National Nanotechnology Coordinated Infrastructure

NNCI Coordinating Office Annual Report (Year 5)

April 1, 2020 – March 31, 2021

NSF Award 1626153

Submitted: February 19, 2021

NNCI Coordinating Office Annual Report 2021

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1. NNCI Overview

1.1. Introduction

The National Nanotechnology Coordinated Infrastructure (NNCI) is an NSF-funded network of academic nanofabrication and characterization sites and their partners, formed to advance research in nanoscale science, engineering and technology. The NNCI site awards were the culmination of a competition conducted by NSF, under Program Solicitation NSF 15-519, which was generated as a result of input from the science and engineering community following the completion of the National Nanotechnology Infrastructure Network (NNIN, 2004-2015). Over 50 proposals from potential NNCI sites were submitted, resulting in 16 awards. The NNCI network is funded by the NSF through cooperative agreements with the individual sites, with the initial site awards being made around September 15, 2015 with an initial award period of 5 years. The Coordinating Office for the network was awarded to the Georgia Institute of Technology on April 1, 2016. The total NSF funding for the initial 5 years of the NNCI network is $81 million.

The NNCI sites are located in 17 states and involve 29 universities and other partner organizations (see Figure 1) that provide researchers from academia, small and large companies, and government with access to university user facilities with leading-edge fabrication and characterization tools, instrumentation, and expertise within all disciplines of nanoscale science, engineering and technology.

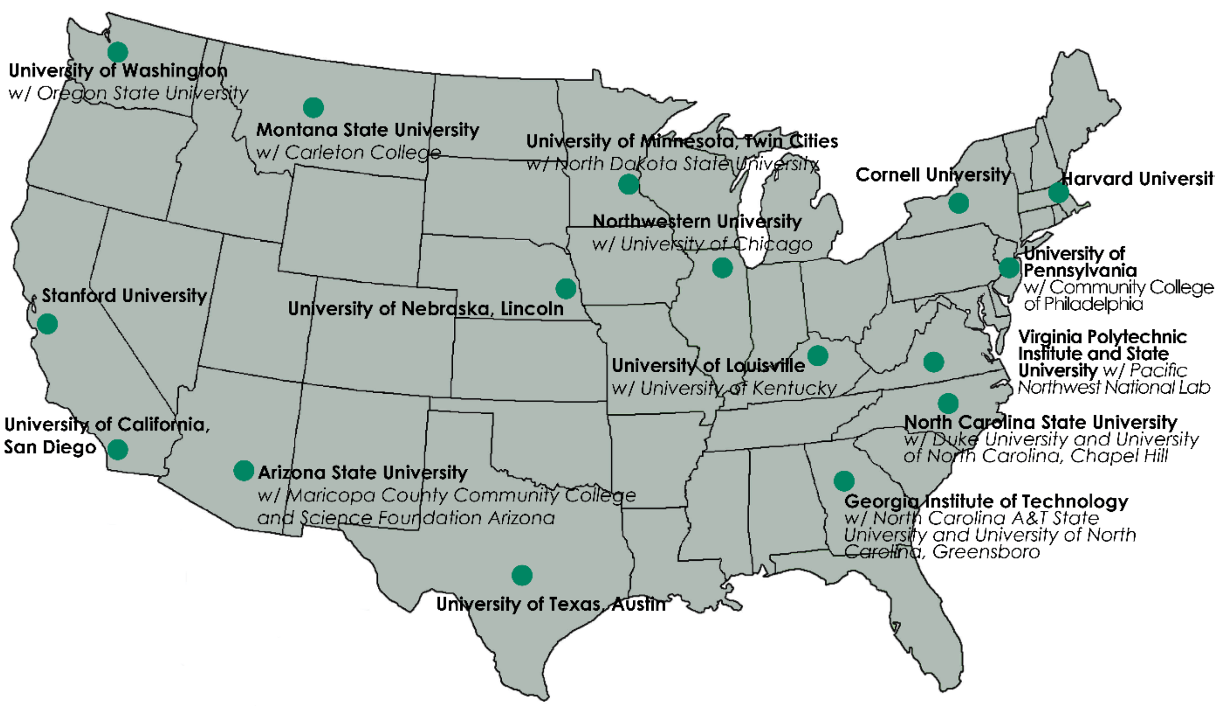


Figure 1: US Map with Locations of the 16 NNCI Sites (Year 5)

The goal of the NNCI network is (1) to provide open access to **state-of-the-art nano-fabrication & characterization facilities**, their tools and staff expertise across US, and (2) to use these resources to support **education & outreach (E&O)** as well as **societal & ethical implications (SEI) programs** in/of nanotechnology.

The 16 NNCI sites and their 13 partners (university, college, national lab, and non-profit foundation) provide access to more than 2,200 tools located in 69 distinct facilities. As will be detailed later in this report, these tools have been accessed during Year 5 by more than 10,000 users including more than 2,800 external users, representing more than 200 US academic institutions, nearly 800 small and large companies, ~30 government and non-profit institutions, as well as ~60 foreign entities. Overall, these users have amassed more than 750,000 tool hours. During the fifth year, the network has trained more than 2,800 new users.

This report summarizes the activities and progress for Year 5 of the Georgia Tech Coordinating Office of the NNCI, from April 1, 2020 - March 31, 2021. NNCI sites are funded via separate cooperative agreements between NSF and each site, with reporting of site-specific data and activities corresponding to Year 5 (October 1, 2019 – September 30, 2020).

It should be noted that NNCI Year 5 entailed two unique events. First, all sites submitted proposals for renewal of their NNCI programs (March 2020) and these were awarded later in the year. This report primarily reflects the sites, partners, facilities, and network as they existed during the Year 1-5 program period, although new initiatives of Years 6-10 are discussed later in the report (Section 9.2). Second, beginning in early 2020, NNCI (and the entire world) was affected by the COVID-19 pandemic. This required the cancellation of numerous programs throughout the network and the closing of most NNCI facilities from mid-March to mid-June. These closures obviously affected the usage of NNCI resources during this time period, and this is reflected in the statistics reported in Section 10. However, NNCI rapidly adapted to the new reality, providing a wide variety of online programs to support users and provide education and outreach opportunities, many of which will endure past the pandemic, and these are also described in this report (Section 9.4).

1.2. NNCI Organization

All of the NNCI facilities, most of which have partners and multiple locations, are available for use by students and professionals from around the country and globally. The sites and facilities within NNCI during Year 5 (Table 1) support research and development for academic education and research purposes, as well as product and process development for commercial purposes. Each site operates under its own procedures for user recruitment, user access, training, rates, billing, and other logistical details. However, each has agreed to provide open access, with as minimal a burden as possible, to their state-of-the-art nanofabrication and characterization facilities, their tools, and staff expertise. All sites use the resources provided by NSF to support a variety of education and outreach activities (Section 4.1), and many also offer programs or research in societal and ethical implications (SEI) of nanotechnology (Section 4.2) and simulation and modeling (Section 4.3).

Table 1: NNCI Sites, Locations and Facilities (Year 5)

NNCI Sites and Locations	NNCI Facilities
Cornell Nanoscale Science and Technology Facility (CNF) Cornell University	Cornell Nanoscale Science and Technology Facility

Center for Nanoscale Systems (CNS) Harvard University	Center for Nanoscale Systems
Kentucky Multi-Scale Manufacturing and Nano Integration Node (KY MMNIN) University of Louisville University of Kentucky	Micro/Nano Technology Center Center for Nanoscale Science and Engineering Huson Nanotechnology Core Facility Electron Microscopy Center Conn Center for Renewable Energy Research Center for Applied Energy Research Center for Advanced Materials Rapid Prototyping Center
Mid-Atlantic Nanotechnology Hub (MANTH) University of Pennsylvania Community College of Philadelphia	Singh Center for Nanotechnology Quattrone Nanofabrication Facility Singh Center for Nanotechnology Nanoscale Characterization Facility Singh Center for Nanotechnology Scanning Probe Facility
Midwest Nanotechnology Infrastructure Corridor (MINIC) University of Minnesota North Dakota State University	Minnesota Nano Center NDSU Packaging Center
Montana Nanotechnology Facility (MONT) Montana State University Carleton College	Montana Microfabrication Facility Imaging and Chemical Analysis Laboratory Center for Biofilm Engineering Proteomics, Metabolomics and Mass Spectroscopy Facility Center for Bioinspired Nanomaterials
Virginia Tech National Center for Earth and Environmental Nanotechnology Infrastructure (NanoEarth) Virginia Tech Pacific Northwest National Laboratory	Virginia Tech Center for Sustainable Nanotechnology Virginia Tech Nanoscale Characterization and Fabrication Laboratory PNNL Environmental Molecular Sciences Laboratory
Nanotechnology Collaborative Infrastructure Southwest (NCI-SW) Arizona State University Maricopa County Community College District Science Foundation Arizona	ASU NanoFab LeRoy Eyring Center for Solid State Science Solar Power Lab Peptide Array Core Facility Nano in Society User Facility Center for the Life Cycle of Nanomaterials
Nebraska Nanoscale Facility (NNF) University of Nebraska-Lincoln	Nebraska Center for Materials and Nanoscience Nano-Engineering Research Core Facility
Northwest Nanotechnology Infrastructure (NNI) University of Washington Oregon State University	Washington Nanofabrication Facility Molecular Analysis Facility Advanced Technology and Manufacturing Institute Materials Synthesis & Characterization Facility Ambient Pressure Surface Characterization Lab Oregon Process Innovation Center

Research Triangle Nanotechnology Network (RTNN) North Carolina State University Duke University University of North Carolina at Chapel Hill	Analytical Instrumentation Facility NCSU Nanofabrication Facility Shared Materials Instrumentation Facility Chapel Hill Analytical and Nanofabrication Laboratory Zeis Textiles Extension for Economic Development Nuclear Reactor Program Public Communication of Science & Technology Project Center for the Environmental Implications of Nanotechnology Duke Magnetic Resonance Spectroscopy Center Chemical Analysis and Spectroscopy Laboratory
San Diego Nanotechnology Infrastructure (SDNI) University of California - San Diego	Nano3 Cleanroom Microfluidic Medical Device Facility Chip-Scaled Photonics Testing Facility NanoMagnetic Material Processing Facility
Southeastern Nanotechnology Infrastructure Corridor (SENIC) Georgia Institute of Technology Joint School of Nanoscience and Nanoengineering	Institute for Electronics and Nanotechnology-Micro/Nano Fabrication Facility Materials Characterization Facility JSNN Cleanroom and Labs
Soft and Hybrid Nanotechnology Experimental (SHyNE)Resource Northwestern University University of Chicago	Northwestern University Atomic and Nanoscale Characterization Experimental Center Integrated Molecular Structure Education and Research Center Northwestern University Center for Atom Probe Tomography J.B. Cohen X-ray Diffraction Facility Northwestern University Micro/Nano Fabrication Facility Simpson Querrey Institute Pritzker Nanofabrication Facility
NNCI Site @ Stanford (nano@stanford) Stanford University	Stanford Nano Shared Facilities Stanford Nanofabrication Facility Stanford Microchemical Analysis Facility Stanford ICPMS/TIMS Facility
Texas Nanofabrication Facility (TNF) University of Texas -Austin	Microelectronics Research Center Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies The Center for Nano and Molecular Sciences Texas Material Institute

Through a 2020 update of the NNCI Staff Directory (following the renewal proposals), sites have identified approximately 250 staff that support the NNCI program (Table 2), although some individuals fulfill multiple roles within a site's operations. In general, Site Leadership includes Site Directors and Deputy/Associate/Assistant Directors. Some of these individuals also serve as project co-PIs. New User Contacts are those site staff responsible for coordinating access to facilities for external users. Program Managers are identified as those staff who most interact with the Coordinating Office, providing data as requested and communicating information to appropriate site staff. Facility Managers are responsible for the operations of site facilities, often assisted by Technical Staff when identified. Education/Outreach Coordinators handle the K-12 activities and sometimes the university student and professional education as well. SEI and Computation Coordinators are responsible for those aspects of site operations.

