, and distributed mentorship further support T-training. Figure adapted from the *Decadal Vision* report (1).

3. **Scientific research experiences should be broad and question-driven**, whether motivated by basic discovery or seeking solutions to societal challenges. Trainees should continue to gain mastery of one or a few core scientific disciplines and their key tools and approaches.
4. **Trainees should be skilled in science communication** and incentivized to engage with and learn from the broader public community, helping to maintain an active dialogue among public, private, and academic sectors.
5. **Training programs should foster and facilitate** the inclusion of individuals with a diverse range of life experiences and should prioritize trainee well-being.

Specific Recommendations

Our recommendations are scalable and can be adapted to various training environments; they also learn from and may be applied to other disciplines (Fig. 3).

1. **Increase the number of competitive grants available to trainees.** Emphasize direct funding of trainees including “gap year” students, graduate students, postdoctoral fellows, and those engaging in continuing education. As the possessors of their own funding, trainees will experience greater ownership of their path, increased choice and mobility, and heightened accountability for their own progress.
2. **Rethink mentoring to emphasize individualized development.** Encourage the formation of distributed mentoring teams that assemble advisers from job sectors that reflect and support a trainee’s personalized aspirations and areas of focus. Individual development plans are recommended to formalize expectations, encourage introspection, foster accountability, and monitor goal-setting and achievements.
3. **Create a validated system of customizable, modular experiences.** Develop a modular approach to supplement institutional offerings, comprising e-learning, short courses, workshops, and internships, thus creating a curriculum that spans institutions, learning methods, technical and professional skills, and topic areas beyond the plant sciences. **In parallel, implement a credentialing system** that documents and validates learning experiences and acquired skills in a widely accepted format.

Core Principles



Figure 2. Empowering Trainees by Providing Them Greater Independence and Responsibility in Shaping Their Own Futures.

The five core principles are: prioritization of and support for diversity, inclusion, and trainee well-being; guidance and resources to define and pursue career objectives; flexible learning, unconstrained by institutional boundaries; disciplinary mastery achieved through research experiences; and community engagement through science communication.

4. **Establish institutional support for and facilitation of life-work transitions.** Promote opportunities for career flexibility, allowing and encouraging trainees to transition more smoothly from the traditional academic pipeline so that they may accommodate diverse personal, community, and financial circumstances, and facilitate training throughout the duration of scientific careers.
5. **Develop policies to promote individual well-being.** Increase diversity and inclusion through policies that support work-life balance, mental health, wellness, and family leave.
6. **Provide opportunities and practical training** to develop communication skills and foster a research environment that promotes two-way public engagement.

Intended Outcomes

These recommendations call for a profound cultural shift—one that embraces and extends educational delivery trends toward self-learning and distance learning, considers trainee well-being as an essential requirement for success, and acknowledges the importance of effective two-way communication with the public. This shift is intended to broaden participation in the plant science workforce, both in terms of diversity and numbers, while maintaining excellence in core scientific training. Cultural change takes time, but among academic institutions the need for significant change and innovation in postgraduate training is increasingly pressing. As such, the immediate intent is for these recommendations to catalyze pilot programs and also build on emergent prototypes that exist globally while creating momentum for larger scale changes over longer time periods.

Background

Advancing the Training Goals of the *Decadal Vision*

In 2013, the plant science research community published *Unleashing a Decade of Innovation in Plant Science: A Vision for 2015–2025* (the *Decadal Vision*; **1**). Among the five major goals described in the *Decadal Vision* is “Reimagining Graduate Training,” which outlines a “T-training” model (**Fig. 1**) that retains deep disciplinary training as a major component (the vertical part of the “T”) while incorporating a broader palette of professional skills (the horizontal top of the “T”) (**2**). The T-training concept is embodied in two programs launched in 2014, the year after the *Decadal Vision* was published: the U.S. National Science Foundation (NSF) National Research Traineeship (NRT) program, which supports transformative graduate training models that serve a range of Science, Technology, Engineering, and Math (STEM) careers, and the NIH BEST program, which supports innovative approaches to prepare postgraduates for a range of career options (**3–5**). Given the resonance of these promising pilot programs, the PSRN sought ways to bring T-training into the mainstream, using plant science as a focus for postgraduate program conception (**6**), but with the expectation that any novel approaches would both learn from and contribute to a range of disciplines.

The PSRN’s strategy was to assemble diverse participants for two successive but independent workshops, in both cases creating an environment that stretched minds and encouraged imaginative rather than incremental thinking. The PSRN first constructed a set of four future scenarios that lay out a spectrum of global contexts in which plant science research and training might be playing out 20 years hence. The scenarios were described in the report *Imagining Science in 2035: Strategies for Maximizing the Value and Impact of Plant Science, and Beyond* (Science in 2035), and envision and explore a range of possibilities for the types of science that will be emphasized and the manner in which that science will be resourced (**7**). In the two workshops, participants asked how T-training could be implemented in each Science in 2035 scenario before homing in on specific strategies that would be most effective across all four highly divergent scenarios. Participants in the first workshop were predominantly industry scientists, academic faculty, and senior university administrators, whereas the second workshop was restricted to early career trainees (**8**). Despite the very different cohorts, their recommendations overlapped extensively and have been merged in the current report.

Recommendations

In this section we outline six focus areas that will empower trainees to achieve outcomes that align closely with their personal and professional goals (**Fig. 4**). In doing so, we challenge two established perspectives on training, recognizing the simple fact that only a minority of doctoral trainees desire or obtain careers as academic faculty. The first paradigm we challenge is that degree attainment marks the acquisition of a suitable set of competencies (**5, 9, 10**). Instead, we believe that success is achieved when the acquired competencies match both the trainee’s need to prepare for their preferred career trajectory and the employer’s expectations with respect to that individual’s competencies and potential. Second, we challenge the pervasive use of “pipeline” terminology, with its impermeable, linear connotation and its susceptibility to imagery of blockages and leaks. Instead, we contextualize training as a network of paths, which may be combined and sequenced throughout one’s training and subsequent career to promote preparation for a variety of professional destinations (**Fig. 5**). The specific recommendations for postgraduate training that resulted from the PSRN workshops are described below (**Fig. 3**).

Specific Recommendations



Figure 3. Specific Recommendations. The six recommendations to reinvent postgraduate training are related to funding, mentoring, modular training career flexibility, well-being, and engagement with the broader community.

Recommendation 1: Increase the Number of Competitive Grants Available to Trainees

We recommend increasing direct funding, not only for doctoral students and postdocs, but also for nontraditional students, such as those in gap years and those seeking training to enable workforce reentry or career switches. Therefore, although funding would include traditional support, such as NSF or USDA Graduate Research and Postdoctoral Fellowships or NIH National Research Service Awards (NRSAs), we recommend creating new types of short- and medium-term fellowships for specific purposes (11, 12). The benefits of funding trainees directly include

- Training driven by intellectual interests, career goals, and individual values, rather than by funding available in a specific laboratory or program;
- Increased personal ownership of training, reflected in increased enthusiasm and improved engagement;
- Experience in developing and managing a budget, networking, and technical writing;
- Increased power to choose the best mentoring environment, incentivizing improvements in mentorship;

- Increased flexibility and institutional support for trainees to independently pursue external internships and earn credits through online programs, short courses, and workshops offered by entities beyond the research institution;
- Stimulating universities and other research- and training-focused organizations to develop creative programming and compete for trainee interest.

A direct funding model challenges current practices that match trainees with open research slots, and it will impact the manner in which laboratories are populated. We recommend adequate additional funding that would be awarded directly to trainees, while acknowledging that continued awarding of research grants to laboratories will be required to maintain infrastructure, technical support, and materials.

A second challenge is that trainees will generally benefit from or require sustained attention to ensure that they effectively design and manage their professional development and technical training. Recommendation 2 addresses the need to couple program and mentor accountability with training to ensure that these expanded opportunities fully benefit the trainee.

