PURM
Perspectives on Undergraduate Research & Mentoring

From Investment to Impact: How NSF REU Programs Shape STEM Pathways and the Scientific Workforce

Bridget Smith-Konter, Ph.D., University of Hawai'i at Mānoa,
Northern Arizona University (brkonter@hawaii.edu)
Sloan Coats, Ph.D., University of Hawai'i at Mānoa
Alyssa Kamanu, Ph.D., University of Hawai'i at Mānoa
Paul Wessel, Ph.D., University of Hawai'i at Mānoa

Introduction

Funded by the National Science Foundation (NSF) since 2017, the Earth Science on Volcanic Islands (ESVI) Research Experience for Undergraduates (REU) Site has played an integral role in shaping the academic and professional trajectories of 88 undergraduate students from across the United States. Hosted at the University of Hawai'i at Mānoa (UHM), the ESVI REU site emphasizes place-based summer research experiences that illuminate geoscience processes through the lens of Hawai'i's dynamic environments. While our specific objectives have grown with the breadth and depth of our program over the last ten years, our core mission has been to invest in cutting-edge research, field, and professional development experiences that strengthen students' science communication skills, prepare students for STEM careers, foster a supportive cohort community, and expand participation of students from institutions with limited access to undergraduate research opportunities in the geosciences.

In 2025, amid tightening federal budgets and shifting funding priorities, the future of the ESVI REU program became uncertain as our REU Site was up for renewal and its continuation was subjected to unprecedented scrutiny. Although we successfully navigated this period of uncertainty and ultimately secured NSF funding to sustain the program for an additional three years, many undergraduate research programs with similar goals and demonstrated successes have been discontinued nationwide over the past year. The loss of these programs is alarming, as transformative undergraduate research programs remain critical investments in the nation's scientific and educational infrastructure. Recent data from ESVI REU alumni reveal that a strong majority of participants have gone on to pursue STEM careers, with narratives consistently identifying their REU experiences as a pivotal catalyst in shaping their academic and professional success.

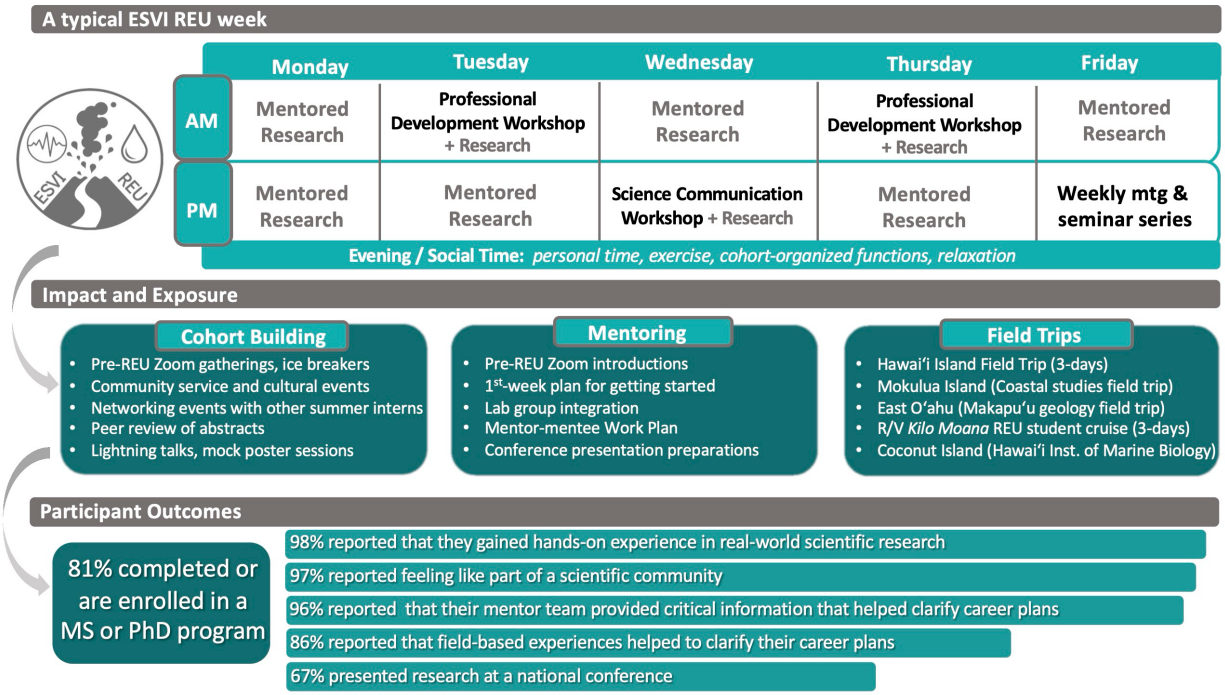
Alumni reflections on the factors that shaped their academic and career trajectories converge on three dominant themes: (1) a supportive and enduring student cohort, (2) meaningful relationships with mentors and research group members, and (3) exposure to extraordinary field experiences throughout the ESVI REU. Irrespective of prior training, geoscience subdiscipline, or research outcomes, alumni regularly report that these core REU elements - cohort strength, purposeful mentoring, and unique field experiences - had the greatest influence on their subsequent paths forward. Interestingly, these same elements are largely what set the REU experience apart from a traditional research activity at a student's home institution. Here, we examine these impacts using

