Intro to HPC Bootcamp: Engaging new communities through energy justice projects

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ABSTRACT

The U.S. Department of Energy (DOE) is a long-standing leader in research and development of high-performance computing (HPC) in the pursuit of science. However, we face daunting challenges in fostering a robust and diverse HPC workforce. Basic HPC is not typically taught at early stages of students' academic careers, and the capacity and knowledge of HPC at many institutions are limited. Even so, such topics are prerequisites for advanced training opportunities, internships, graduate school, and ultimately for careers in HPC. To help address this challenge, as part of the DOE Exascale Computing Project's Broadening Participation Initiative, we recently launched the *"Introduction to HPC" Training and Workforce Pipeline Program* to provide accessible introductory material on HPC, scalable AI, and analytics.

We describe the *Intro to HPC Bootcamp*, an immersive program designed to provide students from underrepresented groups in computing with foundational skills in HPC, scalable AI, and analytics through hands-on experience working on compelling projects using state-of-the-art computational and data science tools and techniques. The first bootcamp, hosted by the advanced computing facilities at Argonne, Lawrence Berkeley, and Oak Ridge National Labs and organized by Sustainable Horizons Institute, took place in August 2023. The program took a novel approach to HPC training by turning the traditional curriculum upside down. Instead of focusing just on technology and its applications, the bootcamp engaged students in energy justice projects while they learned how to use HPC to answer compelling social impact questions. Through this bootcamp, inspired by the implementation guidance of the Justice40 Initiative of the DOE Office of Economic Impact and Diversity, students explored issues related to the social impact of climate risk and resilience, solar power, sustainable cities, and energy usage. Work is under way to refine and expand the curriculum for flexible use in future bootcamps, in campus settings, and for self-study.

KEYWORDS

high-performance computing, training, bootcamp, energy justice

1 DOE HPC WORKFORCE CHALLENGES

Department of Energy (DOE) national laboratories are renown leaders in research and development in scientific and high-performance computing (HPC). However, we face daunting HPC workforce challenges, similar to those faced in science and engineering generally [22]. As stated by the DOE Advanced Scientific Computing Advisory Committee (ASCAC) Workforce Subcommittee [4],

> "All large DOE national laboratories face workforce recruitment and retention challenges in the fields within Computing Sciences that are relevant to their mission. ... Future projections indicate an increasing workforce gap and a continued underrepresentation of minorities and females in the workforce unless there is an intervention."

Addressing these workforce challenges requires broad community collaboration to change computational science's culture and demographic profile. Impactful DOE-wide programs, lab-specific regional initiatives, and activities in the wider computing community are making headway. Work is underway within the Broadening Participation Initiative [2, 9, 24] of the DOE Exascale Computing Project (ECP) [7] to expand the pipeline and workforce for DOE high-performance computing through three complementary thrusts: (1) Establishing an *HPC Workforce Development and Retention (HPC-WDR) Action Group*, which helps to foster a supportive and inclusive culture in DOE labs and communities; (2) expanding the *Sustainable Research Pathways* internship and mentoring program as a multi-lab cohort of students from underrepresented groups (and faculty working with them), who collaborate with DOE lab staff on world-class HPC projects; and (3) building an *"Introduction to HPC" Training and Workforce Pipeline Program* to provide accessible introductory material on HPC, scalable AI, and analytics.

2 HPC TRAINING CHALLENGES

The basics of HPC are not typically taught at the early stages of students' careers, and the capacity and knowledge of HPC at many institutions are limited [12, 25]. Even so, such topics are prerequisites for advanced opportunities such as internships, the Argonne Training Program for Extreme-Scale Computing [1] and the DOE Computational Science Graduate Fellowship Program [6], and ultimately for careers in HPC. The national lab computing complex has expertise, capabilities, and a long history of cross-lab coordination on joint efforts.

[**To do**: Write more justification for program content.] After conducting listening sessions with administrators and faculty at minority-serving institutions to understand the challenges and needs of target schools and students, we have developed a curriculum for a one-week "Intro to HPC" bootcamp and taught this material in a pilot. The "Intro to HPC" training and pipeline program targets undergraduates, students in gap years, and early graduate students who do not have HPC exposure. We also are establishing partnerships with faculty members to refine aspects of the "Intro to HPC" curriculum for use in academic institutions and for self-study. By intersecting the needs of the workforce with the needs of DOE HPC, a goal is to build self-sustaining and integrated programs to expand the pipeline of professionals joining the HPC workforce.