The need to support lifelong training reflects the fact that career adaptability and mobility can be critical assets, but scientists may be unsure how to learn a new technology or discipline, transition between the public and private sectors, or reenter the workforce after a hiatus. We therefore recommend creating funding programs for professionals and faculty at all types of higher-learning institutions, as well as for individuals outside academic settings who otherwise may have no recourse to funding to support their continued education and professional development.

Recommendation 2: Rethink Mentoring to Emphasize Individualized Development

Giving trainees more autonomy and responsibility challenges current training models. Most graduate students are currently guided predominantly by a single mentor/supervisor, with intermittent advice from a committee that is typically composed of academics at the same institution, who tend to be deferential to the major adviser. As a result, training may occur in an environment that fails to build awareness of, and confer access to, a full range of learning and career options. We recommend an alternative to this model, where trainees develop distributed mentoring teams that have complementary expertise and that are selected to help develop and manage professional goals, which often evolve during training.

Mentoring teams, which could advise both thesis students and nontraditional learners, might be drawn from both active and retired scientists from all sectors of the workforce, including academia, industry, non-governmental organizations (NGOs), or public service (13-15). Even if a mentoring team was strictly academic, it should be the rule rather than the exception to include faculty from different fields, as well as from other institutions. New models for committee management should be explored, such as a cochair structure that splits primary responsibility between research advising and career counseling. Those mentors whose role emphasizes career counseling should be offered specialized training so that they can provide effective guidance on transferable skill development and career options, and they should be recognized and rewarded for their contributions in this regard.

Access to mentors is envisioned to occur via a network or marketplace. The American Society of Plant Biologists, with its *Plantae* networking platform, or the National Research Mentoring Network (NRMN) could provide matchmaking re-

sources through which mentors and mentees might connect. This might happen online initially with follow-up, in-person connections via “speed dating” or other professional networking events hosted at large conferences or regionally in a specific physical location or city, or within specific subdisciplines of plant science. Such organizations already enjoy active participation by industry and government scientists, so they are primed for trainees who seek to connect with mentors from various sectors and institutions. It is essential that committed mentors are incentivized and rewarded for participating in this marketplace, which goodwill alone might be insufficient to populate. Trainees should also receive guidance on how to make the connections so that they can identify appropriate mentors and engage with them in long-term, mutually rewarding professional relationships.

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Trainee-Centric Approach



Figure 4. Place the Trainee and Their Needs at the Center.

Individual development plans (IDPs), which enable mentors and mentees to personalize training, should be used to achieve personal and professional objectives. The trainee-centric approach comprises six elements: (1) direct funding of trainees; (2) a flexible, multi-mentor model; (3) modular training that build skill sets outside of degree programs; (4) support for flexible career on-ramps and off-ramps; (5) a focus on trainee well-being; and (6) opportunities for practical training (e.g., science communication, research internships, or experiences in other sectors).

To ensure that mentoring experiences are effective and expectations are clearly enumerated, we recommend that trainees create and maintain Individual Development Plans (IDPs) that establish training and career goals and, importantly, set out realistic pathways toward achieving them (**Fig. 5**) (**16, 17**). The trainee's IDP would be implemented for the duration of a training period and might incorporate coursework, internships, field experiences, learning modules, and major experimental themes and timelines. The IDP would provide a framework for identifying skills that coincide with potential career interests of the trainee and allow the trainee to build those skills in a manner that is efficient, effective, and fulfilling.

Accountability is an important facet of a strong mentoring system. The plan holds the trainee accountable, with funding potentially being contingent on creating and updating the IDP. Mentors also need to be held accountable, perhaps through oversight of a networking platform, which could incorporate both a rating system and an annual record of the type and frequency of meetings held. Annual reports are common practice to monitor the research progress of graduate trainees, but professional career development is not often a component of those reports. Institutional oversight will also need to be incorporated into a revised mentoring model to select and monitor the source of external mentors and to help ensure that their contributions are recognized.

Recommendation 3: Create a Validated System of Customizable, Modular Experiences

Acquiring the skills laid out in IDPs will require a more diverse assortment of learning experiences than those prevalent in today's typical postgraduate training environments. Thus, traditional laboratory or classroom experiences will need to be supplemented by alternative sources and delivery mechanisms. We recommend the creation of a modular system that includes e-learning, short courses, workshops, and internships (**18, 19**). The result will be a flexible, customizable curriculum that spans disciplines, institutions, learning methods, career stages, and career options. A widely recognized and validated credentialing system, developed in collaboration with employers, will be required to document skill acquisition.

Possibilities abound for topics and forums to develop into learning modules. The addition of training modules for broader learning aims will amplify, rather than impinge

upon, the core scientific research experience. Modules may help to reinforce the nature and excitement of discovery while imparting indispensable skills such as hypothesis development and testing, project management, and data analysis. Empowerment and customization, therefore, must be blended into a system in which research and analytical progress are still emphasized.

How will the academic, corporate, government, and other employer communities evaluate and credit completion of modules? Without a formal system in place, there is risk that those accomplishments may be regarded with skepticism or uncertainty by potential employers. Time to the Ph.D. degree may lengthen beyond its already unpalatable duration, especially if the trainee's home institution fails to credit such training. Current practices of accepting Advanced Placement credit, along with limited amounts of transfer credits or summer coursework from other accredited institutions, demonstrate the potential of this approach. Although management of "alternative credentials" is still in its infancy, it is clearly on the radar of higher education (**20**).

We recommend that access to, and credentialing of, modular training for plant science be managed jointly. Access could be optimized by establishing a "one-stop" repository for accredited learning opportunities, with a suitable organizational framework for searches. At present, there is no widely accepted gateway, leaving trainees to rely on career offices, mentors, word of mouth, and web searches. One possibility for content management would be to develop a consortium of professional societies, content providers, and academic representatives. This is not a trivial exercise, but shifting toward a common platform that reflects buy-in from PSRN members, professional societies, universities, and industry would help to standardize and organize resources and would expose students more broadly to plant science and the range of career trajectories available to them (**Pilot 8**) (**48**).

Recommendation 4: Establish Institutional Support and Acceptance for Life–Work Transitions

Currently, leaving for employment without completing a degree tends to be regarded as making the best of a failure; our recommendation is to regard the exit as a positive, strategic choice, so long as it is deliberate and has been planned for. We recommend a wider acceptance of, and

Pathways to Diverse Careers



Figure 5. Pathways to Diverse Careers. An imaginative metro map representing possible career pathways and T-training opportunities. While some stations are more common entry points, trainees can use any station to enter or exit. Although destinations are neither fixed nor preordained, trainees should be adequately prepared for a range of opportunities and career-long adaptability. **Key:** (circles) metro stations represent an activity or development of a particular skillset; (bullseyes) transfer stations represent career transition points; (arrows) each line leads to a different career pathway.

Build your own pathways. Download a blank version of this map at Plantae.org/PSRN-Training.

preparation for, career transitions that do not coincide with completion of a degree and may not even envision a degree from the beginning. Such cafeteria-style curricula are currently under consideration within academia (10). Also, the credentialing system outlined above could be leveraged to validate an individual's competencies and skills beyond or outside of an academic curriculum.

Degree-independent training would provide support for work-life transitions that currently might derail a career. Economic, family, or other considerations might call for one or multiple transitions that could be buffered by retraining that had the benefit of a visible structure of learning modules, mentoring, and possible financial aid. It is additionally likely that this type of framework would assist in broadening participation among groups currently underrepresented in science, who disproportionately face economic or institutional barriers (21).

The specter of economic barriers is also raised by the 2018 Science & Engineering Indicators published by the National Science Board (22). As one example, the time to Ph.D. degree is 7.3 years in agricultural fields overall, but 8.7 and 8.5 years for Hispanic and African American students, respectively. Furthermore, it is debatable whether receiving a doctoral degree will translate into greater earning power in the years ahead. Individuals with biology Ph.D.s awarded between 2009 and 2011 were found to earn \$36,000 in the year after their doctorate, or in the mid-\$40,000 range if postdoctoral appointments are excluded (23). Longer-term prospects are more favorable, but one must account for the seven or more years of minimal income and the effects on retirement savings (24). Graduate student stipends are scarcely sustainable for many trainees, especially those with family responsibilities or undergraduate student loan debt. These facts underscore that alternatives to formal degree paths are urgently required.