exit and longitudinal survey data from our 88 participants from 2017-2025, complimented by alumni reflections collected in January 2026 pertaining to their current perceptions of the REU impact. Together, these data indicate that multiple dimensions of REU engagement – both human-centered and place-based – are the strongest drivers of persistence in the geoscience pipeline and beyond (Levine et al., 2007; Semken et al., 2017; Ward et al., 2018).

The ESVI REU Experience

The ESVI REU Site at UHM is administered by faculty and staff within the School of Ocean and Earth Science and Technology (SOEST), an internationally recognized leader across a broad range of geoscience disciplines. SOEST is home to over 200 undergraduate majors, ~250 graduate students, and over 400 scientists, specialists, and postdoctoral researchers. Each year, the ESVI REU offers a cohort of ~ten undergraduate students the opportunity to spend the summer at UHM-SOEST, engaging in place-based mentored research focused on Hawai'i's volcanic, hydrologic, atmospheric, and marine environments. Participants work closely with research group mentors on ESVI-themed research projects and take part in a structured series of professional development and science communication workshops designed to build foundational research skills, prepare conference-style presentations, and provide graduate school preparedness (Figure 1). Cohort building, inclusive mentoring, and integration of multiple field-learning activities also form the core of our program.

Figure 1. *The ESVI REU program at a glance*



Cohort Strength: Social Foundations of Scientific Growth

Each summer, ~ten undergraduate students from across the nation are selected, through a highly competitive application review and mentor deliberation process, to participate in the ESVI REU. These positions represent only ~2.5% of our annual applicant pool, and thus striking the just-right cohort balance is a critical step for our selection team. While there is no single formula for building an "ideal" cohort, major steps can be taken to mold a diverse group of students (spanning a range of academic backgrounds, institution types, and levels of preparations) into a cohesive, productive, and mutually supportive community (Sloan and Hacker, 2020).

Cohort building for the ESVI REU begins well before students arrive at UHM. Group video meetings are initiated in early spring, with a major emphasis on informal interaction using ice breakers and interactive games. These early engagements are intentionally designed to cultivate a welcoming, low-stakes environment in which students can begin forming relationships. Students also prepare brief (one-page) personal biographies that are shared with the cohort and they are encouraged to establish a group communication platform (e.g., Discord) to sustain momentum prior to the program's start. In several cases, students arrive at UHM already having formed strong social bonds.

Our first full program weekend is typically spent traveling together to Hawai'i Island, an experience that traditionally sets a high bar for positive team building and shared purpose. Throughout the summer, weekly cohort meetings facilitated by graduate student staff provide a safe and supportive space for students to discuss research anxieties and navigate challenges. Structured peer-review activities, including abstract feedback, lighting talks, and mock poster presentations, help reinforce cohort-wide familiarity with individual research projects and provide a constructive environment for intellectual growth, confidence building, and research maturation. Social activities, including community service, cultural events, and networking opportunities with other summer research programs on campus helped to foster a healthy work-life balance and reinforce a sense of community.

The Mentoring Scaffold: Guiding Research and Creating Opportunities

Research mentors serve as the circulatory system of a healthy REU, providing not only novel research ideas and the infrastructure necessary to conduct the research, but also pathways that help students find direction and navigate uncertainty. Beyond scientific inquiry, effective mentors play a critical role in setting the right tone to build student confidence, comfort, and a sense of belonging (Burt et al., 2023). Mentors also model collaboration, ethical professional behavior, and responsible scientific practice, helping students understand the responsibilities of scientists and the broader culture of science (Sloan and Hacker, 2020). Mentors can offer insight into life as a scientist, give supportive career guidance, and can even create opportunities for students as they move beyond the REU summer.