Table 2: NNCI Site Staff (2020)

NNCI Site Staff	
Site Directors	16
Other Site Leadership	44
New User Contacts	31
Program Managers	19
Facility Managers	70
Education/Outreach Coordinators	35
SEI Coordinators	7
Computation Coordinators	4
Safety/Facility Director/Technical Staff	22
Facility Administrative Staff	11

An analysis by the Diversity Subcommittee (see Section 5.1) examined the demographics of NNCI site PIs and co-PIs as reported to NSF. During Year 5 of the initial NNCI awards, 9 of the 61 individuals (15%) listed as PI or co-PI on the sixteen awards were women, which is comparable to the percentage of women tenure-track faculty in departments of electrical and computer engineering in the United States (13%) and engineering departments in general (17%), but significantly under the percentage PhD degree holders who are women in the US (53%). With the renewal process in 2020, 20 of the 66 individuals (30%) listed as PI or co-PI are now women, indicative of a concerted response to their under-representation within NNCI leadership. In addition, several of these new NNCI leaders are African American or Latinx, demonstrating broadening participation by race and ethnicity.

2. NNCI Coordinating Office

The NNCI Coordinating Office is led by Prof. Oliver Brand (Executive Director, Georgia Tech Institute for Electronics and Nanotechnology (IEN) and Director, SENIC) who serves as **Director**. Dr. David Gottfried (Senior Assistant Director, Georgia Tech IEN and Deputy Director, SENIC) serves as **Deputy Director** and oversees the Coordinating Office day-to-day operations, assisted by a **Program Manager** (Amy Duke). Three **Associate Directors** manage the network activities in specific areas. Dr. Quinn Spadola (Georgia Tech) coordinates the NNCI education and outreach programs. Dr. Spadola previously was with the National Nanotechnology Coordination Office (NNCO) focusing on education and outreach on behalf of the National Nanotechnology Initiative (NNI). Prof. Jameson Wetmore (Arizona State University) coordinates the Societal and Ethical Implications (SEI) activities. Prof. Wetmore is an Associate Director within Nanotechnology Collaborative Infrastructure-Southwest at ASU and has been coordinating SEI activities on a national level as Co-Director of the Center for Engagement and Training in Science & Society. Prof. Azad Naeemi (Georgia Tech) coordinates the computational activities and facilitates interactions with nanoHUB/NCN at Purdue University. This Coordinating Office staff meets monthly by conference call.

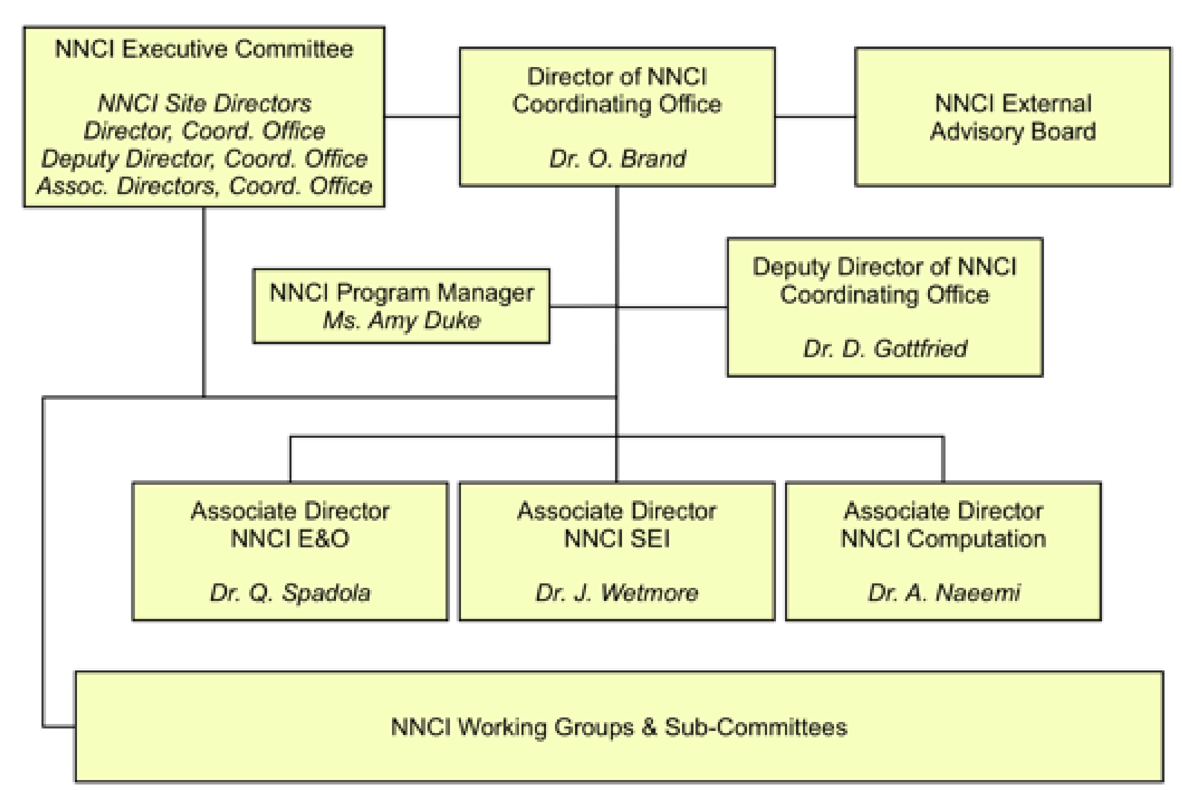


Figure 2: NNCI Coordinating Office Organizational Chart (Years 1-5)

The Coordinating Office staff is guided by an **Executive Committee,** which includes the 16 NNCI site directors and other site leadership. The Executive Committee meets monthly via teleconference and annually in person at the NNCI Conference. The Executive Committee and Coordinating Office are advised by an **External Advisory Board** (EAB, see Section 3) comprised of members representing industry, academia, government, education and outreach, SEI, computation and non-traditional disciplines in nanoscience and nanoengineering. The EAB meets in person as part of the NNCI Conference, with additional conference calls as necessary, and provides an annual written report and recommendations.

In addition to the work of the Associate Directors, several **subcommittees** of the Executive Committee have been formed to tackle high-level issues related to the NNCI network as a whole (see Section 5). Leveraging the distributed expertise at the network level, several **working groups**, composed of staff members from the NNCI sites, have been formed to share and develop best practices for site and network operations, technical areas, and education and outreach (see Section 6). Finally, during Year 5 the network began creation of **research communities**, which are organized around key scientific and engineering challenges and represent an opportunity for the NNCI to interact with the broader research ecosystem (see Section 9.2). Other tasks of the Coordinating Office include:

- creation and maintenance of the NNCI website
- organization of the NNCI Annual Conference
- interfacing with NSF and the External Advisory Board
- facilitating interactions among the sites via an email listserv
- incentivizing sites to collaborate via support of workshops
- marketing the NNCI at conferences and trade shows and through printed and electronic materials
- organization of an annual REU Convocation
- development of an annual user satisfaction survey
- management of the Outstanding NNCI Staff Member awards
- providing unified outlines and templates for site annual reports and reverse site reviews
- collection of site usage statistics and other impact metrics
- collection of annual user highlights
- preparation of this annual report

More details on these activities are shared in the sections below, and plans for future activities are provided in Section 12.

3. External Advisory Board

During the first year of the NNCI, the Coordinating Office established an NNCI External Advisory Board. To this end, names for potential advisory board members were solicited from the 16 NNCI sites. The Coordinating Office then assembled the Advisory Board from the solicited list, ensuring a diverse board in terms of gender, ethnicity and disciplinary background. Since its inception, there have been some changes in the EAB membership and Table 3 shows the Advisory Board members and their affiliations as of January 2021.

Table 3: NNCI External Advisory Board

Name	Affiliation
Prof. Reggie Farrow	Department of Physics New Jersey Institute of Technology
Dr. Andrew Greenberg	Associate Director, Institute for Chemical Education University of Wisconsin
Dr. Elaine Cohen Hubal	Acting Director, Computational Exposure Division US Environmental Protection Agency
Dr. Angelique Johnson	MEMSTIM Louisville, KY
Mr. Joe Magno	Executive Director The North Carolina Center of Innovation Network
Prof. Richard Osgood	Department of Electrical Engineering & Department of Applied Physics Columbia University
Dr. Kurt Petersen	Band of Angels Palo Alto, CA
Prof. Ken Wise	Department of Electrical Engineering and Computer Science University of Michigan

The Advisory Board meets in person during the annual NNCI Conference and virtually via teleconference call as needed. Ahead of the first NNCI Conference in January 2017, the Coordinating Office asked the Advisory Board to take a critical look at what NNCI is doing well and areas where it can improve. In particular, the Advisory Board considered the following questions:

1. What activities can/should NNCI support to achieve the goal of the network surpassing the sum of the parts? This should involve not only research facilities aspects, but also consider

support of education/outreach, computational tools, and societal and ethical implications activities.

2. The NSF considers increasing usage by external users as well as usage by “non-traditional” users of prime importance. Considering the current activities of the sites and the network, what can be improved to achieve this aim?
3. Since NNCI serves to support cutting-edge research in both academia and industry, what capabilities should sites begin to acquire to anticipate 5-10-year research trends?

From the feedback of the Advisory Board at the January 2017 NNCI Conference it became clear that a more detailed “Charter Letter” with input from the NSF on what would constitute a successful network was needed. This document was created during 2017 and communicated to the Advisory Board with a copy provided in the 2017 annual report. The report of the Advisory Board following the most recent NNCI Conference (October 2020) is provided in Appendix 13.1.

4. Associate Director Reports

4.1. Education and Outreach

The mission of the NNCI's Education and Outreach (E&O) efforts is to offer education and training to address the growing need for a skilled workforce and informed public; provide resources, programs, and materials to enhance knowledge of nanotechnology and its application to real-world issues; and support the US economy by enabling a STEM-literate workforce ready to meet the technological challenges of a nano-enabled economy as well as an informed citizenry that supports continued and safe growth of nanotechnologies.

The 16 sites of the NNCI each have separate E&O programs in order to address these goals. Throughout Year 5 of the NNCI, E&O coordinators reached more than 33,000 people through personal/virtual interactions in classroom visits, teacher workshops, remote sessions, short courses, seminars, symposia, community events, booths at conferences, tours, internships, REUs, and RETs. This represents a significant decrease from the previous year's reach (more than 66,000) because of the cancelation of many events due to the COVID-19 pandemic. That being said, sites quickly pivoted to virtual activities and continued to serve their communities. Of the people reached this past year, 58% were K-12 students, 2% educators (K-12 teachers and community/technical college faculty), 12% general public, and 28% professionals (REUs and other student interns, short course and workshop participants, seminar attendees, etc.). The largest drop was among the general public; NNCI events reached only 20% of the number of participants compared to last year. The number of professionals remained approximately the same due to a quick pivot to online content to continue serving this group. As in previous counting, the 33,000 figure also does not include NanoEarth's Pulse of the Planet programs, Nebraska Nanoscale Facility's traveling museum exhibit, or the Nanooze magazines distributed through CNF. Also not included are the number of people enrolled in the online courses offered through RTNN and nano@Stanford, and these are discussed in the Technical Content Development working group report (Section 6.12).

In celebration of National Nanotechnology Day, the NNCI again hosted the image contest *Plenty of Beauty at the Bottom*. Sites submitted images created at one of their facilities during the past two years to three categories: "Most Stunning", "Most Unique Capability", and "Most Whimsical". Public voting took place during the week of National Nanotechnology Day (Oct. 5-12) with sites promoting the contest through their various channels. Over 2,500 votes were cast to determine the winner in each category (Figure 3). In addition to the image contest, individual sites hosted events including local researchers speaking virtually with classrooms, online symposia, virtual celebrations in collaboration with local science centers, and posting social media content.