Recommendation 5: Develop Policies to Promote Individual Well-being

It is well documented that diverse teams are more effective and make better decisions when the participation of all team members is encouraged and equally valued. Moreover, there is a widely held imperative to work actively toward enabling a STEM workforce that mirrors the demographics of the broader population. Although the present

report does not make specific recommendations as to how to broaden participation in the plant sciences, we believe that several of the recommendations will help lower barriers to attracting and retaining diverse populations. These include IDPs and mentoring, which set out goals that are attainable and with purpose, along with funding that supports a variety of career pathways (25). Additionally, modular professional development offerings allow trainees to align career-building activities with other responsibilities in an individualized manner. Third, flexible career transitions allow commitments to be scaled to the realities of an individual's life. Finally, there are relevant communications skills, which are set out in the next section of this report.

Discussions during the PSRN training workshops often returned to the issues of work-life balance and trainee well-being. It is clear from these discussions and from recent research that the current expectations of trainees in most academic research labs frequently run counter to these principles and can directly contribute to depression and other mental health disorders (26). Furthermore, these expectations, especially when coupled with the long-term commitments required to pursue graduate degrees and many postdoctoral appointments, will increase retention among all trainees and help nurture a diverse workforce. We contend that scientific excellence and advancement are not and should not be incompatible with leading a balanced life and that improved work-life balance will lead to better research and professional outcomes. We therefore recommend broad adoption of programs and policies that support individual well-being and work-life balance, including mental health and wellness, and family leave.

Recommendation 6: Provide Training in Science Communication

Workshop participants defined two major categories of communication skills: those internal to a research career and those that connect and engage scientists with the broader non-research community. Training and development in both categories are essential to achieve an adequately prepared future plant science workforce.

Individuals pursuing research-intensive careers deploy a range of communication techniques aimed at colleagues, including creating and delivering poster or slide presentations, technical writing, and teaching. Most graduate

programs have formal or semiformal ways of delivering this training. We recommend adding richness to this training in two ways. First, ethics training should be compulsory. While scientific misconduct is more frequently covered, the gray areas prevalent in collaborative work, including unconscious bias, are ripe for exploration and will enable researchers to handle issues related to credit, responsibility, and scientific disagreements with more confidence. Collaborations increasingly involve biologists of many stripes, as well as data scientists or engineers, and the capacity to communicate effectively across these boundaries is critical but often does not come naturally (27, 28). Furthermore, trainees equipped with such skills will tend to be more effective in team-oriented workplaces, particularly in the private sector.

In terms of engendering two-way communication among scientists and the broader communities such as journalism, public policy, and the general public, the PSRN recommends the development of outreach programs that enhance dialogue among scientists and their local communities. This might include schools, local news organizations, and government agencies. Specific communication skills are required to build trust between scientists and the public. Among them are use of appropriate vocabulary, the capacity to establish empathy, framing the message, and being an attentive listener. In general, scientists are taught to project a message and answer scholarly questions, but not taught listening skills for other audiences and how to be appropriately responsive. Scientists have not been particularly successful at depolarizing topics such as genetic modification, climate change, or vaccine safety, for example. While the training of scientists would not be a one-stop solution, it is an essential component.

The proposed modular system is ideal for developing diverse communications skills. Collaborative skill development could occur on campus—for example, in courses shared with communications, journalism, computational, or engineering departments, or through other campus affiliates (see Pilot 6). Learning from peers lowers barriers and builds a sense of community, and these topics are amenable to online formats, where they can be widely disseminated (29). We also recommend offering focused workshops or courses to provide trainees with experiential communications opportunities; these might be made available on campus or during scientific meetings and could be sponsored by individual laboratories, professional societies, companies, or educational institutions.

Reaching into communities will require a more direct approach and will likely have a larger impact if it is initiated by scientists from the same geographic area, and especially when there are ethnic or socioeconomic commonalities (see Pilot 5). Alignment with programs targeted to improve K–12 and undergraduate education in plant science would build efficiency and also bring forward opportunities for citizen science. On-campus student associations or clubs could be encouraged to develop outreach programs and be incentivized through a reward system. Such activities are fully compatible with the Land Grant mission, where plant science is a major component.

The Case of the Postdoc

How PSRN Recommendations Might Impact Post-Ph.D. Training and Trajectories

Most of the recommendations above apply equally to graduate students and postdoctoral scientists, all of whom would benefit from garnering independent funding, use of IDPs, access to modular training, and improved communication skills. The question that is not addressed, however, is the proper role of postdoctoral training over the coming decades. To wit, none of the four scenarios that make up *Imagining Science in 2035* played out in our workshops featured postdoctoral training; in other words, the hypothetical trainee, Dakota, did not seek or require postdoctoral training to achieve career success.

At present, postdoctoral training is commonly sought by life sciences Ph.D. holders to gain specialized skills or to work with a specific scientist. Such training can be invaluable and is generally considered to be a prerequisite for both industry research team leader and faculty positions in the life sciences, although such a requirement varies across fields (30). A significant number of today's trainees report, however, that they entered postdoctoral study primarily as a cultural expectation or because they were unable to secure other employment (31). Not infrequently, these experiences turn into “permadoes,” that is, lengthy appointments with diminishing chances of career advancement into independent positions that are buffeted by adverse impacts on family life, ranging from inconvenience to extreme stress (32–35).

Dismay with such outcomes could be contributing to the decline in numbers of biology postdocs, which has been partly balanced by an increase in “nonfaculty researchers” as discussed below (36). Postdoc distress may also contribute to poor perceptions of career opportunities among more junior researchers, who instead opt for seemingly less arduous or more lucrative trajectories. As the recommendations described above take hold, however, it is reasonable to expect that an increasing proportion of postgraduate trainees will reinforce this trend by identifying their preferred career trajectories much earlier and receiving the training, experiences, and mentoring they need to achieve their objectives.

Insofar as a time-limited postdoctoral training period remains a logical and legitimate requirement for certain career objectives, we support implementing this report’s recommendations. Although the NSF already requires a mentoring plan for postdocs supported on grants that includes professional development and career counseling, this principle should become universally applied and much more effectively organized. Where appropriate, this plan could also tap into credentialed modular and external training experiences, as well as mentors, that map to expectations and objectives laid out by postdocs through their IDPs. Considerable expansion of portable postdoctoral fellowships would confer trainees with greater ownership and mobility, and these fellowships would provide incentives for laboratory heads to emphasize “added value” training beyond the research experience, such as richer and deeper experience in teaching, writing, development of scientific research projects, and opportunities for mentoring, serving on committees, peer review, and learning more about laboratory leadership and project management. Suggestions made for NSF postdoctoral mentoring plans are a useful touchstone for conceiving such objectives (37).

Whether a stronger alignment between postdoctoral training and specific career trajectories results over time in more or fewer postdocs in any given discipline, a shift in the constitution of the experimental workforce must be contemplated. In some of the *Imagining Science in 2035* scenarios, robotics takes on a major role as many of the more repetitive tasks in laboratories are automated. However, we do not envision the demise of the human scientist. An emerging alternative to permadocs is non-faculty researcher positions, which NSF defines as individuals involved principally in research activities who are not postdocs or members of university faculties. These positions

might include long-term research staff, technicians, system administrators, collaborative team leaders, community managers, and laboratory managers, among others.

Pathway to Implementation

The PSRN training recommendations call for a cultural shift over a 20-year time frame toward empowering trainees to develop and complete customized training pathways (Figs. 4-5). Recognizing this, the PSRN envisions two main implementation phases. Phase 1 would involve the piloting of new support mechanisms (e.g., mentoring teams and associated IDPs) at multiple locations. This support will be supplemented with evaluation of existing relevant pilots (such as the previously mentioned NRTs, the BEST program, and the Foundation for Food and Agriculture Research’s recently announced graduate fellowship program). It would also involve the documentation and development of modular training experiences and mechanisms for credentialing them. Phase 2 would incentivize the expansion of successful pilots from Phase 1 (48). See online Appendix.

