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The National Institute of Environmental Health Sciences Superfund Research Program: a model for multidisciplinary training of the next generation of environmental health scientists

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Abstract

The National Institute of Environmental Health Sciences (NIEHS) Superfund Research Program (SRP) funds university-based, multidisciplinary research on human health and environmental science and engineering with the central goals to understand how hazardous substances contribute to disease and how to prevent exposures to these environmental chemicals. This multi-disciplinary approach allows early career scientists (e.g. graduate students and Post-Doctoral researchers) to gain experience in problem-based, solution oriented research and to conduct research in a highly collaborative environment. Training the next generation of environmental health scientists has been an important part of the SRP since its inception. In addition to basic research, the SRP has grown to include support of broader training experiences such as those in research translation and community engagement activities that provide opportunities to give new scientists many of the skills they will need to be successful in their field of research. Looking to the future, the SRP will

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continue to evolve its training component by tracking and analyzing outcomes from its trainees by using tools such as the NIEHS CareerTrac database system, by increasing opportunities for trainees interested in research that goes beyond U.S. boundaries, and in the areas of bioinformatics and data integration. These opportunities will give them the skills needed to be competitive and successful no matter which employment sector they choose to enter after they have completed their training experience.

Keywords

Training; Education; Professional Development; Alternative Careers in Science; Academia

The National Institute of Environmental Health Sciences (NIEHS) Superfund Research Program (SRP), a part of the National Institutes of Health (NIH), funds university-based, multidisciplinary research on human health and the environment related to hazardous substances. The overarching goals of the SRP are to determine how environmental chemical exposures contribute to disease and to develop prevention and intervention strategies to mitigate these exposures. To accomplish these goals, the SRP awards research grants to a diverse set of university investigators to develop, test, and implement unique, problem-based, solution-oriented approaches that address complex environmental health problems. SRP-supported researchers are improving the understanding of how these environmental contaminants move through the environment, exposure to these contaminants, the diseases that they cause, and how to reduce the risk of exposure, with a goal to improve human health and lower environmental cleanup costs. In this paper, we summarize the various mechanisms the SRP uses to support accomplishments and leadership in training the next generation of environmental health scientists and discuss ways to enhance future training efforts.

A long history of preparing tomorrow's scientists

Training has been an important element of the SRP since its beginnings, as indicated by its official title as the "Superfund Hazardous Substances Basic Research and Training Program." The cornerstone of the SRP is the university-based, multi-project Centers' grant program (i.e., P42 Centers). These SRP Center grants support problem-based, solution-oriented research Centers that consist of multiple, integrated projects representing both the biomedical and environmental science and engineering disciplines; as well as cores tasked with administrative, community engagement, research translation, training, and research support functions. The scope of the SRP Centers is taken directly from the Superfund Amendments and Reauthorization Act of 1986, and includes: (1) advanced techniques for the detection, assessment, and evaluation of the effect on human health of hazardous substances; (2) methods to assess the risks to human health presented by hazardous substances; (3) methods and technologies to detect hazardous substances in the environment; and (4) basic biological, chemical, and physical methods to reduce the amount and toxicity of hazardous substances. Moreover, these Centers conduct scientific research to address the wide array of uncertainties faced by the national Superfund program. The complex problems related to sites impacted by hazardous substances require the expertise of both biomedical and environmental science and engineering disciplines.

The SRP currently funds 18 Centers, which includes more than 190 research projects with collaborations at approximately 120 institutions. In 1987, when the SRP was under development, these multi-project Centers were encouraged to include training activities, leading to the formation of “Training Cores” among some of the Centers. In 2012, the SRP emphasis on training became more formal, with each Center becoming required to include a Training Core that would be integral to the Center’s activities. Each Center’s Training Core has a Training Core Leader, who is charged with acting as an advocate for trainees at the graduate and postdoctoral levels and helps guide their professional development. The training core leader must have the knowledge, skills, and resources needed to organize and implement a high-quality research training program at the grantee organization. Training core leaders must have acknowledged leadership and administrative skills, training experience, and scientific expertise. The Training Cores also reflect the interdisciplinary nature of the overall research effort of the Center by promoting and enhancing cross-training of trainees in the various disciplines represented within the Center. For instance, trainees pursuing degrees in environmental science and engineering (ESE) are encouraged to understand how their research fits into the context of biomedical sciences, and vice versa for biomedical trainees (1). Because the SRP is a research program, the SRP also specifies that Training Cores should support graduate level (e.g., Masters, Ph.D.) and post-doctoral training. Therefore, SRP defines “trainees” within the core as graduate students and post-doctoral researchers who are either supported directly by the Center or performing research or other activities that are supported by the Center. However, Training Cores may also support training beyond the graduate and postdoctoral level, as these Training Core activities may incorporate undergraduates and post-baccalaureates and other staff involved in the research of the P42 projects and cores.