3 BOOTCAMP GOALS & APPROACH

The first "Intro to HPC" bootcamp [15], hosted by the advanced computing facilities at Argonne, Lawrence Berkeley, and Oak Ridge National Labs and organized by Sustainable Horizons Institute, was held August 7–11, 2023 at Lawrence Berkeley Lab. Sixty students [16] worked in groups with fourteen trainers [18] and ten peer mentors [17] on seven energy justice projects [19] that explored issues related to the social impact of climate risk and resilience, solar power, sustainable cities, and energy usage. The bootcamp goals focused on engaging new communities in HPC in order to:

- Raise general awareness of the value, benefits, and rewards of work in HPC, especially at DOE labs;
- Engage more people from historically underrepresented groups, including those with no (or limited) HPC exposure;

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- Include a broader set of disciplines in the HPC community; and
- Increase the available talent to do work in HPC and computing sciences, where we have urgent needs for skilled researchers, research software engineers, systems administrators, and more.

Thus, the bootcamp can be considered as an accessible on-ramp to HPC training, internships, and ultimately careers in the computing sciences at DOE national labs.

Engaging new communities in HPC

The Intro to HPC Bootcamp is designed to provide students from underrepresented groups with foundational skills in HPC, scalable AI, and analytics through hands-on experience working on compelling group projects using state-of-the-art computational and data science tools and techniques. The immersive bootcamp program turns the traditional curriculum upside down. Instead of teaching technology and its applications, the bootcamp engages students in energy justice projects that teach how to use HPC to answer compelling social impact questions. The framework emphasizes social good using project-based pedagogy and real-life science stories to prepare students for internships and future careers at DOE labs.

As shown in Figure 1, the program begins with motivation via challenging problems in science and society, followed by introducing foundations of computation and HPC, while exposing students to the excitement of HPC research and development at DOE labs. This approach is inspired by the programs Advanced Computing for Social Change [11] and Computing4Change [5].

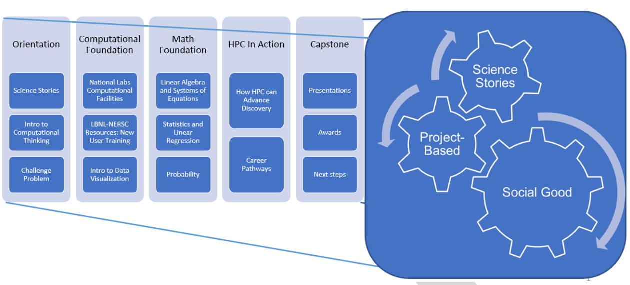

Figure 1: Framework for engaging new communities in HPC: solving problems with positive social impact.

Driving advances in energy justice with HPC

The project-based learning in the Intro to HPC bootcamp is inspired by the Justice40 Initiative [21], whose implementation at DOE is led by the DOE Office of Economic Impact and Diversity [8]. By applying the tenants of justice (procedural, distributional, recognition and restorative justice), energy justice [20] can promote policies that center community needs like reducing energy burden, avoiding disproportionate environmental impacts, ensuring equitable distribution of benefits of energy generation, creating opportunity for reliable access to clean energy, and encouraging democratic participation and enterprise creation in the energy system. DOE's Justice40 framework outlines eight such policy priorities that can better address the energy systems needs of overburdened communities. Energy Justice recognizes that the benefits of energy technologies have not been equally distributed across all Americans, often leaving out Black, Brown, Indigenous, and low-income communities. Underlying structural inequalities have resulted in development projects with higher rates of pollution, negative health impacts, and a higher energy burden in these communities. Energy justice is a complex issue with economic, racial, geographic, and social implications covering issues from energy affordability and access to infrastructure development. As we embark on an energy transition demanded by climate change concerns and fairness, we need to incorporate energy justice in the earliest stages of R&D and workforce development to enable a more just technology development and deployment.