Phase 1: Developing Pilot Programs

Pilot program concepts have been developed both during the writing of this report and as a component of the September 2017 PSRN workshop. In the latter case, the major contributors are credited. The complete programs are fully described in Appendix 3 and summarized here. These ideas are intended either for implementation or to stimulate the creation of additional pilot concepts.

Pilot 1: Unconventional Training Through Direct Funding

Direct funding is critical to encourage nontraditional entry into science training pathways. This pilot would make awards to support career-switching, workforce reentry, retraining, or nondegree training to fill out a résumé. Existing laboratories accommodating such trainees would also help to fulfill the broader impacts aspect of NSF-supported research.

Pilot 2: Team Mentoring

Element 1 – Mentor databases. Resources populated with volunteers from academia, industry, and elsewhere could be built to centralize and democratize access to advising.

Element 2 – Alternative mentoring team structures. Graduate mentoring teams with multiple leadership roles, as distinct from the single chair structure, could be piloted.

Element 3 – Providing support resources. Roles and responsibilities on the mentoring team, and even roles among the broader mentoring community, could be defined and clarified, along with recommended best practices for guiding a trainee through the development of an IDP.

Pilot 3: Building a Successful Mentoring Team

Contributors: Shandrea Stallworth, Valerie Fraser, Natalie Henkhaus, Katie Murphy, Andre Naranjo

This pilot would assist undergraduate and graduate students, postdocs, and young faculty members in developing meaningful and useful mentor/mentee relationships and teams in academia and industry.

Pilot 4: Developing and Credentialing Training Modules

Element 1 – Complementary experience grants. Funding agencies could offer short-term fellowships for students to undertake research or learning activities distinct from their main research project.

Element 2 – Credentialing. Credentialing models for modular learning could be piloted, or existing ones could be enhanced or optimized for plant science.

Element 3 – Warehousing. A repository of accredited modules goes hand in hand with credentialing. Therefore, plant (and life) science will require its own databases housing the fairly eclectic collection of opportunities that trainees may be seeking.

Pilot 5: Industry and Academia Conference for Students

Contributors: Emma Frawley

The development of a two- to three-day conference with two main objectives is proposed: first, to foster an environment to understand and improve the relationship between academia and industry, and second, to facilitate trainee networking with plant science-related industries.

Pilot 6: Science Communication Training

Contributors: Nicole Forrester, Nat Graham, Chris Barbey

Communication skills are essential for successful careers in science, yet students and researchers have limited opportunities to acquire these skills during their academic

training. To address this gap in training, a series of free videos focused on communication skills is proposed that can lead to a credential.

Pilot 7: Diversity Workshop to Increase Participation of Underrepresented Groups in the Plant Sciences

Contributors: Andrea Carter, Chelsea Pretz, Ashleigh Farmer, Nathan Vega

The purpose of this workshop is to bring together representatives from industry and the academic community—to include students and administrators involved in student diversity programming—to discuss how to increase involvement of underrepresented groups in plant science. The ideas presented in the pilot were forerunners to a PS-RN-HHMI workshop on broadening participation to be held in October 2018.

Pilot 8: Mays: Navigating and Networking Your Career in Plant Science

Contributors: Megan Kelly, Megan Sylvia, Crispin Taylor

A multimedia approach is proposed to address lack of readily available information regarding career pathways in plant science.

Pilot 9: Pop-up Leadership Academy

Contributors: Hallie Thompson

A pop-up leadership academy is proposed, which would bring together the concepts of training scientists in non-traditional skill sets via venues that do not rely on classic education through universities or laboratories in a credentialed manner. Focus would be leadership best practices, instilling a culture of continued learning, and developing a sustainable model for training continuation via volunteer curation.

Pilot 10: Creating active participants out of trainees

Contributors: Andrew Nelson, Navadeep Boruah, Bethany Huot, Irene Liao

This proposal encourages the funding of regional training hubs consisting of academic, industry, and affiliated plant science groups, which would be the site of transition-year training programs. Trainees would spend a year sampling different research/affiliated groups and acquiring the transferable skills necessary to take ownership of their future training.

Phase 2: Incentivizing Wide Adoption of Successful Pilot Programs

Phase 2 has two main components: evaluation of pilot programs and incentivizing the broad adoption of the successful and impactful ones. Thus, pilot programs, when fully developed, should include appropriate metrics as well as the capacity to collect allowable data that will facilitate longitudinal studies. In short, a pilot program should, at its inception, address the question, “what would success look like?” Those that achieve success can serve as models, as a whole or in part.

Evaluation. Short-term pilot programs suffer from small datasets and a lack of longitudinal information. Simple evaluation mechanisms are appropriate in such cases that match specific inputs (activities) to desired outputs/goals within a framework of the desired long-term objective. Guidelines are available to select and employ evaluation protocols (38, 39). Where appropriate, pilot program outcomes should also be assessed from the perspective of employers, whether academic or otherwise.

Incentivization. A model of direct funding creates an institutional incentive to optimize training, because prospective trainees, empowered by carrying their own support, will vote with their feet. Furthermore, one trusted source of graduate program rankings is the National Research Council (NRC), whose criteria include several that are directly linked to the proposals put forth here. For example, percentage of first-year students with external funding, proportion of interdisciplinary faculty, various measures of diversity, and number of student support activities all play into NRC rankings (40). By attracting diverse first-year students with fellowships and providing a rich training environment, a program would be likely to improve its ranking. Not only may rankings matter to prospective students, but they often matter a great deal to upper administration and donors.

Incentives can also come from the funding side. For example, NRT awards come with certain requirements for the host institution, and in some cases, such as GAANN awards from the Department of Education, cost sharing is also required. For individual rather than site awards, there can also be incentives for institutional commitment. For example, NSF BIO Postdoctoral Fellows are required to have a sponsoring scientist statement that shows “how the proposed host(s) and host institution(s) provide the

best environment for the Fellow’s proposed research and training plan.” Similarly, USDA-NIFA pre- and postdoctoral fellowships require “productive and interactive mentoring” and “appropriate and applicable training activities.” Institutions and trainers will respond as such criteria are worked into peer review of their applications.

Closing Remarks

Academia is being challenged to change to keep pace with national needs that include preparing a workforce made up of individuals who are adaptable, quick learners, and adept at communicating across boundaries. Digital fluency is an absolute requirement: five of the largest six U.S. companies are in the technology space, with traditional manufacturing and services lagging behind (41). At the same time, however, our universities will be drawing their clients from a well of increasing socioeconomic diversity, suggesting that the need to balance family and career obligations will expand (42).

The personalization and modularization of training articulated in our recommendations resonate with everyday experiences driven by social media, relentless improvements in data analysis and targeting, the needs of the private sector, and the ability to customize most of the interactive world around us. Whether such a world is desirable or not is largely beside the point; science will either learn to function within it, or it will lose its societal support and find itself adrift. This is an end that will serve no one and militates for bold actions that the plant science community is poised to lead.

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Society of Plant Taxonomists, the Botanical Society of America, the Crop Science Society of America, the Council on Undergraduate Research, the Ecological Society of America, the Genetics Society of America, the Global Plant Council, the Phytochemical Society of North America, and the Soil Science Society of America (as of June 2018). The PSRN engages the plant science community through its members to obtain community input on reports and recommendations.

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Appendix 1.

Workshop Attendees

Workshop 1: October 18–20, 2016, in Rockville, MD

Participants

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American Society of Plant Biologists, Rockville, MD

Guest Speakers

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Science

Jeff Hancock
Stanford University

Jacqueline Heard
CiBO Technologies, Cambridge, MA

Isha Ray
University of California, Berkeley, CA

Adrian Taylor
4Sing: Foresight and Strategy for Security and Sustainability
in Governance

Facilitator

Susan Stickley, Stratus, Inc., Philadelphia, PA

Workshop 2: September 19–21, 2017, in Baltimore, MD

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Facilitator

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Appendix 2. Workshop Agendas

Workshop 1: October 18–20, 2016, in Rockville, MD

Plant Science Research Network

Postgraduate Training Strategic Retreat

Location	Hilton , Washington DC / Rockville Hotel and Executive Meeting Center 1750 Rockville Pike, Rockville, MD 20852-1699
Objective	To identify recommendations for action by the PSRN and broader plant science community to enable the potential of the plant sciences through postgraduate training and cyberinfrastructure.