Each Training Core accepts approximately six to ten trainees a year at a typical Center. Through the Training Core, trainees with a biomedical focus can actively participate in collaborations on projects and activities with an ESE focus, and vice versa. Trainees at currently funded SRP centers address a wide variety of scientific questions such as how phthalate exposure influences preterm birth, how arsenic may lead to cancer and cardiovascular disease, and how to design nanomaterials for optimum function and safety. For more examples of the varied scientific areas in which trainees are participating, see: <https://tools.niehs.nih.gov/srp/programs/index267.cfm>.

The SRP regards the Training Cores as vital components of the mentorship, education, and training of the next generation of environmental health and science professionals. Specifically, these Cores conduct professional development workshops (e.g., resume or scientific writing, interviewing skills, and oral and poster presentation skills), host events within their Center to promote collaboration among the trainees (e.g., seminars or field days), invite trainees to advisory board meetings, and provide support for them to travel to professional meetings. In addition, the Principal Investigators of the grants, as well as leaders of all the Cores, serve as mentors to the trainees. Moreover, the problem-based, solution-oriented nature of the research conducted by the Centers means that the trainees see how their work can impact the real world. Trainees’ involvement with the Centers’ Community Engagement Cores and Research Translation Cores provides them the opportunity to meet and speak directly to those affected by the environmental exposures they

are studying, who may be helped by the remediation methods they are developing, and those involved in developing public health policies related to the exposures (2). The broader understanding that these experiences provide is vital to trainees' professional development if they are to pursue meaningful careers in environmental science. These experiences are also unique to SRP trainees, as many graduate and post-doctoral trainees may not receive such experiences as a routine part of their training.

In addition to Center grants (P42), the SRP awards individual research grants (R01) and Occupational and Safety Training Education Programs on Emerging Technologies grants (R25). Currently, R01 grantees at eight universities conduct specific research projects to address issues that complement the multi-project Center grants. At present the R01 grant program is focused on biogeochemical interactions affecting bioavailability for *in situ* remediation of hazardous substances. The trainees conducting research under these grants are given the opportunity to interact with the larger pool of trainees from the Center grants at the SRP annual meeting and other professional meetings. In addition, the SRP supports four R25 grants to universities to develop continuing education and academic curricula on occupational health and safety management practices in the areas of emerging technologies, such as hazardous waste products, green chemistry, and sustainable remediation. These curricula are offered to industrial hygienists, graduate students, and other professionals involved in the evaluation, management, and handling of hazardous substances. The training offered by the R25 grant mechanism has a broad reach, with the capability to offer training to hundreds of other professionals through training modules, webinars, and workshops hosted by the R25 grantees.

SRP staff also facilitates a variety of activities to promote trainees' research and help them network with one another and with potential future employers. For example, an active SRP Student/Postdoc/Alumni Network (SPAN) Leadership Committee was developed to bring together SRP trainees, trainee alumni, and Training Core Leaders from the SRP Centers via quarterly webinar discussions. The members discuss recent research, professional development activities, brainstorm topics for training events at the SRP's annual meeting, and specific topics that pertain to their training experiences. Additionally, SRP staff communicates with trainees via an email listserv and has formed a LinkedIn group to encourage SRP trainees to share and discuss their research, professional activities and events, and upcoming job opportunities. In addition, SRP staff and its contractors have developed an SRP Trainee Webinar Series on professional development and where trainees can present their research. Examples of these webinars include "AAAS Science and Technology Policy Fellowship Experiences," "Funding Opportunities at the National Science Foundation Webinar," "NIH Fellowships and Career Development Awards Webinar," and webinars showcasing the poster winners from the SRP Annual Meeting. Monthly "Trainee Highlights" and other articles are also written by SRP staff and contractors for the SRP newsletter (i.e., SRP e-Posted), for the SRP website, and other NIEHS newsletters. (For more information about SRP Training efforts, please see <https://www.niehs.nih.gov/research/supported/centers/srp/training/index.cfm>).