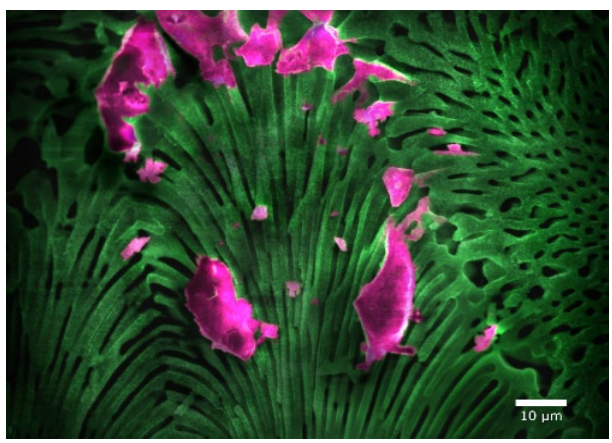


Figure 3: 2020 Image Contest Winner, Most Stunning

To facilitate the sharing of information across the network, E&O coordinators participate in monthly conference calls and post information to a Slack workspace. An education and outreach listserv was also created to further enable cross-site communications. The purpose of the calls is to share information about upcoming events, partnerships, conferences of interest, and for working group leads to update the entire group on relevant information. These calls also provide an opportunity for coordinators to connect over common interests and plan follow-up conversations. Additionally, topic specific teleconferences are organized if multiple sites are interested in learning more from each other. Topics this year included reviewing education and outreach specific feedback from the renewal, best practices for pivoting to virtual programs, and brainstorming for 2021 summer programs. Each year education coordinators are also asked to update a worksheet that lists all of the different types of activities offered across the NNCI. Everyone has access to the sheet so, if someone wants to learn how to run a specific activity they have never done before, they know which sites to contact for information.

Across the network, E&O coordinators make an effort to reach groups historically underrepresented in STEM fields. As part of the discussions on adjusting to virtual activities, sites were cognizant of bandwidth inequality, so many opted to pre-record sessions rather than stream live video. In another example of sites working to provide content to disadvantaged groups during the pandemic, NNF partnered with Girls, Inc. to use existing food distribution systems (for low-income families) to distribute materials for hands-on lessons that were then conducted virtually. Prior to the pandemic, coordinators attended conferences and programs such as those hosted by the American Indian Science and Engineering Society, the Annual Biomedical Research Conference for Minority Students, and the Society for the Advancement of Chicanos/Hispanics and Native Americans (SACNAS) to promote REU opportunities to students from under-represented minority serving institutions. The NNCI Coordinating Office supported the travel of an education coordinator from SDNI to attend SACNAS 2019 and co-present two seminars on nanotechnology and careers with a representative from the NSF-supported NACK network. Additionally, coordinators have been encouraged to include information on all of the other NNCI REU opportunities (the coordination office has provided a flier with all NNCI REU sites listed) when they attend events to promote their own program. Coordinators work to create relationships with and provide information on teacher workshops and student programs especially to Title 1 schools (where at least 40% of students come from low-income families) in their respective areas. Multiple sites are communicating with each other to share experiences and best practices for engaging with tribal colleges in order to reach Native American students. MONT shared that, after taking the time to build a relationship with Salish Kootani College, their group was invited to participate in the college's summer camp for high school students on the Flathead reservation. Unfortunately, the camp was canceled due to COVID-19, but MONT hopes to participate in the future.

With outreach to K-12 students, the NNCI is inspiring our future skilled workforce and helping to create an informed citizenry. Many sites participate in summer camps, high school student internship programs, after school programs, career fairs, and both off-site and on-site visits. A quote from an organizer of a STEM explorer high school event that TNF participated in nicely sums up the importance of these activities: “Thank you for your fantastic and intriguing presentations, hands-on activities, and tour! The students and parents were all very thankful. Many of the students got much more than they imagined. The diversity of disciplines and combination of degree majors involved to solve nanotechnology challenges is inspiring.” In response to the COVID-19 pandemic, many sites saw the switch to virtual programs as an opportunity to expand outreach. RTNN developed Take-out Science (Figure 4) and Sciencing with Abby, two video series designed to teach students about the scanning electron microscope and nanotechnology. NNF, in a partnership with Upward Bound, expanded their after-school program by 400% by using a virtual format and existing distribution methods to send materials to students. SENIC started offering virtual class trips to middle and high school teachers in August. Staff join the teachers’ virtual classroom and present an hour introduction to nanotechnology with demonstrations to students. As part of the site renewals, CNF, NNF, NanoEarth, and MONT are combining efforts to work with 4H. Each site is planning their own activities using ideas and experiences of others to inform them. When possible in the future, NNCI sites will participate in 4H’s National Youth Summits.

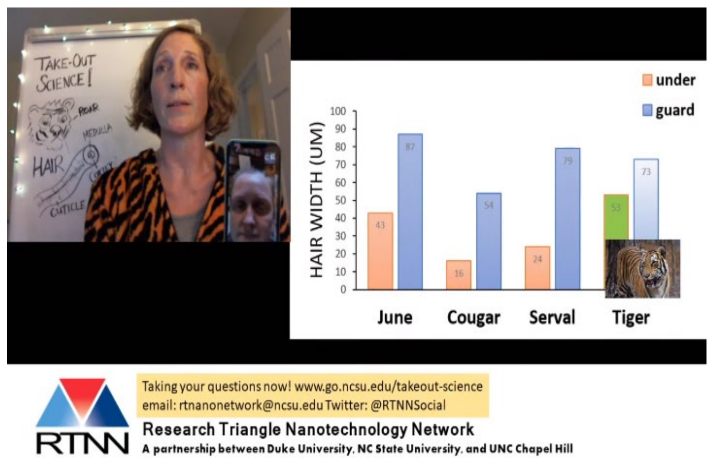


Figure 4: Screenshot from RTNN’s Take-out Science

In order to develop a STEM-literate workforce and informed citizenry, coordinators provide many activities for educators. Often sites provide multi-day workshops, summer long RETs, or sessions at conferences in which teachers leave with free resources and a personal connection to a nearby site. While the number of educators reached this year dropped due to the cancelation of many conferences, including the annual National Science Teachers Association Meeting, sites still spent time virtually providing their local teachers with resources and training. The Research Experiences for Teachers (RET) across the National Nanotechnology Coordinated Infrastructure collaborative proposal submitted to NSF by SENIC, MINIC, SHyNE, and NNF was funded in spring 2020. Unfortunately, the first summer of the program had to be canceled due to the pandemic. Most, but not all, sites had to cancel their individual RET programs; SDNI was able to offer the experience to their local teachers. Nano@stanford and SENIC provided the Nano Summer Institute for Middle School Teachers virtually, providing 15 teachers at each site with 4 days of instruction on nanotechnology and how to implement it in the classroom. NanoEarth adapted their workshop for high school teachers to a virtual format and, based on teacher feedback, used multiple platforms to give teachers a chance to become familiar with what they would be using during the school year. Originally scheduled for early summer, SDNI hosted their SDNI-NNCI Education Symposium virtually in September. With the theme “Integration of Nanotechnology Content with Current State-Wide K-12 Science Curricula: Challenge and Strategies”, the symposium brought together the nanotechnology and education communities to discuss up-to-date achievements, major challenges, and strategies to achieve a sustainable nanotechnology curriculum in the K-12 education systems across the nation. Fifty attendees listened to presentations from UCSD, the San Diego County Office of Education, Stanford, Virginia Tech, Georgia Tech, Omni Nano, Valencia High School, Kearny High School, Micro Nano Technology Education Center (MNT-EC), Penn State University, and the National Nanotechnology Coordination Office (NNCO). SDNI's strategy is to create nanotechnology modules that can be integrated with current NGSS-aligned science curricula across California, as well as raising awareness and reaching out to teachers, school and district administrators, county office of education administrators and curriculum developers, and the California Department of Education. SDNI also intends to share its California experience and collaborate with other NNCI sites to create an impact nationwide. In addition to these activities, sites contributed to a list of resources (NNCI Resources for Virtual Classrooms, Kitchens, Backyards, and Beyond) for students, teachers, families, and adults that could be enjoyed from home. Published on the NNCI website in late spring, the list includes podcasts, videos, online magazines, virtual cleanroom tours, and activities that can be done from home using common items.

As part of building a nano-literate skilled workforce, NNCI sites provide technical workshops, short courses, seminars, webinars, and/or symposia for undergraduates, graduates, post-docs, and other professionals. This group saw the smallest decrease in involvement over the past year. Sites quickly pivoted to virtual resources once access to campuses and facilities was restricted due to COVID-19. Despite the pandemic, NCI-SW was able to provide nine hands-on and one virtual lab sessions for community college students enrolled in Rio Salado College's Nanotechnology AAS/Certificate programs. KY Multiscale hosted their annual "Nano + Additive Manufacturing Symposium" for researchers and users in the fall of 2019 (Figure 5). MANTH started expanding the hands-on programming for the new "Introduction to Nanotechnology" course offered at the Community College of Philadelphia. As part of their site renewal, MONT added a scholarship program for undergraduate underrepresented minorities in STEM attending Montana State University. The first two scholarships have been awarded and one will start in the spring 2021. Sites switched to webinars, virtual Tech talks, workshops, and short courses, created online training modules, and offered virtual office and coffee hours to give users opportunities to talk to technical staff or each other. NanoEarth's "Nanotechnology Entrepreneurship Challenge" moved to a virtual format as well. Sites also plan to increase remote access to their instruments in order to continue to serve professionals. Almost all summer 2020 REU programming at NNCI sites was canceled due to the pandemic. NCI-SW was able to provide one modeling project to a student who participated remotely. The annual REU convocation was also canceled. Coordinators have had one conference call and plan to have more in order to brainstorm together ideas for how to proceed with 2021 summer programs under uncertain conditions.

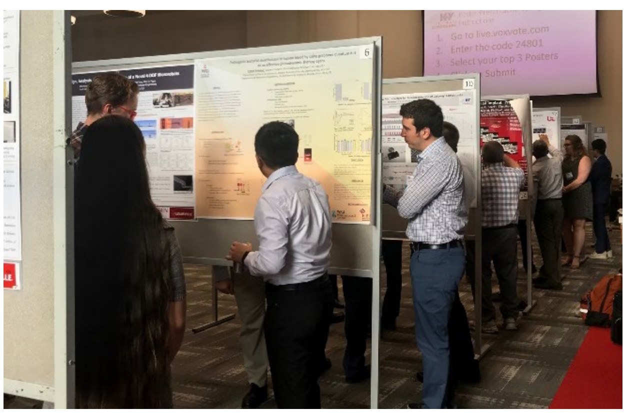


Figure 5: Poster Session at 2019 Nano + Additive Manufacturing Symposium

NNCI sites participate in science festivals, science cafes, science days at their institutions, National Nanotechnology Day, and Nano Days celebrations to help enable an informed citizenry. Prior to mass cancelation of events in early spring because of COVID-19, RTNN and SENIC participated in three events RTNN organized in rural parts of North Carolina. MINIC brought undergraduates to the Minneapolis Public Schools STEM Career Expo which served over 2,200 middle school students. NanoEarth staff collaborated with faculty from Virginia Tech's School of Performing Arts to create "Air, Land, & SEE" as part of the Virginia Tech Science Festival. Traditionally, MANTH organizes presentations by several research labs for visiting high school students for National Nanotechnology Day. This year, based on feedback they solicited from teachers, they had groups develop online presentations including hands-on demos with materials shipped in advance, and they reached almost 100 students and assessed the activity. They intend to integrate virtual content into National Nanotechnology Day moving forward. A virtual lecture on quantum dots was also presented to students at the Community College of Philadelphia for the event. MANTH included their teacher feedback in the best practices for virtual education and outreach document that all sites contributed to following a teleconference on the subject. The document is available to all coordinators as they continue to adapt to and plan for virtual programming.

Education and outreach coordinators have embraced the move to virtual outreach as an opportunity to reach a larger and more diverse audience. While moving back to in-person activities is something everyone looks forward to, the online content that has and continues to be developed will be integrated into sites' programming. Moving forward, sites are working together to engage with larger organizations, expanding the opportunities they offer to students, implementing teacher workshops developed by other sites, and creating more virtual content for training and outreach. More details on education and outreach efforts across the NNCI can be found in the education working group reports. The report of the *Workforce Development and Community Colleges* working group (Section 6.10), led by Dr. Ray Tsui from NCI-SW, includes information on activities related to workforce development and community college engagement over the past year. The report of the *Technical Content Development* working group (Section 6.12), co-led by Drs. Angela Hwang from nano@stanford and Maude Cuchiara from RTNN, provides information on a best practices webinar and toolkit to help sites produce their own training videos that they developed. The report of the *K-12 Teachers/RET, Students, and Community Outreach* working group (Section 6.9), led by Dr. James Marti from MINIC, discusses guidance to improve the education section of the NNCI website, work to assist sites with feedback on evaluation, and activities around reviewing teacher training across the network. The report of the *Evaluation and Assessment* working group (Section 6.11), led by Dr. Quinn Spadola from SENIC, includes information on a collaboration with the *Workforce Development* working group and resources available to sites to help them decide which programs to assess and the best methods to do so.