Tuesday, October 18, 2016

12:30 pm	Registration	<i>PSRN Staff</i>
1:00 pm	Kick-off: Welcome and Stage Setting Opening Remarks Table Introduction and Discussion <i>What do we mean by Plant Science?</i> Keynote Address <i>How entrepreneurship may shape the future of plant science research.</i> Jacqueline Heard (CiBO Technologies, Chief Strategy Officer) Enabling the Plant Sciences: Training and Cyberinfrastructure <i>Discussion of the overarching synergies between postgraduate training and cyberinfrastructure. What is the key underlying question associated with that synergistic space?</i>	<i>David Stern</i> <i>Table Discussion</i>
3:15 pm	Coffee Break	
3:30 pm	Scenario Planning and PSRN 2035 Scenarios <i>Presentation to introduce participants to both the scenario thinking methodology and the PSRN scenarios.</i> Early Indicators <i>Discussion of the early indicators that participants identified associated with the PSRN scenarios.</i>	<i>Susan Stickley</i> <i>Table Discussion</i>

continued on next page

Tuesday, October 18, 2016
continued from page 17

6:00 pm **Keynote Address**
Big Questions and Big Data
Jeremy Berg (Associate Senior Vice Chancellor for Science, Editor in Chief,
Science)

Wednesday, October 19, 2016

8:30 am **Stage Setting and Morning Reflections** *David Stern and
Susan Stickley*

Stretching Our Thinking on the Future of Postgraduate Training *Interview Series*
*Conversations with three provocateurs on how this challenging and changing
world can transform the role and model of postgraduate training.*

Provocative Speakers
Adrian Taylor (Consultant, 4Sing: Foresight and Strategy for Security and
Sustainability in Governance)

Jeff Hancock (Professor of Communications, Stanford University)

Isha Ray (Professor of Energy and Resources, UC Berkeley)

Panel Moderator
David Stern (Professor, President, Boyce Thompson Institute)

10:30 am **Break**

10:45 am **Scenario Deep Dive** *Breakout Groups*
*Exploration of the strategic implications of the PSRN scenarios on the future
of postgraduate training in the plant sciences.*

12:15 pm **Lunch**

1:00 pm **Scenario Deep Dive** *Breakout Groups*
(Continued)

Sharing Insights
*Breakout groups present their discussion highlights and strategic recommen-
dations for action in plant science postgraduate training.*

Robust Strategies

Identification of strategies that work well across the full set of PSRN scenarios.

3:15 pm

Break

3:30 pm

Deeper Exploration of Learnings: Competencies of the Future

Based on our strategic exploration of the PSRN scenarios, what will be the key competencies of scientists? How should this inform strategies in cyberinfrastructure?

Changing Legacy Practices

What needs to be addressed in the plant science community culture and practices to create the future we desire?

Next Steps, Closing Remarks

David Stern

5:00 pm

Adjourn for Evening

Thursday, October 20, 2016

9:00 am

Morning Reflections, Prep for Presenting Strategies and Recommendations

Opportunity to review and refine learnings and content to share back.

10:00 am

Break

10:15 am

Sharing Our Insights

Groups share recommendations from their postgraduate training and cyberinfrastructure sessions.

Enabling the Plant Sciences: Exploring the Shared Space

What are the critical learnings in the shared space of cyberinfrastructure and postgraduate training that enable plant science research? Which insights can be applied to other sciences?

12:15 pm

Working Lunch

Discussion of takeaways for action and the critical next steps to create momentum and progress forward. PSRN's role in progressing the agenda.

1:00 pm

Our Path Forward

Compilation of critical next steps moving forward.

1:45 pm

Closing Remarks

David Stern

2:00 pm

Adjourn

Workshop 2: September 19–21, 2017, in Baltimore, MD

Plant Science Research Network

Workshop to Address Postgraduate Training in the Plant Sciences

Location	The Westin Baltimore Washington Airport – BWI, Salon 2 1110 Old Elkridge Landing Road, Linthicum Heights, MD 21090
Pre-work assignment	Thoughtfully read <i>Imagining Science in 2035</i> (bit.ly/ImaginingScience) Come with an early indicator for each of the four scenarios.

Tuesday, September 19, 2017

6:00 pm	Registration
6:45 pm	Welcome Remarks Keynote Speakers and Provocative Conversations Maria Wheeler-Dubas, Ph.D. (Phipps Conservatory and Botanical Gardens) Sarah Davidson Evanega, Ph.D. (Cornell University) Panel Moderator: David Stern (Boyce Thompson Institute)
9:30 pm	Adjourn for Evening

Wednesday, September 20, 2017

8:30 am	Kick-off: Welcome, Introductions, Stage Setting Opening Remarks Table Warm-up: What Do We Mean by Plant Science?	David Stern
9:15 am	Scenario Planning and PSRN 2035 Scenarios	Susan Stickley
9:45 am	Early Indicators	
10:30 am	Break	
10:45 am	Scenario Deep Dive	
12:15 pm	Lunch	
1:00 pm	Scenario Deep Dive, cont.	
1:45 pm	Sharing Insights	
2:15 pm	Robust Strategies	
3:15 pm	Break	
3:30 pm	Deeper Exploration of Learnings: Competencies of the Future	

4:20 pm **Our Strategic Planning Process and Earlier Findings
Changing Legacy Practices**

5:00 pm **Adjourn for Evening**

Friday, September 21, 2017

8:30 am **Morning Reflections**

9:15 am **Comparing the Results
What's Consistent? What's New? What Assumptions May Be at Play?**

10:15 am **Break**

10:30 am **Robust Strategies Taking Forward – Closing on the Final Content**

11:45 am **Enabling the Plant Sciences: What Have We Learned?**

12:15 pm **Working Lunch**

1:00 pm **Our Path Forward**

1:45 pm **Closing Remarks**

David Stern

2:00 pm **Adjourn**

Appendix 3. Pilot Programs

Pilot 1: Unconventional Training Through Direct Funding

Contributors: Report writing committee

Direct funding is critical to encourage nontraditional entry into science training pathways. For example, it will be important to provide financial support for entering training that is unconventional because it occurs mid-career, or because it is not targeted toward completing a degree program. Support could take the form of short-term internships for workforce reentry (e.g., after caring for a family member, return from military service, a career switch). A program might include annual evaluation of the trainee's progress and career goals, including a discussion of an IDP with an appropriate program mentor. Flexible training could also allow for part-time work or be used for continuing education in combination with an apprenticeship, later developing into full-time employment.

It is very unlikely that a PI would develop a grant budget with funding for a career-switching trainee, but, on the other hand, if such a person made themselves known with specific objectives and funding in hand, they would often be welcomed. In some respects, this is a parallel to Research Experience for Undergraduates (REU) programs, where undergraduates are awarded stipends and join participating laboratories that might otherwise lack their own resources. Accommodating nontraditional trainees through new programs would also help to fulfill the broader impacts aspect of NSF-supported research.

We view the academic research community as being in transition from one that is more focused on developing future faculty to one in which the traditional academic track becomes one among many other equally legitimate and rewarding career (re)development paths. Acceptance will create a virtuous cycle with trainees, who will, over time, lose their reticence to seek these paths. It is already common for conferences to feature professional development workshops with presentations by scientists who “ended up” in technology transfer, law, venture capital, public service, etc. The next steps are to make these destinations more transparent and to match each person's training to their intended individual pathway or destination.

Pilot 2: Team Mentoring

Contributors: Report writing committee

Element 1 - Mentor databases. Resources populated with volunteers from academia, industry, and elsewhere would be built to centralize and democratize access to advising. Although some mentors might add themselves to these databases out of goodwill or individual interest, establishing additional incentives might also be worthwhile. For example, an institution or company could use such participation as a positive criterion in performance evaluation, and a research funder might view active participation as a positive criterion in proposal reviews and project reports.