"Alumni" of the SRP training program have gone on to become successful in employment sectors such as government, industry, and non-profit organizations (several examples are

listed throughout this paper). Many have also gone on to become highly successful independent principal investigators at academic institutions, and some have become SRP grantees. For instance, Dr. Robert Wright, an epidemiologist from Mount Sinai School of Medicine in New York and previous Harvard Superfund Center Trainee Director, was invited to give a plenary presentation at the 2016 SRP Annual Meeting held in Durham, North Carolina. The title of his talk was “Environment, Health and Disease: why the past (and the Superfund Research Program) is so important to the future.” Dr. Wright described his experience as a trainee at the Harvard Superfund Center beginning in 1995 and his path to becoming the Director of the Harvard Superfund Center in 2010. Other SRP trainee alumni that have gone on to become SRP grantees in their own right include: Dr. Ingrid Padilla (University of Arizona Superfund Center trainee to Northeastern Superfund Center Project Leader), Dr. Molly Kile (Harvard Superfund Center trainee to Oregon State University Superfund Center Community Engagement Core Leader), Dr. Jennifer Schlezinger (Boston Superfund Center trainee to Boston Superfund Center Project Leader), Dr. Candice Spier (UC Davis Superfund Center trainee to UC Davis Superfund Center Research Translation Core Leader), and Dr. Thomas Webster (Boston Superfund Center trainee to Boston Superfund Center Project Leader).

Transcending disciplines to solve big problems

Because of the SRP’s focus on solving complex problems in environmental health and conducting integrated projects representing both biomedical and environmental sciences and engineering (ESE) research, trainees’ research experiences are uniquely wide-ranging. The SRP supports university-based research Centers and projects that are transdisciplinary, meaning that they bring researchers from varying fields together to evaluate and solve an environmental problem. Training is offered in fields related to biomedical research, such as mechanistic-based toxicology studies, epidemiology, genetic susceptibility, computational biology, or biomedical engineering. For environmental sciences and engineering, training includes research in the areas of civil/environmental engineering, geology, ecology, microbiology, fate and transport studies, hydrogeology, remediation, and detection sciences. Bringing together scientists from these disparate disciplines can be challenging, but the SRP has been successful in helping biomedical and ESE scientists develop a shared perspective (3, 4). The SRP training component is also unique in that it has evolved to include a wider breadth of experiences, such as in research translation, community engagement, and laboratory support, to give new scientists the skills and experiences they will need for success, whatever career path they choose (5).

Many SRP trainees are finding research translation and community engagement is of great interest to them and that these broader professional areas have become a vital part of their work. For example, at the University of California, San Diego (UCSD) Superfund Center, trainee Andrew Cooper has worked with a community to transform a vacant lot on a Brownfields site into a community garden. His involvement included testing fruits and vegetables to ensure they were safe to eat and working with the UCSD Research Translation Core and Community Engagement Core to discuss the results to the community. The City of San Diego has multiple Brownfields sites being considered for urban garden sites, and this UCSD project will likely serve as a model for other Brownfields around San Diego County.

In addition, UCSD built upon Cooper's work to successfully compete for a grant from University of California Global Food Initiative to understand issues related to urban gardening.

At the University of Arizona SRP Center, every trainee is required to participate in at least one research translation or community engagement project per year. Several trainees have gained insight into the real-world implications of their work through engagement with surrounding tribal communities and with mining industry stakeholders. Trainees Christopher Olivares and Carime Lechner developed tribal educational mining modules for students at Tohono O'odham Community College, such as hands-on activities to understand chemical acids and bases, with application to acid mine drainage. In addition, Lechner meets regularly with tribal stakeholders. Linnea Honeker (another trainee from the Center), whose lab work relates to phytostabilization of mine tailings, participates in meetings with mining industry stakeholders related to academic-industry phytostabilization projects.