4.2. Societal and Ethical Implications

Nanotechnology holds great promise, but the NNCI Coordinating Office recognizes that the introduction of any new technology can have significant societal and ethical consequences. We believe it is important to think about the impacts of nanotechnologies as we conceive them, develop them, and implement them. To that end, the CO is working to help all of the NNCI sites develop Societal and Ethical Implications (SEI) research and engagement programs. Associate Director Jameson Wetmore (also part of the NCI-SW site) is leading these activities.

As with the rest of the NNCI, throughout the past year there have been two primary events that have impacted SEI work: the renewal process and the COVID-19 pandemic. In part because of these events, we were able to get a fair amount done to advance recognition and discussion of societal and ethical implications in the NNCI.

For instance, the renewal served as a focal point for many NNCI sites to reconsider their relation to and involvement with SEI. This resulted in a fair number of conversations and consulting between the CO and the various sites. Wetmore worked directly with a handful of sites to discuss specific strategies and ways to get more involved with SEI activities.

The NNCI CO also helped to coordinate the efforts of the four NNCI sites where most of the SEI work is done – TNF, RTTN, SENIC, and NCI-SW. The goal over the past year has been for each site to formulate an activity or activities that other NNCI sites can partner with to expand the impact of the SEI work already being done. These programs could then be integrated into other NNCI site proposals with the budget necessary to participate.

The SEI team of David Berube at NC State, Jan Youtie at Georgia Tech, LeeAnn Kahlor at Texas, and Wetmore at ASU met several times to coordinate their proposals for the rest of the NNCI. Each coordinator developed a program that other NNCI sites, who may have less access to SEI expertise, can plug into. Berube and Youtie are both developing complementary toolkits for assessing the impacts of NNCI sites, Kahlor will be hosting and sponsoring an SEI engagement workshop designed to help get participants from across the NNCI up to speed on SEI efforts, and Wetmore will be redesigning the "Science Outside the Lab" program to train the participants as SEI Ambassadors who can take what they've learned in Washington, DC back to their home institutions. The resulting ideas were integrated into some of the renewal proposals from across the NNCI which will greatly extend the reach of the SEI work being done.

In addition to preparing for the renewal, Wetmore has been traveling to other sites and (especially subsequent to the COVID-19 pandemic) participating in online workshops to inject SEI into the education training programs being developed by the NNCI CO and other NNCI sites. For instance, in January 2020, Wetmore was invited to the NNCI site at Oregon State University to run a half-day workshop with a dozen graduate students from the College of Engineering focused on thinking about SEI in their own laboratory work. He followed that up with a talk to around 60 people – "Nanotechnology at the Start of the Millennium: A look back at the excitement and fear" – that was part of OSU's Department of Chemical, Biological, and Environmental Engineering Seminar Series.

In March, Wetmore helped NNCI CO Education Director Quinn Spadola relaunch the "Teaching Nano & Emerging Technologies Webinar Series," with a special taping entitled "Teaching the Social Implications of Nanotechnology to High School Students," which can be found at https://www.nano.gov/TeacherNetwork. And in July, Wetmore presented "Introduction to You Decide and teaching the social side of nanotechnology" at the Nanoscience Summer Institute for Middle School Teachers, an online professional development program hosted by Stanford University's NNCI site.

We have also continued our efforts to support SEI work and discussion beyond the NNCI as well. Over the past year Wetmore has engaged a number of organizations to promote SEI in their work. For instance, in June he hosted an online seminar for the TEDI London Summer School on "Users of Technology in the Developing World." And in August he discussed the societal and ethical implications of nanotechnology with Lisa Friedersdorf, Director of the National Nanotechnology Coordination Office, on two podcasts: "Stories from the NNI," which is designed for nanotechnology professionals (https://www.youtube.com/watch?v=Il3s5Xa8vNw&feature=youtu.be), and "Nano Matters," which is aimed at a more public audience (https://www.nano.gov/podcast). In many ways these activities were made easier by the worldwide shift to accept remote engagement as the norm.

The flagship exercise of the NNCI CO SEI effort is the "Winter School on Responsible Innovation and Social Studies of Emerging Technologies." The Winter School is held every January at Saguaro Lake Ranch, just east of Phoenix and is designed to train the next generation of social science scholars interested in the future of science and technology. In January 2020, 14 students from 10 different countries participated in the week-long program and learned research skills and techniques from over a dozen faculty. They got practical experience with the methods and theories developed at ASU and through visiting faculty in their investigations of technologies such as nanotechnology, robotics, geoengineering, artificial intelligence, and synthetic biology. This was the fourth NNCI sponsored winter school and the seventh overall winter school which means we now have well over 100 alumni of the program. We organize alumni meetups at international meetings at least once a year and have helped to foster not just individual researchers, but a cohort of scholars who continue to support each other long after their time in the desert is over.

Due to the pandemic, we were forced to cancel the 2021 version of the workshop. As we proposed in the CO renewal, we are working to retool the program to integrate more young scientists and engineers into what has traditionally been a majority social scientist group of students. We are looking forward to returning to the desert in January 2022 for the fifth NNCI sponsored winter school.

In the early spring of 2020, we prepared for our other major event of the year – the NCI-SW sponsored "Science Outside the Lab" program in Washington, DC. We recruited and accepted 15 eager students ready to participate in the 5th version of the NNCI-sponsored "Science Outside the Lab" program. Unfortunately, due to the COVID-19 pandemic we had to postpone the program. Through the application process, however, we did learn that the "SEI Ambassador" program developed for this year and the renewal looks to be successful. The goal of the program is to not only train students in the social and political implications of science and technology, but to prepare them to share that knowledge with others and serve as a sounding board for their colleagues who may have ethical concerns. Many applicants (including all the accepted candidates) proposed a wide array of interesting ways that they would share their SOtL experience with others once they returned to their home institutions including talks, seminars, courses, clubs, and mentoring. The education coordinators at many sites have also shown interest in the idea over the last year, as they are excited by the prospects of having an SEI resource on campus and perhaps students trained to do different kinds of public engagement.

The plan developed last spring was that we would run two SOtL programs in 2021: one with the current group of accepted students and a second one that would be filled through an open call for new applicants across the NNCI. Given the unsettled state of the world right now we have decided to host an online version of the program during the first two weeks of June 2021 and hope to return to on-the-ground programs in 2022.

4.3. Computation

Modeling and simulation play a key role in enhancing nanoscale fabrication and characterization as they can guide experimental research, drastically reduce the required number of trial and error iterations, and enable more in-depth interpretation of the characterization results. The main objectives of the computation activities within NNCI are 1) to facilitate access to the modeling and simulation capabilities and expertise within the network, 2) to identify the strategic areas for growth, and 3) to promote and facilitate the development of the new capabilities.

To facilitate access to the modeling and simulation capabilities and expertise available within various NNCI sites, an inventory of available modeling and simulation resources and expertise has been complied. The directory is hosted by nanoHub.org and can be accessed via https://nanohub.org/groups/nnci_computation. So far, 10 sites have reported collectively more than 65 commercial simulation tools and 40 internally developed simulation tools available for internal and/or external users (with and without fee).

In addition to software resources, 9 supercomputers or major computing clusters are available in various sites. Most of these hardware resources serve internal users, with the exception of the UT-Austin computing cluster which can be accessed by external users with a nominal fee and the CNF Nanolab Computing Cluster that is available to all users. The users of the CNF Computing Cluster have access to a wide range of modeling software packages tailored for nanoscale systems. Several classes of nodes, all linked via Gigabit Ethernet, are available on the cluster. The cluster runs Scientific Linux 7 with OpenHPC and a batch job queuing system. The staff will install new scientific codes on the cluster upon user request. The users can also remotely access software tools via "CNF Thin" Hotdesking service such as Computer Aided Design (BEAMER, L-Edit, Java GDS, AutoDesk), Simulation (Coventor, Cadence, PROLITH, Layout LAB, TRACER), and Image/Data Analysis (ProSEM, NanoScope Analysis, WinFLX). For tasks that are heavily memory or time demanding, Amazon Web Services (AWS) conversion capabilities are also available. More information on CNF computing resources is available at http://computing.cnf.cornell.edu/Cluster.

On the modeling and simulation side, Professor Dragica Vasileska from Arizona State University (NCI-SW) has developed a comprehensive modeling and optimization framework for 4H-SiC Power electronic devices. The models build upon Prof. Vasileska's prior work on process simulation for such devices and add self-consistent solutions to Boltzmann transport and Schrödinger equations. The transport models include drift-diffusion solver, Hydrodynamic models and Monte Carlo device solver. To solve Schrödinger equation, density matrix and Winger methods are used in addition to Green's Functions and ab initio methods. The modeling framework is validated/calibrated against experimental data and is used to design and optimize vertical double-diffused MOSFETs.

In 2020, Professor Vasileska's group also contributed a simulation tool to nanoHUB for calculating Bound States (https://nanohub.org/tools/bsclab). In less than 6 months, the tool has attracted more than 235 users. Overall, her group has made more than 350 contributions and she is ranked third among all nanoHUB contributors.

5. NNCI Subcommittees

In addition to the work of the Coordinating Office and specific topical areas of the Associate Directors, several subcommittees of the Executive Committee have been formed to tackle high-level issues related to the NNCI network as a whole (Table 4). Positions on these committees were offered to each member of the Executive Committee (site PIs), along with any site co-PIs who wished to participate. Most Site Directors serve on two of these subcommittees with a subcommittee chair selected by the Coordinating Office. Additional input may be sought from members of the External Advisory Board and other experts as needed. Members of the Coordinating Office serve on some of the subcommittees as ex-officio members. As a starting point, the Coordinating Office created a number of guiding questions for each subcommittee. One of the subcommittees is selected to report to the full group of site directors and coordinating office (Executive Committee) every other session during the regular monthly meetings. Reports of the subcommittees on current and future activities are presented below as provided by the subcommittee chair.

Table 4: NNCI Executive Committee Subcommittees

Subcommittee Topic	Subcommittee Chair
Diversity	Jacob Jones (RTNN)
Metrics and Assessment	Stephen Campbell (MINIC)
Global and Regional Interactions	Vinayak Dravid (SHyNE)
New Equipment and Research Opportunities	Kevin Walsh (KY MMNIN)
Entrepreneurship and Commercialization	Mark Allen (MANTH)
Building the User Base	Shyam Aravamudhan (SENIC)

5.1. Diversity Subcommittee

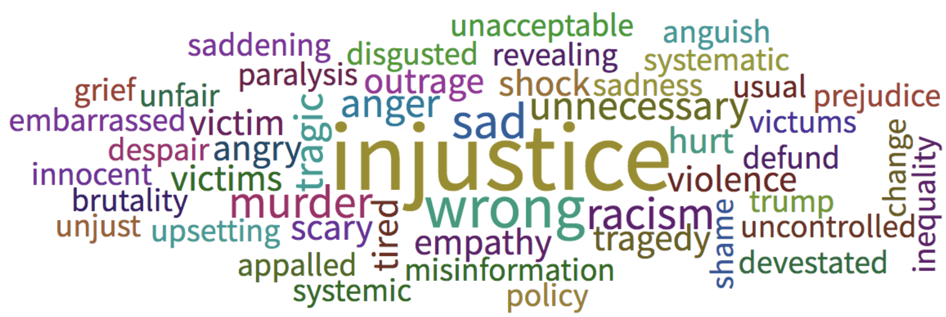
Subcommittee Charge: The NNCI Diversity Subcommittee seeks to broaden participation in the NNCI and nanotechnology nationally by positively impacting culture, developing assessment strategies, identifying strategies to overcome common obstacles, collaborating with sites to share and disseminate best practices, and inspiring and challenging each other.