Element 2 - Alternative mentoring team structures. Graduate mentoring teams with multiple leadership roles, as distinct from the single chair structure, could be piloted. For example, an interdisciplinary program might make an ideal testing ground for distributed responsibility of research mentoring. In more traditional research contexts, poles of responsibility might be set up along mentoring modes, with one cochair tracking research, for example, and a second cochair tracking education and career development. Such activities would allow institutions to recast the dominant model that a given trainee is solely associated with a particular faculty member, department, or graduate program.

Element 3 - Providing Support Resources. Roles and responsibilities on the mentoring team, and even roles among the broader mentoring community, could be defined and clarified, along with recommended best practices for guiding a trainee through the development of an IDP. What additional tools and techniques can be identified to effectively manage the mentoring team? How should progress toward fulfilling the objective of the IDP be tracked? How can professional development, research, and educational goals best be aligned throughout the training process?

Pilot 3: Building a Successful Mentoring Team

Contributors: Shandrea Stallworth, Valerie Fraser, Natalie Henkhaus, Katie Murphy, Andre Naranjo

This program would assist undergraduate and graduate students, postdocs, and young faculty members in developing meaningful and useful mentor/mentee relationships and teams in academia and industry. The goal of the program is to build relationships among students, faculty, and industry partners to better assist students in succeeding in their chosen career field.

Mentoring teams would consist of one of each: new faculty members, industry representatives, postdocs, graduate students, and undergraduate students. The goal is to allow industry representatives and new faculty members to grow young scientists into the careers that they see themselves in and to ensure that the scientists are able to perform in their industry. Mentoring teams allow for “no stone to be left unturned” by providing significant interactions to students throughout their academic and professional career. Mentoring teams, outside of the students’ adviser(s), give students the opportunity to build relationships with individuals who have their best interest at heart and want to see them succeed in their chosen field, not the one the adviser sees them in. Mentoring resources would be made available for both partners (43, 44).

To achieve these teams, Plantae would serve as a resource to provide a large pool of potential mentors and mentees (45). Plantae could be used to match individuals based on specific interests and goals. To increase participation from industry representatives, we propose advertisement for companies participating in the pilot program in return for access to the mentors and mentees. Program participants would receive financial assistance to attend PSRN conferences, private access to sponsored events such as coffee breaks and mini-receptions, and workshop-based training to assist with professional development.

To measure the effectiveness of the program, evaluations from mentors and mentees would be completed two to four times a year. Program participants would also be provided materials to assist them throughout the program. The pilot would run for two to three years with a six month to one year ramp-up to ensure thorough program development. A small feedback session during the ramp up would allow for input from faculty, industry, and students to understand what needs should be met during the program. Based on feedback, a strong mentoring team program can be developed that benefits all participants.

Pilot 4: Developing and Credentialing Training Modules

Contributors: Report writing committee

Universities in their legacy operational models are neither accustomed, incentivized, nor particularly well set up to support experiences acquired outside of their physical location(s) and formal partnerships. But the needs and desires of the consumer (both the student and future

employers) are changing, and universities are motivated to evolve to maintain their attractiveness (46). The following mechanisms would test and explore the implementation of modular learning experiences:

Element 1 - Complementary experience grants. Funding agencies could offer short-term fellowships for students to undertake research or learning activities distinct from their main research project. In the private sector, support might be combined from the fellowship (travel/living) and the host (stipend). Pilot 10 would create regional hubs to connect trainees and employers for this purpose.

Element 2 - Credentialing. Credentialing models for modular learning could be piloted, or existing ones could be enhanced or optimized for plant science. Existing organizations, such as scientific societies, might choose to set up credentialing mechanisms, or community-based models could be supported on a competitive basis. Also, degree-granting institutions could experiment with offering reciprocal credit with other institutions through student exchanges or could create arrangements with e-learning providers to share revenues in return for granting credits. Alternatively, a consortium of degree-granting institutions could offer credit via open badging, an emerging system for verifying skills and achievements (47). Integrating new and existing credentialing models will be critical. One incentive will be that prospective trainees will tend to seek institutions that are willing to credit their prior training and also encourage external training as part of their own programs. For transparency, training opportunities should be accompanied by information regarding stakeholder acceptance of credit to be obtained. Engaging employers from all sectors as credentialing systems are being developed will also be vital to ensure that the systems are relevant and useful to all.

Element 3 - Warehousing. A repository of accredited modules goes hand in hand with credentialing. Aggregating and organizing a meaningfully delimited set of learning opportunities is an exercise in information science. For example, a collection of thousands of MOOCs without a sophisticated search engine might thwart all but the most determined trainee. Therefore, plant (and life) science will require its own databases housing the fairly eclectic collection of opportunities that trainees may be seeking. Exploratory concepts for implementing such a resource could be funded on a pilot basis.

Pilot 5: Industry and Academia Conference for Students

Contributors: Emma Frawley

Synopsis

The final day of the September 2017 workshop largely centered on developing tangible objectives and strategies for improving the training of plant science students. Workshop attendees emphasized pressure about the polarity of plant science career paths (i.e., “academia” vs. “industry”) and further noted a lack of awareness and opportunity to learn about industry employment—especially for students who do not attend school in research hubs like Silicon Valley, the Durham-Raleigh Research Triangle, or St. Louis.

As a result, we propose the development of a two- to three- day conference with two main objectives: (1) foster an environment to understand and improve the relationship between academia and industry, and (2) facilitate trainee (undergraduate, graduate, and postdoctoral) networking with plant-science related industries. The conference would follow several organizational structures to ensure its success: its attendees must be at the postgraduate (e.g., not faculty/supervisory) level, the cost of attending the conference for trainees would be covered by tiered entrance fees for industries or student travel grants, and there would be an application process for trainees, industry, and academia representatives, requiring a commitment to the conference objectives of educating students about diverse career opportunities, the skill sets needed to thrive in an industry environment, and a future-forward perspective on training the next-generation workforce.

We envision the conference agenda as a mix of lectures from industry representatives, open-forum panels with academic and industry delegates, trainee-run lightning talks, and low-stakes mixers to make informal connections with potential employers and mentors. Importantly, the lecture series functions not as a “business pitch” opportunity, but rather as a *resource* for trainees to learn about necessary competencies and future expectations for the company in relation to student development. Furthermore, open-forum panels serve as a space for discourse around common contentions and best practices between academia and industry, such as intellectual property, transparency, public perception, research collaborations, and the role of education in developing employable students. We suggest that trainees devise and submit questions for the panels prior

to the conference for anonymity. Lastly, to include trainee participation in the conference, trainees could deliver 3- to 5- minute lightning talks to share their own ideas on how to improve relationships and communication between industry and academia, among other topics. A selection process including abstract submission would be required to participate in the lightning talks.

A variety of industry and corporate representatives would be selected to participate in the conference—from corporate incubators, to small businesses and local startups, to well-established conglomerates. This presents smaller corporations with an opportunity to publicize and brand their science and incentivizes larger corporations to participate in a form of public and community outreach. Ideally, the conference would have a mix of representatives from agriculture, biotechnology, science communication and policy, and more.

This conference is unique in that at its core, it revolves around student development and engagement, all the while attempting to cultivate cohesion between academic and corporate visions for the future. By providing trainees with the opportunity to network and learn about diverse career paths, we can open the door for them to hone their own skills and passions through higher education. Adequately educated and mentored students will succeed in a variety of career environments, including industry, a result that ultimately benefits both their academic institutions and future employers.

Pilot 6: Science Communication Training

Contributors: Nicole Forrester, Nat Graham, Chris Barbey

Motivation

Communication skills are essential for successful careers in science, yet students and researchers have limited opportunities to acquire these skills during their academic training. Specifically, scientists must be able to effectively discuss research methods and findings with other scientists, politicians, stakeholders, industry employees, and the public to contribute to solving global issues. Although training in science communication can be conducted within institutions or at workshops and conferences, young scientists often have limited institutional resources, funding, and time to receive this training. To address this gap in training, we propose a series of free online videos focused on communication skills that will be available to K–12, undergraduate and graduate students, and postdoctoral scientists. These videos will

provide fundamental training in science communication as well as enable scientists with skills geared toward a variety of science careers beyond academic research.