Providing training that crosses disciplinary boundaries has gained increasing importance in the larger scientific enterprise. For instance, in the early 2000s, the National Academies and the Institute of Medicine both published reports promoting cross-disciplinary education (6–8). Cross-disciplinary approaches are particularly relevant for complex social or health problems (9). In addition, increasingly, trainees must be prepared for a wide variety of careers outside of traditional bench science. According to the National Science Foundation, only 10.6 percent of biological or life science PhD graduates held a tenure-track position five years after graduation (10). In one analysis of careers for PhDs, nearly 40 percent of research-grant-supported degree recipients obtained a position in high-tech and professional service industries, in many cases near the university where they received their training. This analysis supports the idea that training plays an important role in transferring knowledge from universities to the broader economy (11). Moreover, the NIEHS, which administers the SRP, has indicated the importance of training in Goal #9 of its 2012–2017 NIEHS Strategic Plan, which states that it will “inspire a diverse and well-trained cadre of scientists to move our transformative environmental health science forward, and train the next generation of EHS leaders from a wider range of scientific disciplines and diverse backgrounds.”

To create a scientific enterprise that is more sustainable, it will be important to help early career scientists to pursue a broader range of careers (12). Though training programs have historically focused on single disciplines (9), a few others have taken a transdisciplinary approach to training similar to the SRP. For example, to address the complex problem of cancer prevention and control, Washington University in St. Louis launched a transdisciplinary training program in its Division of Public Health Sciences (9). In this program, postdoctoral fellows are matched with primary mentors and assemble a multidisciplinary mentoring team that spans basic, clinical, and social/public health sciences.

Developing “soft skills”

Another important aspect of the SRP training component is the development of “soft skills” that are not gained by conducting a research project or writing a dissertation. Such skills include collaboration, interpersonal interaction, project management, personnel

management, conflict resolution, networking, and negotiation, all of which are important parts of a successful scientific career, especially since the scientific enterprise is increasingly a collaborative endeavor. Such skills must be nurtured and taught (13). These skills are taught to SRP trainees through a variety of experiences offered directly by the Training Cores as well as by other programs at individual universities. For instance, the New England Superfund Centers (which includes Dartmouth, Boston University, Brown, University of Pennsylvania, Columbia, and Northeastern) developed an annual workshop titled “The Northeast Superfund Research Program Training Workshop” for trainees with sessions focused on encouraging individual reflection and professional growth, balancing time with family and personal priorities while planning a career, communicating science to non-scientific audiences, how different personality types can translate into leadership skills and group dynamics, and development of individual development plans and CVs. Trainees also participated in a session led by the Alan Alda Center for Communicating Science, which focused on improving the communication skills to convey their work and enhance public understanding of scientific research. SRP staff highly encourages other SRP Centers to consider developing these types events for trainees to grow in the areas of leadership and professional development listed above and to increase collaboration between the trainees and Centers.

Professional development and promoting leadership

SRP Trainees are given multiple avenues for presenting their research, networking, and learning about career options. Trainees are encouraged to attend and present at both national and international conferences and workshops, especially at the SRP Annual Meeting, which includes two to three days of scientific presentations (including trainee presentations), a graduate student poster competition, and networking events to encourage trainees to meet other researchers, alumni of the program, and trainees from the various SRP Centers and other SRP grant mechanisms. In addition, the SRP provides specific funding to SRP grantees hosting scientific meetings to use for SRP trainees to travel to and participate in these meetings. The trainees receiving travel stipends are selected on a competitive basis by the meeting organizers based on their abstract submission, career stage, and research relevance to the focus of the meeting. These conferences allow trainees to present advances in the field of environmental health sciences, to share their data, engage broadly with the scientific community of all levels, participate in career discussions, and initiate collaborations within a national and international context. Moreover, these opportunities provide an environment to increase the expertise of the trainees, as well as create opportunities for new collaborations and potential employment.