The committee's discussions and work in the year 2020 were dominated by considerations for promoting inclusivity, equity, and diversity during a time of global pandemic and racial reckoning. This included factors such as: promoting equitable access to online materials and necessarily synchronous events by staff and users working from home who experience varied home pressures and internet accessibility, the potential for racism and xenophobia at the outset of the pandemic, the equitable treatment of staff during laboratory reopening phases (e.g., referencing ageism in a public health crisis), and furthering efforts to identify and combat racism of any type in NNCI shared user facilities.

In March 2020, at the outset of the pandemic, the Diversity Subcommittee reminded users, staff, and site leadership about many of these considerations in an email to the nnci-general listserv maintained by the Coordinating Office.

As a period of national racial reckoning unfolded in the summer of 2020, the committee recognized a need for connecting, learning, and facilitating dialogue within the NNCI community around the topics of racism and anti-racism. The committee organized an "Anti-Racism Town Hall" that was held online using a Zoom webinar on June 24, 2020. The event was promoted through the nnci-general listserv and through the site PIs. Over 230 individuals registered to attend the online Town Hall event and approximately 170 participated. Periodically throughout the event, technology from polleverywhere.com was used to solicit participation and information from the attendees.

One of the earliest questions in the webinar was, "What words come to mind as you (scientists, engineers, and facility staff) think of George Floyd, Rayshard Brooks, and others?" Approximately 100 responses were used by Poll Everywhere to create the word cloud shown below, in which the size of the words reflect their frequency of occurrence in the responses.



Other questions solicited the following information from attendees:

- 2% of respondents viewed the Town Hall topic as "insignificant" to NNCI. 56% thought it was highly significant and 38% thought it was significant.
- 92% of respondents would like to be an ally for anti-racism within their NNCI facility.
- 3% of respondents have seen clear and obvious racism related to shared nanotechnology facilities.
- 66% of respondents think that implicit bias or systemic racism exists in users, staff, or leadership of NNCI facilities.
- 39% of respondents do not know how to respond if they witness racism.

These statistics point to a staff and user base that wants to take action, though many may need more information on how to take action and what actions to take. As a follow-up, the site PIs were asked to bring up the results from these survey questions during NNCI site meetings and facility staff meetings with an objective to identify actions that can be taken utilizing the local, unique resources available within their universities.

An important part of the Town Hall was time dedicated to drawing out personal experiences, concerns, and stories from NNCI users, staff, and stakeholders related to racism. Prior to the meeting, several registrants volunteered to tell a story publicly during the meeting. There were also volunteers to tell stories and participate from the attendees. Feedback from attendees at the Town Hall indicated that these stories, which included personal accounts of racial bias and stereotyping, were important to remind everyone of the experiences and perspectives of individuals from all backgrounds.

Diversity: The "state of diversity" in the NNCI can be assessed by considering several different aspects of unique groups participating in the NNCI, a few of which are given below:

1. Institutional characteristics of NNCI sites (e.g., HBCU, MSI status): In the first five years of awards, institutional participants included one HBCU (NC A&T in SENIC), one Minority-Serving Institution or MSI (UNC Greensboro in SENIC), one Primarily Black Institution (Community College of Philadelphia in MANTH), and four *emerging* Hispanic Serving Institutions or HSIs (UT-Austin in TNF, Arizona State in NNI SW, UC San Diego in SDNI, and Stanford in Nano@Stanford). Note that *emerging* MSI status is not well-defined nationally but is defined here as an institution with undergraduate student populations that are between 15% and 24% minority students. In the renewal awards of 2020, additional educational and research partnerships were established across the NNCI with Salish Kootenai College, Chemawa Indian School, Morgan State University, and FAMU-FSU. Northern Arizona University was also added as an equal partner to the NCI-SW site.
2. PI/co-PI of NSF NNCI grants (i.e., NNCI site leadership): In the final year of the initial 5-year NNCI awards, of the 61 individuals listed as PI or co-PI on the NSF awards, 9 (or 15%) were women, which is comparable to the number of women in the Electrical and Computer Engineering professoriate (13%) and the Engineering professoriate (17%). In the 2020 renewal awards, of the 66 individuals listed as PI or co-PI on the NSF awards, 20 (or 30%) are women, demonstrating a significant broadening of participation by gender. In addition, several of these PIs/co-PIs are African American or Latino/Latina, demonstrating broadening participation by race and ethnicity.
3. NNCI/Site user institutional characteristics (e.g., HBCU, MSI status): The institutional characteristics of external users of NNCI facilities is described in a separate section of this report (Section 10.2).

Plans for 2021: The subcommittee is preparing to re-deploy the NNCI Staff Diversity Climate Survey in early 2021. An earlier survey in 2019 provided useful information to guide the actions of the NNCI and the subcommittee. The 2019 questions were revisited by the Diversity Subcommittee and a social scientist (David Berube). The survey is ready to send out in early 2021.

<u>Highlights of Best Practices from Around the NNCI:</u>

CNS continues to support a "CNS Scholars" program. The CNS Scholars program seeks to support inclusive excellence by offering access to advanced instrumentation and expertise by early-career scientists who diversify the user base and STEM disciplines. Current scholars are from Smith College, Howard University, Mississippi State University, Mount Holyoke, and the University of Alabama at Birmingham. The scholars work on a broad range of topics and some projects have since become supported by the NSF Center for Integrated Quantum Materials at Harvard, moreover several have developed collaborative interaction with local faculty at Harvard and MIT. In addition, this year CNS has begun sponsorship of a new Student Chapter of the National Society of Black Physicists (NSBP) at Harvard, which has a nice mix of both undergraduate and graduate students. Bill Wilson is serving as the advisor to the new group, which hopes to expand to a New

England regional Chapter next year. Wilson is also now serving on the Advisory Board for the new IBM-HBCU Quantum Center.

CNF has introduced a new partnership with Morgan State University, the HBCU that graduates the largest number of African American electrical engineers, to its REU program. We expect to host the most diverse group of REU students in the history of CNF's REU program this summer. CNF has also added a new associate director, Prof. Claudia Fischbach-Teschl, to its leadership team to increase its connection to the life science community. CNF works with Cornell's Diversity Programs in Engineering (DPE) to recruit a diverse community of students and faculty to Cornell, to take part in its annual open house, to send students selected by DPE to act as ambassadors for nanofabrication to the SHPE and NSBE annual meetings and aid its LSAMP program. CNF has annually presented the Nellie Whetten Memorial Award since 1989 to outstanding women scientists who are CNF users. All recipients have gone on to outstanding careers in nanoscience and this year we were fortunate to be able to present two awards. A past winner, Dr. Lidija Sekaric (Siemens), spoke at the CNF annual user meeting about energy related nanoscience while also serving as a role model for the next generation of researchers. CNF also took part in several Town Hall meetings triggered by recent events such as the death of George Floyd including the NNCI-sponsored discussion as well as several focused on the Cornell community.

KY Multiscale site initiated a national search in Year 5 for a senior faculty researcher who will also serve as the faculty director of the UofL MicroNanoTechnology Center (MNTC) and associate director of our NNCI site. Preference will be given to a candidate who will increase the diversity of our leadership team. This past year, KY Multiscale also formalized a collaboration with Prof. Charmane Caldwell of HBCU FAMU/FSU to increase the number of minority student applicants to our recently-awarded NSF REU program called IMPACT-NG (Interdisciplinary Micro/nano/additive Program Addressing Challenged Today – Next Generation).

MANTH and the Community College of Philadelphia (CCP), through their NNCI-facilitated partnership, have explored options to bring nanotechnology education and training to CCP students. These ongoing efforts towards broadening participation around nano include creating three new courses at CCP, developing extracurricular programming that exposes students to content and careers in nanotech, offering professional development workshops for CCP instructors on incorporating nano into existing STEM courses, and developing a new paid internship program at the Singh Center for CCP students that would evolve into a program in which local industry would host the interns. A best practice taken from this project thus far is to build in significant time early on and at regular intervals for stakeholder meetings focused on sharing and understanding needs and perspectives and for (re)assessing progress; MANTH believes this intentional approach of inclusion will result in more effective and sustainable outcomes.



MiNIC has partnered with local colleges to develop a lab researcher internship program. Black and female interns are recruited from minority- and women-serving colleges in the area for a one to two semester internship experience. Over the past few years, eight students from a variety of backgrounds have completed internships at MiNIC facilities (see photos at right).

MONT was invited for the first time to participate in Salish Kootenai College's Family Science Night at K. William Harvey Elementary School on the Flathead Indian Reservation. MONT took NanoLand on a 5-hour (one way!) road trip to introduce about 200 students and their families to small-scale science. MONT's relationship with External Advisory Board member Prof. Antony Berthelote of SKC helped secure its invitation; MONT has been working to be invited to the event for several years. MONT was fortunate that the event was held on March 5, 2020 before Montana schools were closed due to the pandemic. The picture at the right shows elementary school students (standing) with a graduate student at SKC Family Science Night, Flathead Indian Reservation.

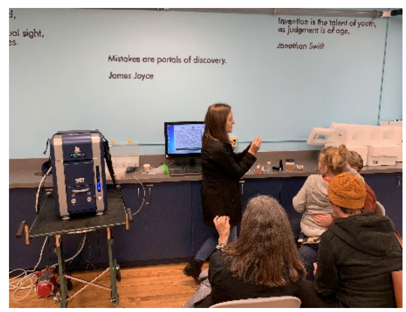
NCI-SW partners with Rio Salado College (RSC) to host the advanced laboratory component of its 2-year associate degree in nanotechnology. RSC provides education to the underserved (education and internet deserts, limited education access, rural areas) and underrepresented (minorities, women, veterans, first generation college students) population and geographic areas of Maricopa County. The college has a student body close to 50,000, of which 26% are Hispanic/Latino, 5% are Veterans, and 2% are Native American or Alaska Native. To date, 12 students have graduated from the RSC program and the eight who responded to our post-graduation survey all report obtaining jobs as engineering technicians/technologists or have enrolled in undergraduate and graduate programs at 4-year institutions. Some pictures from this program are shown below.

NNF led multiple diversity programs during the last year including After School, In School, Summer Nano Camps, workshops, and lab tour programs, both remote and in-person for middle and high school student populations, teachers, community college students and 1st-generation, college-bound high school students. The workshop initiatives reached 65 rural middle school/high school girls, 60 middle school/high school teachers from 30 rural schools across Nebraska, and 25 diverse Upward Bound high school students. Four rural Native American community college administrators participated in NNF's Traveling Exhibit nanoscience training as well as 15 rural community college undergraduate students. In another program, over 550 students from 13 schools statewide used pre-distributed nanoscience materials

to learn nanoscience lessons with hands on activities delivered remotely. Almost 100 diverse Educational Talent Search middle/high school students in After School programming received regular nano materials and presentations virtually each month August-November 2020. The challenges of COVID-19 have forced many programming changes that have been difficult but also resulted in some positive outcomes in terms of diversity.

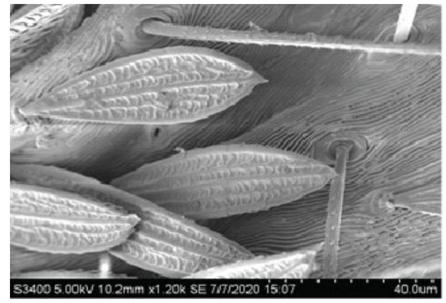
The **NNI**, including the affiliated Nano-Engineered Systems Institute (NanoES), the Washington Nanofabrication Facility (WNF), and the Molecular Analysis Facility (MAF) seek to foster an inclusive culture that celebrates differences in identity, background, and experiences free from biases or hostility. To address widespread inequities that exist in academia, NNI is committed to equitable hiring practices and workplace policies to recruit and support faculty, students, and staff from underrepresented groups. NNI aims to make resources, services, and opportunities accessible to all, and create community accountability through bias concern reporting. NNI strives for continuous improvement, and will continue to embed principles of diversity, equity, and inclusion into its work.