Mentoring relationships within the ESVI REU begin in early spring. Research mentors participate in mentor training and are expected to initiate a research dialogue with their students prior to the start of the summer program. Mentors are encouraged to meet with students online at least once before their arrival at UHM, a practice we have found to be critical in building rapport, clarifying expectations, and reducing research anxiety. Graduate students are often included in these early meetings to help establish a healthy group environment. During this period, mentors discuss available resources, share introductory literature or lecture materials, and outline the conceptual framework of the anticipated research project. Equally important, mentors are encouraged to communicate enthusiasm for their work and to ground research discussions in the "big picture" – why the work matters and what motivates them as scientists.

The First Week Matters

Initially, students may arrive feeling uncertain or questioning whether they belong in a research-intensive environment. A central responsibility of REU mentors is to proactively find ways to show students that they do belong. The ESVI REU first-week schedule is carefully designed to help establish this sense of belonging, where mentors play a key role in designating workspaces, introducing students to lab members, and developing a clear plan for initial research activities. We also prioritize frequent check-ins during this period to further reinforce support and establish productive mentoring norms.

Utilize Planning Tools
To support research progress and student development, the ESVI REU employs structured planning tools that are collaboratively developed by mentors and students. The ESVI REU "Work Plan" (Sloan and Haacker, 2020) is completed in the first week and encourages students and mentors to articulate project objectives, identify key tasks, establish timelines, and anticipate deliverables (e.g., abstracts and poster presentations). The work plan also includes planned reassessment stages, reinforcing the iterative nature of research and helping students to learn how to adapt goals as projects evolve.

Leveling Up
Identifying opportunities for students to present their summer research beyond the REU program provides students a bigger target to aim for and reinforces the idea that their research contributes to a broader scientific community. ESVI REU mentors are encouraged to identify and gently promote these opportunities early on, integrating abstract submission deadlines into project timelines as needed. This approach has yielded strong outcomes: 67% of ESVI REU participants have led first-authored abstracts at national conferences such as AGU, GSA, Ocean Sciences, and SACNAS. Additional opportunities, like the Council on Undergraduate Research REU Symposium, further support engagement within the professional scientific community.

Beyond the Lab: Learning Through Dynamic Environments

For many participants, the ESVI REU represents their first opportunity to visit Hawai'i; accordingly, our program places a strong emphasis on field-based learning opportunities (both land- and sea-based) that explore the islands of O'ahu and Hawai'i. Exposure to real-world research environments, through hands-on field experiences, has been a foundational component of the ESVI REU since its inception.

Each summer begins with a three-day geologic field trip to Hawai'i Island, with a focus on volcanism and scientific monitoring of Kīlauea volcano. Typically scheduled during the first full weekend of our program, this experience serves as both an introductory geoscience capstone and a major cohort-building activity. During this trip, students explore a variety of volcanic landscapes within Hawai'i Volcanoes National Park, interact with field experts and graduate student assistants, and when conditions permit, observe active volcanism firsthand. Preparation for the trip includes a pre-field information workshop, targeted background readings, and a custom field guide designed to support learning in the field.