Another opportunity for trainees to present their work comes in the form of the annual Karen Wetterhahn Memorial Award, a prestigious award among SRP researchers. The award honors the life and scientific accomplishments of Dr. Karen Wetterhahn, a professor from the Dartmouth College Superfund Center, who established the effects of heavy metals on biological systems. Wetterhahn’s career was cut short by her death from dimethyl mercury poisoning, caused by an accidental spill that occurred while she was conducting laboratory research. In memory of Wetterhahn’s dedication to teaching and mentoring, the Wetterhahn award recognizes an outstanding graduate student or post-doctoral researcher who best

demonstrates the qualities of scientific excellence and leadership exhibited by Dr. Wetterhahn. The chosen applicant is academically strong and is performing cutting-edge research but also has demonstrated the ability to mentor other young scientists and to grow into a leader in their own scientific program. The award recipient receives support to attend one major scientific conference of their choosing and the SRP Annual Meeting, where the awardee presents his or her research. In addition, the recipient is invited to give a seminar of their work to NIEHS scientists and to network with senior NIEHS staff.

The SRP has been presenting the Wetterhahn Award for the past 18 years, and its recipients have gone on to productive careers in industry, academia, and public health. For instance, the 2005 recipient, Tiffany Bredfeldt, PhD., was selected for her contributions to environmental metals research and her work on the interaction of monomethylarsonous acid with human bladder cells, improving understanding of how arsenic exposure leads to bladder cancer. She completed a postdoctoral fellowship in molecular carcinogenesis at the University of Texas M.D. Anderson Cancer Center and now works as a toxicologist for the Department of Environmental Quality in Texas. The 2010 recipient Courtney Horvath, PhD, conducted thesis research that was the first to demonstrate that arsenic exposure can increase susceptibility of mice to sub-lethal doses of influenza virus. The results of her research garnered attention from the scientific community and the mainstream media, and she used the opportunity to raise public awareness about arsenic exposure. Horvath is currently a Scientist at Genzyme, a Sanofi company, where she leads nonclinical toxicology efforts on a variety of programs. The 2014 Wetterhahn award winner was Bradley Newsome, PhD., from the University of Kentucky Superfund Center, who investigated how nutrition can modulate the effects of exposure to environmental chemicals as well as research to develop systems that use nanomaterials for removal of contaminants in water supplies. After completing his research, Newsome completed an American Association for the Advancement of Science (AAAS) fellowship, which familiarized him with US education policy needs. He was hosted at the NIH Office of the Director in the Immediate Office of the Director's Scientific Workforce Diversity team where he worked to analyze transition barriers faced by scientists at each stage in the biomedical career path, especially those from underrepresented groups. These are just a few examples of the productive scientists who have benefitted from the Wetterhahn award and have become highly respected in their fields. For more information about the other Wetterhahn recipients, see <http://www.niehs.nih.gov/research/supported/centers/srp/training/wetterhahn/index.cfm>.

Transferring technology

SRP trainees have several opportunities to gain new technical skills and to learn how to apply their research innovations to the real world. One example is the K.C. Donnelly Externship, which is a unique vehicle to provide SRP trainees experience in collaborating with those outside of their areas of expertise as well as help them develop new skills. The externship is named for the late Dr. K.C. Donnelly, from the Texas A & M SRP Center, who was a longtime SRP grantee and was dedicated to his students and to active promotion of partnerships. This supplemental award provides current SRP-funded graduate students and postdoctoral researchers with translational and transdisciplinary opportunities and experiences with other SRP-funded Centers, R01 grantees, government laboratories

(USEPA, ATSDR, NIEHS), or other agencies (state, local, Tribal). Recipients of this award have used their externships to, for example, conduct collaborative research projects with scientists at the USEPA, work side-by-side with experts in the field of remediation, and learn and apply advanced techniques in engineering, modeling, and bioinformatics (14). The externship also facilitates transdisciplinary research, because the trainee brings methods, ideas, and questions from the externship back to his or her home laboratory. As collaborative science has become increasingly important, other scientific teams have found benefit in graduate students or postdoctoral fellows gaining experience in a lab outside of their home lab, even if for a short time (13). Thus far, the SRP has supported 39 externs. For more information about the KC Donnelly Externship, see <https://www.niehs.nih.gov/research/supported/centers/srp/training/donnelly/index.cfm>.