RTNN piloted this past year a new program to reach outside of the Triangle by taking hands-on activities and portable SEMs to rural schools, libraries, and museums where there is limited access to Research-1 (R1) institutions. In early 2020, RTNN staff and students partnered with SENIC volunteers to bring nanotechnology resources to two different NC locations: Hickory (160 miles from the Research Triangle) and Asheville (230 miles). These events were organized across multiple days and involved pairing a school or community college event with a larger public-facing event at a museum in an effort to reach a broad swath of the community. The pilot events engaged over 200 K-gray participants. By hosting the event in a "bustling, public place," such as a library, RTNN was able to engage participants from different socioeconomic groups and capture participants accessing the library for reasons other than the nanotechnology event.



SDNI has worked consciously to increase diversity among its staff and trainees, with particular emphasis on the leadership positions. Over the past year, one female faculty from the Nanoengineering Department was appointed as the deputy director for the site. SDNI appointed a Hispanic faculty member from the Nanoengineering Department as the associate director to lead and expand outreach and diversity initiatives. In addition, two female faculty members from the physics and ECE departments have been appointed to co-lead the nano/meso/metamaterials and nanophotonics thrust areas. SDNI also has a female scientist to lead the nanotechnology/electron beam lithography area. Overall, women and underrepresented minorities represent about 35% of SDNI's leadership team. SDNI also has well over 50% trainees who work as paid interns to be female or underrepresented minority students. Through solid training and great exposure to the cutting-edge technologies and network opportunities with industry, a large number of these minority interns have been hired by industry right after graduation or admitted to graduate schools to pursue advanced degrees.

SHyNE partnered with Northwestern's NSF-funded Science in Society to strengthen STEM learning and mentorship opportunities for K-12 youth and the Boys and Girls Club of Chicago, to create a virtual microscopy lesson targeted to underserved middle school children. The "SEM: Scanning Electron Microscopy" curriculum/program was held virtually in 2020. Each child received a Foldscope and participated through online remote content. This summer camp program was very well received by the participants and will expand to include live lab demos and interactive Q&A sessions with future specimens to be recommended by the children. The virtual program is linked here: https://youtu.be/7L4uKv0kFDs.



SENIC has increased the diversity in its leadership from 20% to 40% women and from 0% URM to 20% URM. Within SENIC, the three institutions have established a strategic focus on broadening participation in nanoscale research and education activities through delivery of courses/workshops by diverse faculty, recruitment of diverse graduate students and postdocs, and its outreach programs. For example, the GT Office of Hispanic Initiatives has ten Hispanic/Latino student organizations, while FOCUS is a program that seeks to recruit URMs for graduate school. In addition, new users and students are recruited for the REU program through the consortium of HBCUs. In order to increase awareness of SENIC programs and opportunities, staff participate in the Atlanta Science Festival, Atlanta Science Tavern, North Carolina Science Festival, and K-12 school, community college, and local and statewide Chambers of Commerce events. The STEM Ride (formerly NanoBus) at NC A&T/UNCG, news stories, and social media, have also been used to increase awareness. Furthermore, at NC A&T/UNCG, an annual event titled "Find Your STEM" is hosted for high school girls to increase their awareness of science and engineering. The site continues to increase the number of women and underrepresented minority users.

Nano@stanford continues its commitment to promoting diversity by staying engaged with its local community colleges and minority serving institutions. The Nanoscience Outreach Group, established in 2018, regularly participates in local events such as the Bay Area Science Festival, Stanford Splash, and National Nanotechnology Day. Nano@stanford attended Diversity in Tech panels at College of San Mateo and delivered guest lectures at Phoenix Academy in East Palo Alto, both HSI. Nano@stanford is also continuing research partnership with Prof. Ryan Smith from California State University, East Bay (an MSI). In Years 4 and 5, nano@stanford piloted a Community College Internship Program with four interns from Canada College, College of San Mateo (both MSI), and highly racially diverse Foothill College. None had prior experience in a lab, and yet after starting with routine tasks they all managed to advance to operating equipment and performing experiments under staff mentorship. All interns have now been accepted to highly ranked institutions such as USC, UC Berkeley, or Cornell University. Unfortunately, the program had to be suspended in 2020 due to the pandemic but will be continued once the public health situation allows for it. Finally, for the past 3 years, nano@stanford held a Nanoscience Summer Institute for Middle School Teachers (NanoSIMST), a 4-day professional development workshop where participants learn about nanoscience and prepare lessons for their classrooms. The goals of the program are to excite middle school teachers about nanoscience, equip them with content knowledge, empower them with pedagogy, and teach thousands of students about nanoscience. Nano@stanford recruits a diverse cohort of teachers based on location, demographics, and subject matter expertise – 44% of all NanoSIMST teacher alumni have come from Title 1 schools. Nano@stanford shared its experience with the SENIC site and helped it develop and implement their workshop, as well as continued offering the NanoSIMST experience in 2020 by hosting the workshop online via Zoom platform.

TNF has focused on underrepresented minorities and women in many of the education and outreach activities. The average participation of underrepresented minorities in the REU program over the last five years was 46%. TNF also hosts annual activities targeted towards girls, including "Girl's Day" in the cleanroom for middle school girls. In the next five-year program, TNF has redesigned its REU program for Austin Community College (ACC). This will be a year-round program for ACC students in our cleanroom, and at least 50% of the recruited students will be underrepresented minorities or women.

NanoEarth launched its NTEC-MUNI program in 2020, which combines elements of NanoEarth's NanoTechnology Entrepreneurship Challenge (NTEC) and its Multicultural and Underserved Nanoscience Initiative (MUNI) program. In the US, entrepreneurs are disproportionately white and male. Efforts are needed to encourage and support entrepreneurs from diverse and underrepresented groups. The objective of NTEC-MUNI is to provide focused support to entrepreneurs from Historically Black Colleges and Universities (HBCUs) who have accessed NanoEarth through the MUNI program. Through the NTEC-MUNI program student entrepreneurs participate in a seven-week virtual experience designed to help students develop sustainable nanotechnology innovations into a minimum viable product (MVP) and to conceptualize business models that can be leveraged to help bring their MVP to market. Teams that complete NTEC and NTEC-MUNI are likely to be more competitive for external programs like NSF I-Corps and SBIR/STTR grants offered through various federal agencies. In 2020, a team from Fayetteville State University (FSU) led by FSU student, Tyson Daniel, with support from FSU professor, Sambit Bhattacharya, received the first NTEC-MUNI award. The focus of their NTEC-MUNI award was to develop an artificial intelligence (AI) based tool for high-throughput image analysis of nanoparticles in complex environmental media. The tool is expected to support the efforts of environmental nanoscientists as they seek to better understand the fate and transport of nanoscale particles in environmental systems.

Members: Jacob Jones (RTNN, NC State, Chair), Liney Arnadottir (NNI, Oregon State), Bruce Clemens (nano@Stanford), Kristin Field (MANTH, U Penn), Mike Hochella (NanoEarth, Virginia Tech), Sherine Obare (SENIC, NC A&T and JSNN), Christopher Ober (CNF, Cornell), Heather Rauser (MONT, Montana State), and Bill Wilson (CNS, Harvard). In November of 2020, Gabriel Alonzo Montano (NCI-SW, Northern Arizona Univ.) joined the subcommittee.

5.2. Metrics and Assessment Subcommittee

The Metrics Subcommittee addressed the task of how to better quantify the impact that NNCI was having on the user community. This impact specifically includes only the core operations. The education and outreach and the SEI impacts are measured by other groups. During Year 3 the subcommittee developed a method to measure the impact of academics and their funding agencies. This was implemented near the end of Year 3 and reported in Year 4. The technique provided solid, quantitative measures. We have been told by colleagues at NSF that the first survey had a significant impact at the Foundation and is viewed as the "gold standard" for other networks. Unfortunately, the survey could not be conducted using Year 4 data and reported in Year 5 due to the COVID-19 pandemic.

During Year 5, the Metrics Subcommittee discussed how to better assess the economic impact of industry usage of the NNCI network. Obtaining quantitative data such as was done for academic users is a significant challenge as industrial users are far more reticent about sharing information about their projects, funding sources, and economic information. Mark Allen briefed the participants on discussions held in the Commercialization Subcommittee. They distinguished between input metrics (inventions, patents, etc.) and output metrics (products, jobs, income, etc.). The latter is preferred, especially as an area becomes more established, but they are generally more difficult to extract. Polling the experience of the metrics subcommittee members showed that even input metrics would be extremely difficult to achieve. The best case would be to restrict the data to input variables from small companies who are the most dependent on use of the facilities. It is not clear, however, that such data would be sufficiently complete to be useful. Ways to incentivize participation in such information gathering were discussed briefly, but may be difficult to implement in practice.

David Gottfried discussed the Canada National Design Network, which he recently reviewed. One metric they use to quantify their impact on industry is the number of highly qualified persons (HQP) created. They define an HQP as someone who has taken relevant courses. We might adopt a different definition if we choose to adopt such a metric. Other metrics they use include patents, licensed technologies, startups, companies moving to Canada, and collaborative activities. They report the same difficulty that we see; the response rate to questions to industry users is about 50%.

The subcommittee seems to be converging on a solution that depends largely on anecdotal information to measure industry impact. This could build on the current vignette-based approach where small companies, which are typically the most cooperative, tell their story and the vignettes are stored on the NNCI website. The subcommittee felt that an interviewer could ask a set of questions designed to extract an accurate picture of the NNCI impact. While on-site interviews would be ideal, remote interviews would be extremely cost effective and a single interviewer could provide better continuity. The goal would be to create a series that provides a flavor of the NNCI industry impact. Discussions were held on how this could be implemented.

Several subcommittee members also participated in the Metrics discussion as part of the 2020 NNCI Annual Conference. Hosted by Jan Youtie (Georgia Tech/SENIC), and David Berube (NC State/RTNN), the group held a lively discussion on the same topics, but also included a discussion of the impact of the network's education and outreach activities.

Members: Steve Campbell (Minnesota, Chair), Sanjay Banerjee (Texas), Christian Binek (Nebraska), Mitsu Muriyama (Virginia Tech), Daniel Herr (JSNN), David Gottfried (Georgia Tech/CO)

5.3. Global and Regional Interactions Subcommittee

The Global and Regional Interactions (GRI) subcommittee was formulated with the core philosophy that NNCI should coordinate with and leverage local, regional and global nano-initiatives. Some of the simpler reasons for the regional coordination comprise sharing good practices and feed off each other to enhance overall and especially local impact of nanoscience and nanotechnology activities.

GRI Activities: At the earlier stages of the subcommittee/meeting and Year 4 onwards, SHyNE shared and discussed local examples of regional coordination, such as “i-Nano”, which coordinates NU, UC (under SHyNE) and ANL CNM user program, coupled to regional interested parties (professional societies, industries).

The first iNANO meeting was held in Year 3 and the subsequent meeting was held in Spring 2019 (May 2, 2019) under the topic of “Quantum Information Sciences.” Further, SHyNE, in partnership with NU-MRSEC, sponsored the Midwest Microscopy and Microanalysis spring meeting at Northwestern University on “Microscopy at the Interface of Materials and Biology.” SHyNE also reached out to regional community and other colleges provide demonstrations, open-houses and extended visits to expose students and teachers to soft and hybrid nanostructures and the associated fabrication/characterization capabilities.

The subcommittee members appreciate and recognize that such shared experiences and activities can be extended to other regions and parts of NNCI Network. The ideas behind machine learning can be further developed with local context and coordination the idea of the predictive maintenance to detect equipment/facility problems before the failure occurs and prescribe remedies. This development will be shared with other NNCI sites.

In the later stage of NNCI program (since Year 4) the GRI subcommittee focused primarily on opportunities for in-depth and cross-training for NNCI staff across NNCI network. The NNCI staff have special expertise that spans a wide range of topics including specific fabrication or characterization equipment, nanoscience focus areas, education and outreach strategies and facility management and operations. The GRI committee plans to continue to seek ideas for professional development opportunities across the NNCI network. In post Covid world, providing travel and related support to NNCI staff will facilitate participation.

Future Plans: In the renewal cycle, the subcommittee will continue to refine and formalize staff exchange program. We will soon explore the role of offices of Corporate Engagement and Corporate Relations to expand the external user base by strengthening external partnerships with large established corporations and expanding our reach to non-traditional users. Finally, we will plan on expanding the discussion and ideas to include international collaboration and cooperation.