Building HPC skills via project-based learning

Project-based learning in computational science [26] engages students through an active educational approach focused on real-world problems. It involves collaborative project work where students apply computational tools to address complex challenges, fostering a deeper understanding of both subject matter and practical applications. This method introduces authentic issues mirroring research, industry, and societal contexts, motivating students by demonstrating the tangible impact of their skills. Project-based learning encourages active participation, empowering students to drive their own investigations, make decisions, and take ownership of projects, fostering a sense of agency and responsibility. It emphasizes critical thinking and problem-solving as students analyze, design, and implement solutions to intricate challenges. Collaborative teamwork is highlighted, mirroring the collaborative nature of scientific research and computational work. Students gain proficiency in using computational tools through hands-on projects, with the iterative process fostering skills in inquiry, reflection, and resilience. Instructors and mentors offer personalized guidance, enhancing the learning experience, while presentations and communication of project outcomes refine students' ability to convey technical concepts. Overall, project-based learning in computational science equips students with practical skills, nurturing curiosity, critical thinking, and readiness to contribute to scientific and technological advancements.

4 BOOTCAMP DESCRIPTION & INNOVATIONS

As described in Section 3, the "Intro to HPC" bootcamp's novel approach engages students in energy justice projects, where they learn HPC fundamentals and gain exposure to exciting career opportunities in computing sciences at DOE national labs.

Building a diverse bootcamp team

Collaboration on the Intro to HPC Bootcamp is a partnership among experts in advanced computing, computational science, energy justice, workforce development, education, training, social science, and program evaluation. With collaborators from multiple DOE national laboratories, Sustainable Horizons Institute, the DOE Office of Economic Impact and Diversity, and academic partners, the team's breadth of experience has been essential for devising this first-of-a-kind program to introduce HPC at DOE labs in the context of mission-centered energy justice projects, with emphasis on engaging early-career students from underrepresented groups.

Workshop to "train the trainers"

A pivotal step in developing the bootcamp program was hosting a "Train the Trainer" workshop in spring 2023, which served as a platform for promoting effective team collaboration. Through two days of in-person interactions, the workshop fostered strong interrelationships among the bootcamp leadership team. The workshop introduced the bootcamp concept to project leaders and trainers, while highlighting shared values related to inclusivity and energy justice. Workshop participants discussed the foundational principles of energy justice and inclusivity, enriched by a panel comprising organizers and mentors with extensive experience in social justice-focused computational science workshops. A key focus of the workshop was "training the trainers" in the art of modifying existing HPC training materials to suit the unique requirements of the bootcamp pedagogy, while also imparting effective coaching techniques to ensure students' successful engagement with the bootcamp's social challenge projects. The forum provided an opportunity for the team to deliberate on anticipated outcomes of the bootcamp, delineating the essential takeaways for students, along with post-bootcamp opportunities for their continued growth. Notably, the workshop stimulated the generation of innovative HPC project ideas aligned with the theme of energy justice, laying the foundation for a series of compelling energy justice projects to be explored in the bootcamp.

Welcoming diverse bootcamp participants to HPC

Demographics. As shown by Figure 2, nearly half of the sixty bootcamp participants were first-generation scholars (the first in their family to attend college), and XXX. [**To do**: Explain demographics.]

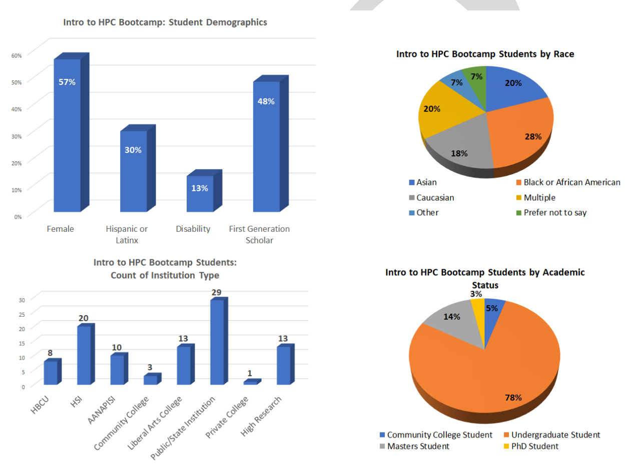

Figure 2: Demographics of bootcamp participants.

Student recruitment. We achieved this demographic profile by broadly recruiting students from underrepresented groups to apply to the bootcamp, emphasizing the unique opportunity to advance understanding of *both* energy justice and HPC, while learning about career opportunities at DOE national labs. This approach appears to have strongly resonated with the target community, as we received applications from several hundred students at US-based institutions, even though we could accommodate only sixty learners in this pilot session.