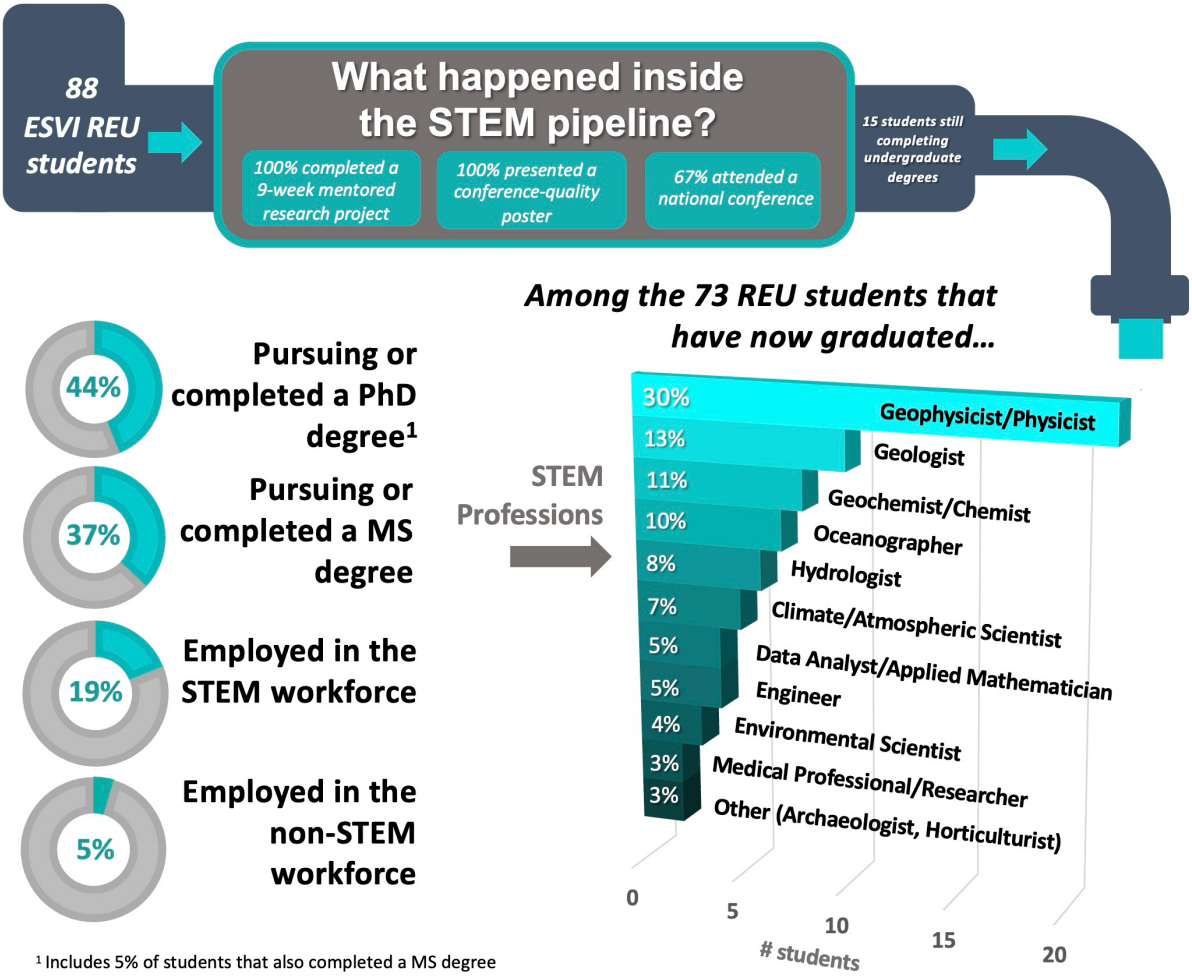
In addition, the ESVI REU aims to offer a three-day student research cruise each summer aboard UHM's research vessel R/V *Kilo Moana.* For most participants, this cruise opportunity serves as their first experience conducting research at sea, an opportunity many describe as transformative. These research cruises have targeted multiple areas around the Hawaiian Islands and have incorporated a range of sea-going research activities, including mapping the seafloor and subsurface structure using acoustic, gravity, and magnetic methods, sampling the seafloor through rock dredging, and measuring fundamental oceanographic properties. Additional seagoing activities, such as sampling microplastics and collecting sediments for microbiological research, have further broadened students' exposure to interdisciplinary marine science.

The REU Catalyst: From Undergraduate Research to STEM Careers

In January 2026, we reached out to ESVI REU alumni, asking them to help update our database with their current academic and professional status, and to reflect on how their REU experience influenced their thinking about future career and graduate school plans. These data, combined with previously collected longitudinal alumni survey results, reveal strong persistence in STEM pathways and substantial progression into graduate education amongst our former participants.

Across eight cohorts (2017–2025; n = 88), 83% of participants had completed their undergraduate degrees as of January 2026; 17% had not yet graduated but were on track for graduation over the next two years. Among those who had completed their undergraduate degrees, a large majority (95%) were either employed in the STEM workforce or currently enrolled in or had completed graduate programs at the master's or doctoral level (Figure 2): specifically, 37% were pursuing or had earned a master's degree and 44% were pursuing or had earned a PhD (5% of these had also earned their MS). We also discovered that alumni career trajectories closely mirror the distribution of ESVI REU mentored research project subdisciplines: approximately 33% of projects emphasized geophysics, with a comparable representation in geochemistry (18%), hydrology (14%), oceanography (13%), and climate/atmospheric science (10%).