Members: Vinayak Dravid (Northwestern, Chair), Karl Bohringer (Washington), Bob Westervelt (Harvard), Chris Ober (Cornell), Bruce Alphenaar (Louisville), Debbie Senesky (Stanford)

5.4. New Equipment and Research Opportunities Subcommittee

The New Equipment and Research Subcommittee has been involved in 4 major initiatives during its five years of existence as part of the NNCI network. In Year 1, the subcommittee surveyed the 16 NNCI sites about *new research opportunities* and *the tools needed to support those communities*. The result of that survey can be found in pages 22-23 of the Coordinating Office Year 1 Annual Report. In Year 2, the subcommittee started a comprehensive biennial survey of each site to identify all the new pieces of fabrication and metrology equipment purchased during consecutive 2-year periods. This produced some very noteworthy results as shown in Table 5 below. In Year 5, the subcommittee was able to better analyze the data and came to the following interesting conclusions.

a) The 16 sites collectively added an amazing **632 new tools** in Years 1-4, worth a total of **$156 million**.
b) Of the 632 tools, 350 (55%) were for fabrication and 282 (45%) were for metrology (including imaging).
c) Although a similar number of fabrication and metrology tools were purchased (350 vs 282), **more than twice** the amount was spent on metrology tools compared to fabrication tools ($106M vs $50M).
d) The NNCI award funds were used for only **1%** of the total cost of these new tools.

Table 5: Summary of Equipment Purchased During NNCI Years 1-4

Time Period	Fab Tools	Cost	Metrology Tools	Cost	Total Tools	Total Cost	Tools Using NNCI Funds	Amt. Paid by NNCI
Years 1-2	177	$23M	117	$45M	294	$68M	14	$1M
Years 3-4	173	$27M	165	$61M	338	$88M	10	$1M
Total	**350**	**$50M**	**282**	**$106M**	**632**	**$156M**	**24**	**$2M**

The third major initiative of the committee involved the collection of NSF MRI proposals submitted by the 16 NNCI sites and an analysis of the success rate of the network. This initiative began in Year 4 and continues to this day. Table 6 presents a summary of all the MRI proposals submitted by the NNCI sites for the 2018 NSF funding cycle which had a proposal due date of Jan 2018 (with funding starting in Sept of 2018). In total the NNCI network submitted 23 proposals for a total of $18.5M dollars. Of those 23 proposals, 8 were awarded for a *success rate of 35%* (which compares favorably to NSF's commonly stated 25% success rate). These efforts brought in **8 new tools** into the NNCI network worth a total of **$9.2M**. This subcommittee will continue tracking our network's submission for the subsequent NSF MRI cycles and present those results next year.

Table 6: Summary of NSF MRI Proposals Submitted for the 2018 Cycle (January 2018 Due Date)

Site University	Tool Requested	Funding Amount	Tool Description	Status
KY MMNIN Univ. of Louisville	Deep Reactive Ion Etcher	$412,636	Tool used to etch patterns in silicon (will replace our failing 20yr old DRIE system)	Declined

KY MMNIN Univ. of Louisville	Multiscale Additive Manufacturing Instrument with Integrated 3D Printing and Robotic Assembly	$1,530,219	Development of an instrument for flexible multi-scale manufacturing of Micro/Nano Opto Electro Mechanical Systems (MEMS/NEMS) by precision robotic assembly and additive manufacturing.	Awarded
NCI-SW Arizona State Univ.	Inductively coupled plasma, time of flight mass spectrometer	$697,595	ICP-TOF-MS for single nano-particle analysis	Declined
NNF Univ. of Nebraska-Lincoln	Attocube	$550,000	Acquisition of a Low-Temperature High-Magnetic-Field Multifunctional Scanning Probe Microscopy System	Awarded
MANTH Univ. of Pennsylvania	TESCAN S8000G focused ion beam / scanning electron microscope	$923,077	Equipped with a cryogenic transfer system and a time-of-flight mass spectrometer (ToF-SIMS) to allow the development and application of novel characterization methods for soft materials, as well as to support a broad range of existing research.	Awarded
RTNN NC State Univ.	X-ray nanoCT system (e.g. Xradia 520 Versa High-Res 3D XRM	$695,668	The equipment uses high-energy X-rays for nondestructive, quantitative, three-dimensional characterization of material morphology and composition	Awarded

RTNN NC State Univ.	Anasys Instruments, NanoIR2-FS	$553,875	The equipment uses atomic force microscopy coupled with infrared tip-enhanced excitation for nanoscale mapping of infrared vibrational modes in materials.	Declined
CNF Cornell Univ.	Nanoscribe Photonic Professional GT	$385,304	It would enable the rapid prototyping of nano-, micro- and mesostructures with minimum feature sizes ranging from ~ 200 nanometers up to several micrometers	Declined
nano@stanford Stanford Univ.	Empyrean X-ray Diffractometer from PANalytical	$654,089	For Nondestructive Characterization of Energy Materials in Cross-Disciplinary Research	Declined
SHyNE Northwestern Univ.	eBL System	$994,000	Dedicated Electron-Beam Lithography	Awarded
SHyNE Northwestern Uniiv.	High energy Single Crystal XRD	$669,620	Single Crystal X-Ray Diffractometer	Declined
SENIC Joint School of Nanoscience and Nanoengineering	Illumina NextSeq 550	$498,929	High throughput DNA sequencing system	Declined
SENIC Joint School of Nanoscience and Nanoengineering	Zeiss Xradia 510 Versa	$1,108,126	3D X-ray Microscope for digital material design and engineering	Withdrawn
SENIC Georgia Institute of Technology	Hitachi Focused Ion Beam Instrument	$967,940	Focused Ion Beam Instrument for Nanoscale Machining and Manipulation of Diverse Materials, Structures, and Devices	Declined

CNS Harvard Univ.	Aberration Corrected Low Energy Electron Microscope (AC-LEEM) for high resolution spectroscopic imaging of surfaces	$1,380,679	To explore surface states and surface interfaces, by imaging (LEEM), diffraction (LEED) and spectroscopy, both optical and electron (PEEM & ES)	Awarded
MONT Montana State Univ.	200 kV cryo-electron microscope (Talos Arctica)	$2,421,477	Structural biology atomic models for macromolecular assemblies in mulitple confromations	Awarded
MONT Montana State Univ.	Inductively Coupled Plasma-Mass Spectrometer (ICP-MS)	$639,325	For characterization of microbial communities, elemental cycling, biocorrosion	Declined
NNI Univ. of Washington	Nanoindenter	$454,179	Acquisition of an advanced nanoindentation system for multidisciplinary research and training	Declined
NNI Univ. of Washington	Development of a Big Data Atomic Force Microscopy System	$999,999	The proposal seeks to develop a unique and powerful Big Data AFM to excite, acquire, and analyze multidimensional physical datasets for machine learning based adaptive AFM experiments on the fly.	Declined
NNI Univ. of Washington	Quantum matter at low temperatures	$665,000	Development of an instrument combining optics, transport and strain for studying quantum matter at low temperatures	Awarded
NNI	Biophysical imager	$390,785	Instrument Development: A nanoscale, unbleachable	Declined

Univ. of Washington			orientation and postiion sensor for biophysical imaging	
NNI Univ. of Washington	SQUID Magnetometer	$333,879	MRI: Acquisition of a Cryogen-Free MPMS3 SQUID (Semi-Conducting Quantum Interference Device) Magnetometer	Declined
NNI Oregon State Univ.	Probe Corrector for G2-200 Titan TEM	$597,156	The bolt on probe corrector will will re enable STEM (scanning transmission electron microscopy) after the probe corrector is added into the TEM column.	Declined
NanoEarth	None			
MINIC	None			
SDNI	None			
TOTAL		**$18,523,557**		

Finally, the fourth major initiative lead by the New Equipment and Research Subcommittee was a collection of "workhorse equipment" needed by the NNCI network. From the NSF MRI data presented above, we noticed it was very challenging to get workhorse equipment funded through federal programs such as the NSF MRI program, as such programs preferred to fund either the latest or next-generation technologies. However, there is still a large number of critical but "less glamorous" pieces of equipment that are required by the nanotechnology community and their users to perform state-of-the-art research. These include such aging tools as thin-film deposition equipment, etching systems, and scanning electron microscopes. Therefore, this subcommittee compiled a list of "aging workhorse tools" from each of the NNCI sites and forwarded them to Dr. Larry Goldberg for further discussion of how we might collectively address this urgent need.

Members: Kevin Walsh (Louisville, Chair), Jacob Jones (NCSU), Yuhwa Lo (UCSD), Mark Allen (Pennsylvania), Stephen Campbell (Minnesota), David Dickensheets (Montana State), Karl Bohringer (Washington), Vinayak Dravid (Northwestern), Oliver Brand (Georgia Tech, CO).

5.5. Entrepreneurship and Commercialization Subcommittee

The NNCI Commercialization Subcommittee is charged with understanding, promoting, assessing, and reporting on the commercial and translational impact of the NNCI Sites and the NNCI Network.

Over the past year, the subcommittee discussed the following items and made specific recommendations to sites.

- **Assessment of NNCI Site and Network Economic Impact.** How do we determine the economic impact of NSF's investment in our NNCI sites? Is there a set of quantitative metrics we can develop, analogous to the metrics associated with our clean room usage that we can use to determine this? If so, what are they? How can we report this to the Coordinating Office in a way that allows NSF to argue in favor of economic impact of NNCI investment?
- **Collection of commercialization best practices and 'success stories.'** What are our sites currently doing that is working well, and can we disseminate these successes network-wide? Can/should we add to our current scientific nugget collection, the collection of commercialization nuggets? If so, what format should we suggest to the sites? What examples should we suggest to the sites? (Spinouts? Successful SBIR grants? Other?)
- **Recommendation Generation.** What programs can we recommend to the Sites to be put in place to foster commercialization? Seed grants? Differential rates (which might be another way of saying seed grants)? SBIR support? Other? What information, potentially required in order to participate in these programs, can we ask from participants?
- **Educational Leverage.** Since we are universities, is there a way that we can connect existing or newly developed educational programs to commercial impact of the NNCI? Seminars, leveraging internal and external innovation programs, other? Can/should we involve our university tech transfer offices, even though the NNCI is aimed at external use? Can we leverage our trained students for more impactful industry engagement?
- **Network Synergy.** Is there a way that the network can be more than the sum of its parts when it comes to commercialization? If so, how?

We have recommended to the Network the following possible action items for sites to consider:

- **Assessment** – Our sites, and the network, have tremendous economic impact. How do we count? What are our metrics?
  - Job creation (self-reported count)
  - Number of startups utilizing your node
  - How much money have they raised / have you helped them raise (SBIR, investment, etc.)
  - Harder to identify a metric for this, but we should consider a metric for large companies as well, beyond just 'use'
- **Tell our story**
  - Collect a list of SBIR awards 'our' companies have won
  - Contact users and extract a 20-second video testimonial of how the facility has helped them
  - Facility directors reach out individually and get print testamonials (picture, quote, paragraph description)
  - Information 'push' – ping web/conventional media with results from our sites

- **Facilitization of our translational users**
  - Seed grant programs – could be transformational for 1-2 person organizations
  - Letters of support for grants; this could range from 'we are available' to detailed scientific support depending on the need and ask
  - Host a conference for small businesses in your local area to facilitate networking and opportunity
  - Assistance in grant preparation, expertise matching between faculty/staff and companies to assist in fundraising
- **Network greater than the sum of its parts**
  - Compile statistics and their nationwide impact
  - Facilitate our companies' transition OUT of our facilities and into foundries, which are nationwide; many of us have knowledge and expertise about local foundries that can be diffused throughout the network
  - Coordinate with I-CORPS Programs distributed among member sites
  - Coordinate career placement data and available positions in locations across the network to facilitate student placement in industry

Members: Mark Allen (Penn, Chair), William Wilson (Harvard), David Dickensheets (Montana State Univ.), Kevin Walsh (Louisville), Trevor Thornton (Arizona State), Yuhwa Lo (UC San Diego), Daniel Herr (JSNN), Nick Melosh (Stanford)

5.6. Building the User Base Subcommittee

The goal of the NNCI Building the User Base (BUB) subcommittee is to disseminate best practices for sites and NNCI as a whole to increase the user base, with particular emphasis on non-traditional users. A non-traditional user may be defined based on (1) research areas: those that do not typically use nanotechnology facilities; (2) demographic groups: women and under-represented minorities; (3) users from non-Research I educational institutions; (4) Small companies; and (5) K-12 students, community college students, and teachers.