HPC skills. Requirements for the bootcamp were some exposure to computing *and* an interest in energy justice topics. Because the bootcamp focused on introducing HPC, we did not expect applicants to have significant prior HPC exposure. We were able to engage a few applicants whose HPC skills exceeded the program scope as *peer mentors* in the bootcamp.

Student travel and stipend. The bootcamp fully supported travel, lodging, and meals for participants in the 5-day program. Participants received a modest stipend of $500 after completion of the bootcamp. We consider a stipend to be essential—making it possible for students who truly need the earnings from their usual jobs to sacrifice a week's employment in order to attend the bootcamp; without the stipend, some students could not participate.

Critical roles of peer mentors

Inspired by the approach used in the Advanced Computing for Social Change workshops, we engaged peer mentors [17] to provide support to students during the bootcamp. Peer mentors addressed technical questions, while also providing guidance on collaboration, presentations, and workshop expectations. Their contributions to the bootcamp were considerable, from providing a manual for mentors to use as a guide, to being a conduit of information between the students and the organizers. For example, peer mentors conveyed questions that students felt more comfortable asking them (rather than the trainers), fostering a supportive and responsive environment. The peer mentors facilitated discussions and tutorial sessions, while working closely with trainers and project groups. Most peer mentors were invited to apply, having had previous mentoring experiences; others were invited from the student applicants.

Energy justice projects: HPC for DOE social good

Throughout the bootcamp, students worked in twelve small groups on projects, led by trainers and peer mentors. Bootcamp projects [19] were designed with the intention of teaching HPC and AI tools in the context of wide-reaching energy justice problems. The following are key themes in social good and HPC technologies for the seven bootcamp projects.

- **AI-powered equity analysis of renewable energy**
  - *Social*: Equitable energy law, accessible energy justice info
  - *Tech*: Machine learning, large language models, web scraping
- **Energy justice analysis of climate data**
  - *Social*: Geographic climate disparities, variable correlations
  - *Tech*: Data visualization, big data wrangling
- **Solar power for affordable housing through computational design of low-cost/high-efficiency solar cells**
  - *Social*: Sustainable solar cells, renewable energy optimization
  - *Tech*: Machine learning, big data analysis
- **Energy cost for disadvantaged populations and methods of energy efficiency and optimization in computing systems**
  - *Social*: Power sustainability in HPC, equitable energy affordability and distribution

- *Tech*: Top500 and Green500 energy efficiency ratings, HPC resource utilization
- **Understanding the impact of HPC center energy usage on low-income and minority populations**
  - *Social*: Power sustainability in HPC, equitable energy affordability and distribution
  - *Tech*: Code optimization, Top500 energy efficiency ratings, strategies for HPC resource utilization and allocation
- **Power outages and inequities in energy access for medically vulnerable populations**
  - *Social*: Weather impact on energy access, energy access for medically vulnerable populations
  - *Tech*: Data visualization, statistical analysis of large data sets
- **Socioeconomics of power outages and heatwaves**
  - *Social*: Power outage data, weather impact on energy access, discrepancies in weather event impact across populations
  - *Tech*: Data visualization, statistical analysis of large data sets

To address the energy justice questions posited by the projects, bootcamp participants employed publicly available data sets, including climate data for national lab projects such as ClimRR [3] and EAGLE-I [27], Top500 and Green500 power consumption statistics [13, 29], a dye-sensitized solar-cell device database [10], the HHS emPOWER Program [14], and U.S. census data [30].

Advanced computing for bootcamp projects

So that students could use HPC to pursue advances in energy justice projects, participants received access to the NERSC supercomputer Perlmutter [23], ranked 8th on the June 2023 Top500 List [28]. In contrast to training accounts usually provided for user training events, NERSC created a regular allocation project using the Director's Reserve Pool, so that students could continue Perlmutter access through the end of the current allocation year (until mid-January 2024). Students received detailed instructions about applying for a Perlmutter account and setting up multi-factor authentication. Multiple office hours were held prior to the bootcamp to help resolve any account and login issues, so that students were ready to work on projects immediately during the bootcamp.

Students largely employed Jupyter Notebooks for bootcamp projects. NERSC staff prepared a bootcamp-specific kernel for use with the Notebooks, thereby streamling access to necessary Python and other data analytics and plotting packages. GPU compute node reservations were made in advance; usage in a shared mode by multiple students was integrated smoothly upon launching the Notebooks.