Another example of a highly successful training opportunity offered to SRP trainees is the University of California-Davis (UC Davis) Entrepreneurship Academy hosted by the UC Davis Superfund Center. This three-day Academy is a premiere academic program for commercializing science and engineering innovations. It is a springboard for moving research out of the lab and into the world. The academy is taught by venture capitalists, entrepreneurs, university faculty, industry executives and angel investors who serve as mentors and guest speakers. Trainees gain the knowledge and networks needed to develop the commercial potential of their research idea. SRP trainees are highly encouraged to take part in these types of activities along with similar laboratory management, leadership courses, and professional development opportunities offered by university doctoral and post-doctoral programs or career counseling centers.

Promoting diversity

The SRP recognizes the need to promote diversity in the biomedical, environmental science and engineering, and community engagement and research translation workforces, not only to reflect the diversity of the population more accurately but also to increase productivity. In 2010, Hispanics, African Americans, and Native Americans combined made up more than 30 percent of the United States population (15). Yet, less than 9 percent of science, technology, engineering, and medicine PhD recipients in a 2008 report were members of one of those groups (15). There is evidence that diversification leads to greater innovation and productivity in problem solving (15), and increasing diversity is expected to energize efforts to address health disparities (15). SRP's efforts to encourage diversity include the SRP Diversity Administrative Supplement Program, which offers a research experience to new trainees from diverse backgrounds to be added to SRP-supported grants. Eligible trainees must be from underrepresented racial and ethnic groups, have a disability, or be from socially, culturally, economically, or educationally disadvantaged backgrounds. In 2013, SRP awarded a diversity supplement to Tiffany Sanchez, an SRP trainee from the Columbia Superfund Center, to gain additional laboratory and statistical training and to complete her dissertation related to the elucidation of the adverse health effects of arsenic and manganese in a group of 800 Bangladeshi adolescents whose exposure to arsenic has been well-documented since conception. Pulmonary function, biomarkers of lung disease (oxidative stress (8-isoprostane)), airway inflammation (decreased pH), intelligence, and other brain functions were evaluated.

Another SRP Diversity Supplement was awarded in 2014 to the University of Pennsylvania Superfund Center to support an African-American MD/MPH student, Atu Agawu, in study of asbestos exposure around the Ambler, Pennsylvania, Bo-Rit Superfund site. This supplement enabled Agawu to work determining the range of mechanisms (geographic, social, and lifestyle factors) through which asbestos exposure occurs and the spatial distribution of health effects from these routes of exposure. The “Social Determinants of Risk and Attitudes about Asbestos Exposure,” project is led by Dr. Francis Berg. This supplement provided the opportunity to capture asbestos disease cases that have yet to be developed and those that are diagnosed outside of Pennsylvania. Through this award, Agawu received epidemiological training and studied the combination of historic census data from 1930 to 1940 and information from the National Death Index. He was also able to capture the links among occupation, residence, and mortality over a longer time period, in both children and adults, which was not being currently captured in the parent project. Furthermore, the supplement provided support for obtaining the data sets, tuition, courses, and travel to the SRP Annual Meeting and to the Society for Epidemiological Research Meeting.

An added highlight of the SRP training program is that it provides some trainees with international experiences such as conducting research in Bangladesh and Mexico (e.g., Columbia University, University of California-Berkeley, and University of North Carolina-Chapel Hill Superfund Centers), gaining knowledge and experience in the study of widespread public health problems, such as arsenic contamination. Trainees have also had many chances to present their research to international colleagues through SRP-supported conferences (e.g., through the R13 grant mechanism). These include:

- The Central and Eastern European Conference on Health and the Environment in Prague (16, 17)
- The Halifax Project, held in 2013 in Halifax, Nova Scotia, where 174 scientists from 26 countries and many disciplines met to discuss the possible role of low-dose chemical mixtures in activating changes in pathways that may lead to cancer (18)
- The Princess Chulabhorn International Science Congress, held every 4 to 5 years in Thailand to exchange information and advances in selected topics in science and technology
- The International Polychlorinated Biphenyl (PCB) Workshop, now in its tenth year, which provides an exchange of ideas and information on analysis, transport, exposure assessment, metabolism, toxicity, and public health policy surrounding PCBs (19)
- The Products of Incomplete Combustion (PIC) congress meeting, held every two years to provide an international forum to discuss topics on the origins, fate, and health effects of combustion by-products (20)
- The Pacific Basin Consortium meeting, which brings together individual researchers and engineers, as well as organizations with diverse professional expertise, to discuss the most pressing environmental and health issues of our

time, engage in cooperative research, and develop and disseminate innovative strategies for addressing these issues (21).