Program Goal

Enable young scientists to communicate the value and impact of scientific research with the public through free online training programs.

Design

Science Communication 101

We will create a series of 5- to 10- minute videos to aid students in developing a robust, professional skill set in science communication. Each video will focus on a key aspect of communication: for example, written, visual, and oral communication skills. These videos will be designed and created by experts within the field of communication with input from individuals with backgrounds in scientific research. The science communication series will be shared at plantae.org/AmpliComm.

Assignment Format and Program Assessment

Each video will be accompanied by an optional assignment specific to the skill highlighted in the video. For instance, in the written communications video, students can write a short description of their research for a public audience. These assignments will be uploaded to a website where they will be peer-reviewed/edited by other students, instructors, and teaching assistants. These assignments will not only help students implement the skills they learn from the videos, but can also be used to assess the effectiveness of the training program.

Credentials

Students that choose to complete all assignments for the video series will receive a certificate in Science Communication from the American Society of Plant Biologists and the National Science Foundation. Once a student receives this credential, they will be permitted to enroll in the *Specialized Communication Skills* video series. Additionally, they will be able to work as a teaching assistant where they can provide feedback to new students and catalyze discussions about science communication.

Specialized Communication Skills for Diverse Science Careers

To prepare young scientists for diverse careers beyond academic research, specialized programs catered toward

distinct career paths (e.g., industry, journalism, teaching, and outreach) will be created. These videos will provide more detailed information and assignments specific to these career paths, as they will be made by established professionals within those fields. These programs will be recognized by additional credentials and enable young scientists to be better prepared for diverse careers in plant science.

Online Format

To ensure students have equal access to training opportunities in science communication, all videos will be freely available through an online platform, which will be used for uploading assignments and discussion forums. Additional resources relevant to science communication as well as career opportunities (e.g., internships, fellowships) will also be available to students.

Update on Pilot 6. The program described here is currently under development by a team of early career trainees and will be launched on Plantae. See plantae.org/AmpliComm for more information.

Pilot 7: Diversity Workshop to Increase Participation of Underrepresented Groups in the Plant Sciences

Contributors: Andrea Carter, Chelsea Pretz, Ashleigh Farmer, Nathan Vega

The purpose of this workshop is to bring together representatives from industry and the academic community, including students and administrators involved in student diversity programming, to discuss how to increase involvement of underrepresented groups in plant science. It is hoped to spark a rich dialogue rooted in the different perspectives, experiences, and expectations of participants. Diversity is desired by industry and universities alike; however, the means by which we create a more diverse student body and workforce often remains more abstract than acted upon.

This workshop will be novel in its inclusiveness. Faculty members, advisers, and administrators leading or managing student diversity programming would be invited to attend along with one to two plant science students from their university that are currently involved in a diversity program (e.g., scholarship, fellowship, or mentorship program). Ideally the participating administrators would be specialized in STEM field student recruitment and retention. The administrators of diversity programs will have the

opportunity to share what has worked at their institutions as well as learn from the successes and challenges faced at other schools. Lessons learned from other administrators will help inform better programming back at their own campuses as will feedback from industry representatives.

Participating students would be either undergraduate or graduate level, and self-identified as part of an underrepresented group including the following: ethnic minorities, first-generation college students, low-income, community college transfer, older/nontraditional, and different gender/sexual orientations. Students will have the opportunity to share their experience as an underrepresented plant science scholar. They will be asked to share what has specifically helped and hindered their academic career and how programming could be improved to ensure their success. The use of students' firsthand experience will be key to improving diversity efforts at the university and industry level.

Invited industry representatives will be members of human resource departments or those some way involved in diversity initiatives at plant science–related companies. By attending this workshop, they will be able to express their expectations and desires for future employees as well as learn what they can do to create and attract a more diverse workforce. In addition, they too will be able to learn from one another by sharing diversity efforts that have and have not worked at their respective companies.

A first of its kind, this workshop will be used to produce actionable recommendations that universities and industry can implement to ensure diversity becomes a realized aspect of the plant science field.

Update on Pilot 7. The program described here has been adapted into a PSRN workshop proposal, which will take place in collaboration with HHMI in early 2019. The workshop will use scenario-based thinking to discover novel paths for increasing diversity and inclusion.

Pilot 8: Mays: Navigating and Networking Your Career in Plant Science

Contributors: Megan Kelly, Megan Sylvia, Crispin Taylor

Preamble

A lack of readily available information regarding career pathways in plant science represents both a barrier to entry and an ongoing frustration for trainees. We propose

a multimedia approach to address this problem. The solution—dubbed “Mays” to represent both a connection to the crop plant species *Zea mays* and the fact that one may pursue multiple opportunities and pathways in a plant science career (“maze”)—combines an app, Plantae profiles, and online information and videos, along with a gaming tool to assist exploration. Mays will explain different careers and career trajectories to students and trainees, and it will facilitate direct (online) connections among early career scientists and those who’ve already taken a few steps along a particular career pathway.

Details

- **Pathways Map:** A central feature is a road map that includes stops along the way (e.g., degrees), as well as destinations (specific jobs/careers). Thickness of the road indicates the numbers of people who typically traverse that route.
- Individuals navigating Mays would tag their own pathways and stops, in much the same way that users of mapping/driving apps crowdsource information of utility to all.
- Information will be available both as general descriptions of each position or topic and as specific profiles of scientists available for networking.
- Specific information tailored to cohorts—e.g., if an undergrad thinks they want to go to grad school, they need to know that they should get some research experience.
- All information will be tagged and structured to maximize discoverability and utility in terms of navigating and exploring distinct pathways. Core information for profiles might include qualifications (and dates earned), years in specific position, salary ranges, and topical keywords.
- Information can be sliced and diced in various ways—by position, qualification, and employer type, for instance, as well as by topical areas (e.g., “food security,” “discovery research,” “breeding technologies,” “ethnobotany”).
- Mays profiles, hosted on Plantae, would include a “being a scientist” component—individuals telling their stories through written word or videos.
- Contact information would be included; this is to facilitate both peer-to-peer networking and networking

among trainees and those further along their career pathway. These conversations could take place on Plantae, whether in private or in public. Participation would be incentivized in various ways, including discounts, badges, and networking opportunities. Employers would be encouraged to have employees participate in the website/app.

- Gamify with quiz aimed at keyword matching between a student/trainee's interests and people whose profile is on the site.

Diversity

- Profiles of “scientist of the week” would allow us to highlight diversity (ethnic; gender; but also career type—e.g., someone working at a small/startup company)

Paying For It

- Mays would be monetized through job ads, institutional subscriptions (for large institutions), and individual toll access (for those at small institutions). We would adopt a “freemium” model, in which a portion of the content is freely available, lowering barriers to entry and providing enough useful information for, say, high school students. Higher-order capabilities, including networking and conversations with mentors and guides, would require payment.

Metrics

- We would rely on a star rating system to assess users' appreciation for particular functions and/or pieces of content in the program.
- We would use focus groups to directly assess the utility of the site. An initial assessment would gauge understanding of career pathways in plant science and the extent of a trainee's network. Following a few weeks on the site, we'd assess again, using a control group without access to the site.
- More mundane online usage statistics would also be tracked—IP addresses, page views, etc.

Getting Started

- Initial technical development will be via an app design competition, driven by detailed technical specifications generated in collaboration with ASPB digital strategy staff.
- Mays will grow over time, both helping to seed and benefiting from the growth of the Plantae network. We

would test and launch with a minimum viable product that contains a few dozen key/well-traveled pathways, but would aim to rapidly increase the breadth and depth of information included in the program through outreach and engagement of plant scientists in various professions and workplaces.