A single GitHub repository provided easy access to all bootcamp project materials and presentations. The data sets and Jupyter Notebooks for bootcamp projects also were made available on the Perlmutter file system in each project's workspace.

Supporting learning through group activities

As shown by the overall bootcamp framework in Figure 1, tutorials introduced computational concepts that students could apply to energy justice projects. Sessions included introductions to computational thinking, scientific computing, data visualization, and regression analysis, as well as a how-to on using Perlmutter.

Staff and leaders of DOE national labs spoke to the students about their career paths and motivations. During a DOE staff panel session, students learned about research applications of HPC and engaged in questions/answers about HPC careers.

Networking and relationship-building opportunities were built in formally and informally throughout the bootcamp, giving participants opportunities to connect with others sharing common interests in both computing and energy justice. Students connected with peer mentors a little further along in their academic journeys, DOE lab staff who have careers in HPC, and other students. During lunch each day, students and invited speakers discussed topics ranging from energy justice to whether to complete a Ph.D. to work-life balance.

On the final bootcamp day, each of the twelve project groups presented an overview of the team, project goals, approach, insights gained during the bootcamp, and ideas for future work. Through an online form, each bootcamp participant provided feedback to another group on its presentation. Lively questions and discussion followed each presentation.

5 EVALUATION AND LESSONS LEARNED

The participants were surveyed both before and after the bootcamp by am external evaluator.

[**To do**: Explain evaluation approach and insights.] [≈ **1.0 pages**] [Mary Ann, Lizanne, others TBD]

Successes. Preliminary feedback from participants indicates that by focusing on project-based HPC for energy justice topics, the bootcamp captured the interest of a wide range of students from underrepresented groups, exposing them to the power of applying HPC to challenges in science and society. In addition, the bootcamp introduced students to the impactful HPC research under way at DOE labs, providing pathways for future internships, education, and more.

Lessons learned.

6 NEXT STEPS

[≈ **0.5 pages**] [Charles L]

We are pioneering this innovative "Intro to HPC" approach to create easy on-ramps to DOE labs through HPC training, internships, and ultimately careers, with a long-term goal of diversifying and strengthening our workforce. Looking ahead, the team is working to refine this model and expand its reach through other modalities such as academic curricula and online learning, especially targeting students from underrepresented communities. By exploring novel approaches and incorporating flexibility, we aim to provide more accessible on-ramps to DOE labs and equip individuals with essential skills for impactful careers. At a high-level these measures could include, but are not limited to:

- **Asynchronous learning component:** To accommodate various schedules and learning styles
- **Frequent offerings:** Responding to increasing demand, we are working toward offering the bootcamp more frequently, ideally two to three times a year.
- **Broadening DOE lab involvement:** By inviting greater participation from DOE researchers and staff, we seek to enhance

the depth and breadth of expertise available to bootcamp participants.

Acknowledging the diverse commitments and schedules of potential participants, we are considering the incorporation of an asynchronous learning component into the bootcamp. This would enable learners to access foundational materials and introductory content at their own pace, ensuring that individuals can engage with the curriculum without being constrained by a specific time frame. Asynchronous learning would not only cater to different learning styles but also facilitate participation from individuals who may have limited availability due to academic, professional, or personal commitments. This flexible approach aligns with our goal of making HPC education more accessible and accommodating to a broader range of participants. The synchronous components of the bootcamp would enable participants to fully focus on their HPC projects during the group sessions.

To meet the demand for furthering HPC education and engagement, we are working towards offering the bootcamp more frequently, with the aim of having two-three HPC Bootcamps per year and providing avenues for more local lab involvement in offering the bootcamps at a regional level. This increased cadence would not only allow us to reach a larger number of participants but also contribute to building a sustainable pipeline of talent for DOE national labs, increasing DOE Research and Staff involvement to broaden the HPC fields reach. By providing multiple opportunities throughout the year, we can better accommodate the schedules of potential participants and ensure a steady influx of skilled individuals into the HPC workforce. This step aligns with our commitment to fostering a vibrant and diverse community that drives scientific progress and innovation.

As we look ahead, these strategic directions will guide us in furthering the impact and accessibility of the HPC bootcamp. By embracing innovative approaches, emphasizing flexibility, and increasing our offerings, we aspire to cultivate a workforce that reflects the diversity of our society and leverages the power of high-performance computing to address critical challenges in energy justice and beyond.

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A REPRODUCIBILITY APPENDIX

Abstract: The paper has no computational results.

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