Careers: bench science and beyond

SRP trainees are offered a broad range of experiences and exposures to career paths outside of bench science, such as community engagement and research translation. Particularly since 2010, efforts have been made through the SRP's Strategic Plan to encourage grantees to involve trainees in stakeholder interaction, community engagement, research translation, and in projects that promote coordination or collaboration among grantees. For example, the SRP encourages each of its Center's Training Cores to facilitate practical opportunities for trainees to communicate research outcomes to diverse audiences (i.e., research translation). This can be through the trainees speaking to the general public and to groups of scientists from many disciplines, in a manner easily understood by the intended audience. In addition, some SRP trainees are inspired to focus their work on community engagement. The SRP supports the notion that once a trainee expresses their interest in community engagement or research translation, rather than basic laboratory research, that the mentor should encourage this career path and provide opportunities for the trainee to gain experience in these growing fields. In addition, the SRP encourages mentors to make trainees aware of other career paths, such as government, industry, the non-profit sector, or scientific writing, all of which require knowledge of research translation. In one example, a previous SRP trainee, Dr. Monica Ramirez of the University of Arizona Superfund Center, found a novel avenue to start her career in research translation; she created a novel citizen science program in collaboration with gardeners living near a Superfund site, to measure the amount of arsenic uptake in their homegrown vegetables (22). She found that certain vegetables are more prone to arsenic uptake, which can help these gardeners more safely plan their gardens. She did so with funding from the NASA Space Grant Program's graduate fellowships, which are awarded to students who want to promote the understanding of science to the public. Another example: former trainee Dr. Jay James has gone on to start his own small business, Picoyune, and apply for an SRP small business grant. In 2012, Dr. James ventured to commercialize a portable mercury detector that he helped develop as an SRP trainee at the University of California-Berkeley. This reliable and easy-to-use mercury detector replaces complex laboratory equipment typically used to analyze samples from contaminated sites and allows on-site analysis.

Efforts are also under way to follow the accomplishments and career paths of SRP trainee alumni and current trainees, using the NIH CareerTrac database (<https://careertrac.niehs.nih.gov/>). This searchable database, launched by several NIH institutes and centers, including the NIEHS, facilitates effective evaluations of health research training programs for both NIH and for the grantees using the database. CareerTrac enables tracking of trainees over time and allows data entry of a wide variety of accomplishments, such as employment, funding, publications, and patents (see Figure 1). The system can also accommodate narratives about how training grants have helped trainees' career trajectories. As of May 2017, 1,893 trainees have been added to CareerTrac. SRP staff have been encouraging grantees to enter as much data about their trainees as possible, and the SRP expects that data will be ready for analysis within the next three years. As SRP grantees

assist in data refinement in CareerTrac, the SRP will be able to determine how well its training program is being implemented and how it might be improved. A future report will provide a detailed analysis of trainee outcomes, once additional data is gathered via CareerTrac. The types of questions that SRP will be asking include:

- How many SRP trainees have entered academia and what is their success in receiving future grants from NIH and other funding agencies?
- Which employment sectors are SRP trainees entering after completing their SRP training experience (academia, private/industry, non-profit, government)?
- How many publications are coming from SRP trainees and how many demonstrate interdisciplinary science? Which journals are they publishing?
- What other accomplishments are coming from SRP trainees (e.g., patents, awards, fellowships, presentation of research at meetings)?
- Which meetings are SRP trainees participating in and which of these meetings require interdisciplinary experience?

Looking to the future

The SRP has a long history of promoting the development of trainees through its Center grants, R01s, and other grant mechanisms and opportunities. SRP staff are actively reflecting on the future directions of its training efforts. The SRP will:

- Continue promoting trainees from diverse backgrounds and determining ways to ensure that they stay successful
- Continue promoting the use of the Individual Development Plan (IDP) to provide a structured approach to articulate career goals and track achievements
- Provide greater opportunities for R01 trainees to become more involved in SRP training opportunities and with the other SRP Center Training Cores, since this group of trainees does not belong to a structured Center Training Core.
- Promote mentoring relationships across Centers, especially when doing so can help bridge the differences in approaches between engineering and biomedical disciplines.