Figure 2. *Where are they today? Of those participants that have graduated with their bachelor's degree (n = 73), 95% have continued their involvement in the STEM pipeline, either employed in the STEM workforce or as graduate students that are actively receiving graduate training*



Alumni feedback overwhelmingly characterized the ESVI REU as a pivotal, confidence-building experience that clarified and strengthened intentions to pursue graduate school and research careers in STEM fields. Alumni widely credited the program with developing foundational research competencies, such as project design under tight timelines, professional communication, networking, and scientific presentation skills, that directly contributed to later success in graduate

school and the STEM workforce. Alumni narratives also articulated the value of learned transferable technical and analytic skills (i.e., coding, instrumentation design) that strengthened self-efficacy. Additionally, several alumni respondents, including first-generation and nontraditional students, described the REU as pivotal in fostering confidence, validating their place in science, and motivating them to pursue opportunities they had not previously considered feasible. For many alumni, the value of place-based research, inclusive mentoring, and a supportive cohort culture ranked high in providing a sense of belonging and affirming their capability to succeed in research.

Figure 3. *Alumni narratives. Recent feedback provided by ESVI alumni, acquired in January 2026*

"My REU experience is THE most influential research experience during my undergraduate tenure. Although I was already conducting research at my undergraduate institution, my REU opened my eyes to the world of academia. I learned so much from so many different minds at UH Manoa, from geochemistry, to hydrology, to coastal geology, to remote sensing. This influx of geoscience knowledge from experts in their respective fields, along with the extremely patient, professional, and friendly demeanor of faculty and staff, gave me the confidence and excitement to pursue graduate studies."

"This research experience was invigorating and inspiring for me. I always knew I wanted to work in science and contribute to Hawaii, my home, but I had no real knowledge of a tangible way to accomplish that. My mentor provided me with invaluable experience, advice, and knowledge regarding ways I can come back home and work in science. I feel more inspired to excel in coursework at school and already added minors to my program to help me prepare (chemistry & environmental science). This program was life changing and I am forever grateful."

"Prior to participation in the ESVI REU, I had not planned to attend graduate school or consider it a realistic pathway. The research experience directly influenced my decision to pursue a master's degree. It introduced me to graduate students that were non-traditional students like myself."

Cohort Support

Alumni identified their cohort community as a central source of support, belonging, and professional growth. They also attributed strong peer relationships in helping to normalize the challenges of research, enhancing peer-to-peer learning across subdisciplines, and reducing feelings of isolation, particularly among students transitioning into geoscience or coming from institutions with limited research access:

- "I felt incredibly welcomed by my diverse cohort and the supportive graduate students … it made me very comfortable with moving into geoscience for graduate school and my long-term career."
- "Meeting graduate students and others with nontraditional paths helped me realize that my experience was valid and that graduate school was actually attainable."
- "There were a few very special people who helped me work through my insecurities and see a pathway forward."
- "Being surrounded by people navigating similar challenges made research feel manageable and helped me believe I belonged."
- "I gained lifelong friends and expanded my network."

Mentorship

Alumni credited strong mentor relationships with reducing anxiety about independent research, demystifying graduate school, and opening doors that directly informed graduate admissions decisions, funding opportunities, and even selection of graduate advisors. Multiple participants referred to interactions with mentors and graduate students as key steps that led them to feel that graduate school pathways were more attainable:

- "The extremely patient, professional, and friendly demeanor of my mentoring team gave me the confidence and excitement to pursue graduate studies."
- "It was the springboard for me to connect with many faculty members through my advisor at Hawai'i, which was undoubtedly beneficial when I applied for PhD programs."
- "Open conversations with my mentor about my future careers inspired me to pursue graduate school."
- "I had a great mentor-mentee relationship with my mentor; I have a better sense of what I'm looking for in a grad school advisor."
- "I had an exceptional mentor who encouraged me to ask questions, make mistakes, and work through problems collaboratively… I've gained a mentor for life."