Pilot 9: Pop-up Leadership Academy

Contributor: Hallie Thompson

Throughout the September 2017 workshop, attendees discussed the necessity of soft skills, or non-mainstream skills for graduate-level scientific training. Furthermore, modes of education and professional development outside of the traditional scope of graduate and postdoctoral education were underscored to avoid reliance on institutional changes, which are often incremental.

We propose a pop-up leadership academy, bringing together the concepts of training scientists in nontraditional skill sets via venues that do not rely on classic education through universities or laboratories. This academy has three main objectives: (1) train a subset of conference attendees on leadership best practices; (2) instill a culture of continued learning in leadership and management and counter harmful barriers to professional development; and (3) develop a sustainable model for training continuation via volunteer curation.

The academy will fulfill initial criteria designed to achieve the above objectives, but will remain flexible enough to change upon information collection. More specifically, this will be a plant scientist leadership module designed to travel from conference to conference and across the country. The module will need to be appealing to encourage a variety of involved parties. This will be achieved through an active training design placed within conference concurrent sessions and will provide a change of energy for attendees, engaging them for the academy and preparing them for the next conference lectures. The program will be adaptable enough to apply to a variety of plant science-related conferences. Programming will focus on students but will be open to students through faculty and structured to challenge limiting assumptions around leadership. A point of focus will be the value of reflective practices in a research setting, also an important leadership habit among other professionals. Team science will be another core tenet of the training, as the necessity of collaboration grows in plant science.

Certification will be available upon course completion. To encourage volunteer involvement two levels will be included: (1) single course completion and (2) teacher in training certification. Those that complete the teacher in training certification are eligible to volunteer as staff at a future pop-up leadership academy and will be eligible to train independently in the future pending availability. Volunteers and coordinators of the pop-up will also be eligible for complimentary conference registration.

Preparing Tomorrow's Leaders for Science is a student- and postdoc-oriented leadership program in existence at the University of Missouri in Columbia. It is a year-long program and focuses on a broad spectrum of leadership skills and the applications of these to science. The pop-up academy will utilize the expertise available through the development of this program and others across the country. However, a plant scientist leadership academy traveling to and from conferences is unique in that it makes this brand of training available to students from a larger number of institutions and, in turn, may inspire local courses or programs. Ultimately this will result in student ownership of training and an increase in high-utility skills among plant scientists, no matter their future career path.

Pilot 10: Creating Active Participants Out of Trainees

Contributors: Andrew Nelson, Navadeep Boruah, Bethany Huot, Irene Liao

Background

Transition years, defined as the year following each of the different stages of academic training (high school → undergraduate → graduate school → postdoc), are a time of enormous uncertainty for most aspiring scientists. Many promising young scientists lack a clear vision of their available career/education options and thus proceed along the traditional training pipeline by default. This is a problem for several reasons, including fit (many may be happier in non-academic positions), supply and demand (there are not enough academic research positions available), and societal need. Also, while this pipeline funnels trainees toward academic research positions, it provides little training for the actual tasks performed in such positions. In spite of the fact that five out of six will not obtain an academic position, career paths outside of this sector are typically not identified in a purposeful manner. To break down this unsustainable and wasteful training regime, a

program that effectively exposes trainees to the diverse array of postgraduate careers available to them as plant scientists is needed. Ideally, this training program would be dynamic and driven primarily by the trainee's needs and interests. If successful, this program would match strong candidates with all possible career paths, thereby reducing the oversaturation of the academic job market and better supplying the demand for scientists with versatile and diverse skill sets. As the path through education becomes more successful, and actively chosen careers in diverse job sectors become the norm, we anticipate an increase in the number and diversity of students choosing to pursue higher education in plant science.

Proposal Specifics

As a pilot program, this proposal encourages the funding of one or two regional training hubs consisting of academic, industry, and affiliated plant science groups (e.g., science policy experts, K-12 science education programs). These hubs would be the site of transition-year training programs, targeting competitive candidates who are within a year of graduating high school or completing a bachelor's, master's, or Ph.D. program as potential recruits. Trainees would spend a year in this program, sampling different research/affiliated groups and acquiring the transferable skills necessary to take ownership over their future.

Exposure to Diverse Research Groups

As part of the program, trainees would rotate through a minimum of three to four groups in various job sectors. Trainees could negotiate with mentors/advisers on length and goals of each particular rotation. Where appropriate, rotations could occur concurrently, allowing for a more organic training process. The focus of rotations would be less on completing a particular project and more on sampling different research environments/cultures within the various partnering sectors.

Mentoring

For mentorship through the training program, each trainee would be assigned three advisers from academic, industry, and affiliated groups based on their career interests, who would provide advice and valuable insights into each of these sectors. In addition, this proposal would pay for the hiring of a career placement adviser who would assist trainees in examining future job or educational prospects. Finally, trainees within the program would be paired with other trainees further along in their professional develop-

ment to foster mentoring skills and encourage exchange of experiential knowledge.

Soft Skill Developments

Alongside rotations, trainees would develop soft skills through a series of workshops and public outreach programs. Soft skills development workshops would contain content preselected by the training program, with topics centered around making and giving presentations, all aspects of manuscript preparation and publication, tips for interviewing and putting together applications, and considerations for establishing and maintaining collaborations. Trainees could then choose additional content specific to their interests (e.g., grant writing, composing budgets, and personnel management). These workshops would be taught by stakeholders within the program or by consultants. Soft skill development through public outreach programs would occur by partnering with local organizations to bring “digestible” science to the public, such as to K–12 classrooms, Rotary and Lion’s Club meetings, and assisted living homes. With assistance from the career placement adviser, trainees would develop appropriate activities to engage with the public about the importance of plant science. Additionally, trainees will be involved in the process of putting together such an activity, thereby building leadership, communication, networking, and organizational skills.

Technical Skill Development

In addition to focusing on soft skills, short (one to two week) courses would discuss technical skills being utilized by the various partners in the program. Technical skill development would begin with introductory “courses” in the various skill categories being offered (e.g., genetics, bioinformatics, biochemistry, statistics, education, policy), focusing on how the different approaches can address applied or basic research questions. From there, trainees would be able to select from different modules based on preference, without prerequisite, and in a nonlinear fashion. Skill set courses could be taught by any member of the participating partners’ groups. The prerequisite for teaching a skill set would be proof of that skill (published or acknowledged by peers). A course rating system would inform future trainees.

Assessment

The success of this training program will be assessed through evaluations and reflections. Trainees will be asked to evaluate their perceived prospects prior to participat-

ing in the program, and then on a yearly basis for five years after leaving the program. Similar to the peer review process, trainees will give both private and public reviews for workshops, modular training, and rotations following completion. These evaluations and feedback will also be used to constantly improve the program in order to provide the tools and experiences that the participants seek and require as the times change. Participants’ professional positions will also be tracked to see how well this program helped participants reach their career goal.

Sustainability

This program would initially form as a collaboration among industry, academia, and other interested partners. During the first year, NSF or other funding agents would absorb 50% of the program cost (stipends, salary for career placement adviser, workshops, etc.), with the other 50% split evenly among partners. Over the lifetime of the program, support from funding bodies would diminish (e.g. 5–10% per year), with increasing support from participating partners. Academic partners would be offered supplemental support on existing NSF grants to cover costs. Although unnecessary, endowments could also be pursued to minimize long-term costs to the program. As an additional incentive, participating partners would have first chance at recruiting from a well- and broadly trained group of scientists.

Conclusion

The number and diversity of trainees choosing to pursue higher education in plant science may be restricted by a lack of training tailored toward specific, visible career outcomes. Providing access to knowledge, resources, and experiences that facilitates trainee ownership and strategic career management will help trainees develop the transferable skill sets and confidence needed to actively choose their future career. We also expect this program to reduce the length of time it takes for trainees to obtain their desired career by maximizing fit through tailored training and helping establish a network within the job sector of their interest. If these outcomes are realized, we anticipate an increase in the number and diversity of students drawn to higher education within plant science.



Plant Science Research Network

Join the community: plantae.org/PSRN

Download the report: plantae.org/PSRN-Training



Workshop 2 participants in Baltimore, MD (September 20, 2017).