The SRP also aims to find more ways to promote training in research translation and in community engagement. Currently, the SRP highly recommends that these opportunities be encouraged through the Center's Training Cores, but a challenge with this endeavor is that trainees involved in translational research and community engagement say they find it challenging to negotiate the balance between their own interests, priorities, and goals and those of their mentors, a comment that has been made by others in the scientific community (23). In addition, the SRP will be further encouraging young scientists to receive training when conducting research with populations with unique backgrounds, such as Native American Tribal communities, and those from other countries and to recognize the complex contributors to population health and disease, including social, economic, geographic, and cultural forces (24). Similar to the transdisciplinary nature of the SRP centers, the goal of

such programs is to encourage trainees to learn the “languages” of other disciplines and gain field experiences beyond narrow, predefined curricula.

As the SRP training efforts evolve, the program will also aim to ensure that trainees are receiving robust experience in the skills needed to analyze and understand “big data.” Solving the environmental health problems of the 21st century will require scientists who have the expertise to analyze large amounts of data but who also understand the biology behind that data (25). In its 30 years of supporting research and training, the SRP has generated a wealth of data about biological response, epidemiology, exposure, sustainable remediation, and chemical fate and transport. Trainees can be a vital part of mining this diverse data, integrating these data across various platforms, and creating a new knowledge architecture, as technological advances make data integration more feasible. The use of computational tools to manage and analyze a vast amount of data will only increase, as technology has advanced and acceptance has grown for the “exposome” concept—that to truly understand health and disease, we must understand all the exposures that occur from conception to death, along with the associated biological responses (26). The exposome also requires trainees to learn advanced analytical techniques such as proteomics and metabolomics, including how to operate and maintain the specialized equipment and validation of assays. Such advanced technical knowledge will become increasingly important for trainees who want to work in industry at companies developing these technologies or those trainees who become research scientists at universities who will manage core laboratories. As policies regarding data sharing evolve, future generations of trainees will play a large role in making the data-sharing vision a reality and incorporating data sharing into the daily practice of science. Our training program will strive to prepare them for that.

Conclusions

Training the next generation of scientists has been an important part of the SRP since its founding in 1987. In 2012, training became even more integral to the program when the SRP began formally requiring that each P42 Center have a Training Core that is central to the Center’s training activities. Each Center designates a Training Core Leader who is charged with advocating for and guiding the professional development of graduate and postdoctoral trainees. Trainees receive cross-training in the various disciplines represented within the Center, which is by nature interdisciplinary. SRP staff work to provide trainees with multiple avenues for presenting their research, networking, and learning about career options. In addition, opportunities for SRP trainees have evolved to emphasize professional development and to include activities that develop a wide range of skills to ensure success in a variety of scientific endeavors, even those outside traditional academic bench science, such as research translation and community engagement. Many former SRP trainees have become principal investigators at academic institutions, while others are successful in the government, industry, and non-profit sectors.

Looking to the future, the SRP will continue to grow its successful training program by following trainees’ accomplishments and career paths by using such tools as the NIEHS CareerTrac database system, continuing and expanding its efforts to promote diversity in the

scientific workforce, and increasing opportunities for trainees interested in global health, bioinformatics, data integration, and “big data.” Once a larger body of quantitative data on trainees is available in CareerTrac, a future report will provide a more detailed analysis of trainee outcomes. SRP staff will continue to listen closely to the SRP trainees for their feedback regarding new areas of research and professional development and listen to their suggestions on areas of improvements. SRP Staff will also continue to have discussions with SRP principal investigators to continue evolving the program so that trainees will enter the work force with the skills they need to be successful, no matter the employment sector they choose.

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Figure 1. Where Former SRP Trainees Work after their SRP Trainee Experiences

Shown here are the employment sectors SRP Trainees entered after completion of their SRP training experiences. Positions are last known employment held by each trainee. Some trainees may have been in other sectors prior to most recent employment. (N=636)