Field-based Learning

ESVI REU alumni narratives also emphasized the importance of hands-on research, field and ship-based experiences, and exposure to a breadth of geoscience subdisciplines, in expanding their view of possible career pathways. For many participants, exposure to Hawaii's volcanic landscapes and participation in a research cruise represented a first-of-their-kind scientific experience that clarified interests, directly influenced graduate training and career decisions, and expanded awareness of geoscience pathways not available at their home institutions:

- "My REU was my first experience on a research vessel. This greatly influenced my career path."
- "Working in volcanology and witnessing those environments felt like a dream come true."
- "The hands-on research, field and ship-based work expanded my view of what career paths were possible."
- "The REU introduced me to marine geophysics - a field I would have never been exposed to at my home institution."
- "My experience aboard the Kilo Moana cemented that I really do want to work with ROVs."
- "This was my first experience conducting scientific research at sea… truly transformative."

REU Funding Uncertainties: What Is at Stake

Federally funded programs like the NSF-REU serve as a critical transitional training environment for undergraduate students, helping to solidify academic identity and clarify career pathways at a formative stage. These experiences play a particularly important role in advancing the scientific workforce by transforming graduate school opportunities from an abstract aspiration into a tangible, attainable pathway. Many ESVI REU participants reported that prior to participation, they were uncertain about pursuing graduate degrees or lacked confidence in their ability to succeed. Through structured research and inclusive mentoring offered by the REU, however, students gained clarity, self-efficacy, and a sense of belonging in scientific communities. Moreover, these types of programs demystify graduate school by providing early exposure to the application processes, advisor relationships, research expectations, and the daily realities of scientific work. Without sustained funding for programs like the NSF-REU, a large population of undergraduate students would lose equitable access to not only research and mentoring opportunities, but also to role models capable of guiding them toward graduate school or successful workforce placement.

Perhaps equally compelling is the return on investment associated with REU programs. The average cost of a geoscience REU participant is approximately $20,000, substantially lower than typical federal graduate training investments, which are often on the order of $50,000 - $70,000 or more per trainee-year when accounting for stipend, tuition/cost-of-education, and training-related expenses (e.g., NSF GRFP: $37,000 stipend + $16,000 cost-of-education allowance (NSFGRFP, 2026)). Using a conservative annual return-on-investment (ROI) metric [(Earnings − Cost) / Cost × 100], and assuming estimated net annual earnings of $40,000 per student during graduate training, this corresponds to an approximate 100% ROI per participant per year of graduate training, even before accounting for long-term career earnings or downstream grant revenue. Additional value should be considered with respect to extensive REU-generated scholarly output, like the 59 conference abstracts and other pilot data generated by ESVI REU students that resulted in co-authored publications and subsequent federal funding. Workforce outcomes provide further evidence of return: 81% of ESVI REU alumni are currently enrolled in or have completed graduate programs. These impressive returns demonstrate how relatively small, early-stage investments in REU programs can efficiently catalyze scientific productivity and workforce readiness at a fraction of the cost of later-stage federal training mechanisms.

Considerations for the Future

Since its inception in 2017, the ESVI REU has demonstrated clear and measurable impacts on undergraduate student outcomes, STEM persistence, and the development of a skilled scientific workforce. To date, 95% of ESVI REU alumni remain in the STEM pipeline, and 81% have gone on to pursue graduate degrees. Alumni feedback collected in 2026, arguably one of the most compelling indicators of program advocacy, consistently characterize their REU experience as transformative and enduring, and one that shaped both professional trajectories and personal growth. Alumni reflections also portray the NSF-REU program as not only a high-impact research training program, but also a community-centered experience that provides lasting professional networks, mentorship, and personal affirmation that continue to influence participants' careers and lives years after program completion.

More broadly, undergraduate research programs like the NSF-REU function not only as essential pillars of educational research training, but also as foundational infrastructure for the future of the U.S. scientific workforce. Looking ahead, sustaining programs like the NSF-REU will require deliberate strategies to address federal funding challenges. Continued efforts to recruit and engage talented undergraduate researchers nationwide are essential; equally important are efforts to amplify awareness of participant achievements, program accountability, and investment return. These data provide strong evidence that programs like the ESVI REU do more than just train future

scientists - they also help develop a skilled, confident, and motivated workforce that strongly recognizes the value of undergraduate research and is likely to serve as the next generation of effective mentors. They also demonstrate how targeted undergraduate research training programs systematically translate federal investment into measurable educational, professional, and workforce outcomes. Sustained federal support for NSF-REU initiatives ensures not only a responsible (and responsive) investment in undergraduate professional development but also a strategic commitment to scientific excellence, equity, and long-term national resilience.

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The authors report there are no competing interests to declare.

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Informed Consent
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