In 2019, the BUB subcommittee conducted a survey among NNCI sites (https://ncat.az1.qualtrics.com/jfe/form/SV_6KHEowelx7ySgCh) to collect information on how sites are: (1) creating awareness among potential users to its facilities, (2) attracting new users to its facilities, particularly non-traditional users, and (3) increasing user diversity. 12 of the 16 NNCI sites responded to the survey.

The survey results were provided to all sites with the recommendation to implement as appropriate in their respective sites. The main conclusions of the survey were:

1. **Create awareness** primarily by directly engaging with potential users through seminars, courses, open houses, visits, education and outreach activities and by using collateral materials, website and other forms of communication.
2. **Attract non-traditional users** primarily by using seed grant programs, workshops/trainings, direct interactions and by partnering with research centers in non-traditional areas.

3. **Increase user diversity** by using seed grant programs, partnerships with HBCUs/MSIs, community colleges, research experience programs and outreach activities.

However, because of the current unprecedented COVID-19 pandemic, new/potential user (particularly external user) engagement, training, access and education and outreach programs have been severely curtailed. The subcommittee understands that sites were unable to test/implement the recommendations in any meaningful manner, other than creating awareness by virtual marketing. 2020 has been a challenging year to increase or diversify the user base. Most sites have used this time to create virtual training modules and are finding ways to effectively train users remotely, along with becoming more efficient in performing remote work. The BUB committee recommends that sites, if possible, implement site-appropriate recommendations in 2021.

Members: Shyam Aravamudhan (North Carolina A&T/JSNN, Chair), Nan Jokerst (Duke), Todd Hastings (Kentucky), William Wilson (Harvard), Gregory Herman (Oregon State), Andrew Cleland (Univ. of Chicago)

6. Working Groups

One of the greatest strengths of the NNCI network is the combined staff expertise of the individual sites. To leverage this expertise at the network level, the Coordinating Office initiated the formation of working groups composed of staff members from the NNCI sites. While these working groups meet primarily via phone and video conferences, they also have the ability to organize workshops and/or dedicated sessions at the annual NNCI Conference. We have created and are encouraging working groups (Table 7) in (1) important "network" responsibilities, such as environmental health & safety, vendor relations, or equipment maintenance, (2) particular process technologies, such as lithography or characterization (although these are only examples of possible topic areas), and (3) education and outreach activity. Most of these working groups began in Year 1, while new ones were added in Years 2 and 3. Additional topics can be added later on as interest and need arises, and some topics may sunset if importance wanes. In addition, some topical areas (EBL, Etch, and ALD) have begun working groups through grass-roots efforts of NNCI staff, with support from the Coordinating Office. The outcomes of these working groups can have many forms, including process recipes, recommendations to vendors for future equipment development, maintenance and training videos/webinars, recommendations on how to evaluate the safety of new processes, or direct recommendations for new users. Each working group has one or more dedicated coordinators selected from one of the NNCI sites, and staff participation in the working groups can be one measure for site performance. Participation in these working groups can also be considered as a mechanism for staff growth and career development or as support for an NNCI Outstanding Staff Award.

Table 7: NNCI Working Groups (2020)

Working Group Topic	Working Group Lead(s)
Network Support Working Groups	
Equipment, Maintenance, and Training	Meredith Metzler (Univ. Pennsylvania)
Vendor Relations	Charles Veith (Univ. Pennsylvania)
Environmental Health & Safety	Nasir Basit (Northwestern) Greg Cibuzar (Minnesota)
Technical Working Groups	
E-Beam Lithography	Devin Brown (Georgia Tech) Stanley Lin (Stanford)
Etch Processing	Vince Genova (Cornell)
Atomic Layer Deposition	Michelle Rincon (Stanford) Mac Hathaway (Harvard)
Photolithography	Pat Watson (Penn)
Imaging and Analysis	David Bell (Harvard)
Education and Outreach	
K-12 and Community	Jim Marti (Univ. Minnesota)

Workforce Development and Community Colleges	Ray Tsui (Arizona State)
Evaluation and Assessment	Quinn Spadola (Georgia Tech)
Technical Content Development	Angela An-Chi Hwang (Stanford) Maude Cuchiara (RTNN)
Societal and Ethical Implications	Jameson Wetmore (ASU)

During NNCI Year 5, sites or groups of sites hosted technical workshops related to fabrication, research, or education topics (see Section 9.1). The Coordinating Office encourages working groups to use these programs as opportunities for the working group to meet in a face-to-face setting, as a supplement to virtual discussions, although the pandemic restricted all such meetings to virtual formats this past year. When travel is available, the Coordinating Office provides financial support (up to $1000 travel funding each for 5 attendees) to encourage staff participation.

- NNCI ALD/MOCVD/MBE Symposium, October 3-4, 2019 (Harvard) – Attended by members of the ALD Working Group
- NNCI Etch Symposium, December 5-6, 2019 (Harvard) – Attended by members of the Etch Processing Working Group and the Equipment, Maintenance, and Training Working Group
- NNCI Facilities Recovery and Operations Workshop (virtual), April 21, 2020 (Stanford, Cornell)
- E-beam Lithography Webinar for NNCI Staff (virtual), April 23, 2020 (Stanford and Georgia Tech)
- NNCI Technical Content Development Webinar (virtual), May 1, 2020 (Stanford, Penn, NC State)
- SDNI-NNCI Education Symposium (virtual) with the theme "Integration of Nanotechnology Content with Current State-Wide K-12 Science Curricula: Challenge and Strategies", September 12-13, 2020 (UC San Diego)
- NNCI Etch Symposium (virtual), December 9, 2020 (Cornell)
- Advanced Lithography Unsymposium (virtual), January 21-22, 2021 (Stanford)

<u>Received reports of current working groups, as provided by the leads, are presented below.</u>

6.1. Equipment, Maintenance, and Training

During the past year, communication within this working group occurred through email exchanges, one-on-one phone conversations, and a face-to-face meeting coinciding with the NNCI Etch meeting at Harvard on Dec. 5-6, 2019. The group's effort remains focused on the collection and collation of common lore knowledge and information on troubleshooting and maintenance of vacuum and RF process equipment. Much of this information is not readily available in literature or online.

For the Year 6-10 period, the working group will re-focus on Equipment Maintenance, as the training aspects have been taken up by a different working group, and Jeremy Clark (Cornell) will assume the role of working group lead.

Members: Meredith Metzler (Penn), Mary Tang (Stanford), Bob Geil (UNC-Chapel Hill), Jesse James (UT-Austin), Jeremy Clark (Cornell), David Nguyen (Univ. Washington), Tony Whipple (Univ. Minnesota)

6.2. Vendor Relations

The Vendor Relations Working Group Report continued the processes started in 2019 to build a larger group with more points of contact at each lab based on their relations with the working group (Building Size and Responsiveness). Our second goal is to communicate our existence out to the suppliers as more suppliers leads to lower prices through competition, increase access to limited material stock, and access to material we might not even know exists. The final focus of the group is to improve communications between labs which can improve sustainability, efficiencies, and rapid increase in innovation.

The number of schools within the working group is now 12 with the addition of Minnesota, Stanford, UCSD and Arizona State. The group now has 25 contact names. There are currently 14 vendors providing special discounts to NNCI-affiliated universities. Current projects of the working group include:

- Discounted XeF_2 savings
- Washable face masks
- Vacuum pumps savings between 20-50%
- Valex joined as a lower cost supplier of high quality stainless steel for gas systems.
- Garment cleaning service and improved safety systems for cleaning. This is an open invitation for labs to use during contract negotiation.
- Wipes, disinfectant and surgical masks. This project is still going on with all information being sent to the working group contacts. Presently helping startup surgical mask manufacturer to support NNCI.

Members:

Name	**Affiliation**
Trevor Thorton	Arizona State University
Ron Olsen	Cornell University
Jeremy Clark	Cornell University
James Reynolds	Harvard University
Julia Aebersold	University of Louisville
Michael David Martin	University of Louisville
Curtis P McKenna	University of Louisville

Gregory Cibuzar	University of Minnesota
Heather Rauser	Montana State University
Bernd Fruhberger, PhD	UC San Diego
Dr. John Tamelier	UC San Diego
Matthew Hull	Virginia Tech
Masoud Agah	Virginia Tech
Bill Reynolds	Virginia Tech
Mary Tang	Stanford
Phil Himmer	Stanford
Ai L Tan	Stanford
Charles R Veith	University of Pennsylvania
Maria Huffman	University of Washington
N Shane Patrick	University of Washington

6.3. Environmental Health & Safety

Year 5 Activities: There have been no activities of this group during this year because of Covid-19 related issues.

Suggested Activities for next year:

- Effects of Covid-19 protocols on environmental health and safety issues
- Effects of step-wise relaxation of Covid-19 protocols
- A look in to post-Covid safety

Members:

Name	Affiliation	Safety Expertise
Nasir Basit (Co-lead)	NUFAB Northwestern University	Microfabrication equipment safety, facility setup and growth
Greg Cibuzar (Co-lead)	Minnesota Nano Center University of Minnesota	Facility management and safety protocols
Philip Infante	Cornell Nanoscale Facility Cornell University	Lab safety and safety related infrastructure
Robert Rose	IEN Georgia Tech	Lab safety, policies & procedures, emergency response

Mark Walters	Shared Materials Instrumentation Facility (SMIF) Duke University	Research facility management, cleanroom fabrication, XPS, SEM, TEM
Andrew Lingley	Montana Microfabrication Facility Montana State University	Facility management, safety training, procedures, and documentation

6.4. E-Beam Lithography

We are an active working group that hosts at least two meetings per year. Although 2020 has been a difficult year for all, the EBL WG has several highlights and contributions to the NNCI community including leadership development of a new co-chair, increasing user response/attendance by 100%, an NNCI wide seminar, and the completion of an EBL brochure highlighting the NNCI EBL tool capabilities and national sites.

In a December 2019 EBL WG meeting, Devin Brown (Georgia Tech) asked the group for interest in taking on a leadership role of the EBL WG. Stanley Lin (nano@stanford) answered that call and began as co-chair beginning January 2020. The co-chair position was determined most beneficial for training and support. The double-team effort has brought accountability and encouragement throughout the year for jobs well done and ideas for improvement. As a result, we've increased our WG attendance, co-led an NNCI seminar and added a new advertising project.

In December 2019, our attendance was around 5-6 members. Our next meetings in March 23 and May 19 attracted about 10-12 members. We came together for methods of engaging users during the COVID-19 pandemic and plans on how to restart research. We also updated all of the site contacts by adding new members and removing non-responsive members that have moved from their roles. As a result, this led to an idea of creating an EBL WG brochure as described below.

On April 23, 2020, Devin and Stanley co-led the first NNCI wide seminar about the EBL WG. The topics presented were the problems the EBL community faced with the popular negative ebeam resist hydrogen silsesquioxane (HSQ) due to its limited supply chain from manufacturer Dow Corning. Devin presented data from an alternate provider showing DisChem's HSiQ provides a quality replacement. Stanley presented on a newly acquired EBL system at nano@stanford and its impact among the NNCI site and users by creating new capabilities and expanding research opportunities.

Lastly, Devin and Stanley started a project to promote the different EBL tool capabilities and locations across the NNCI network. The brochure highlights each site by providing a photo, specifications, description, and staff contact for more information. It also contains six research highlights with quality photos and descriptions of the research from various NNCI tools. The project has a planned completion date of December 2020 for distribution January 2021.

The plan for 2021 is to roll out the EBL WG brochure. We also plan to do at least two additional online meetings. Pending COVID-19 restrictions, we may plan an in-person gathering before or after a large EBL-related conference.

Members:

NNCI Site	Institution	Tool Owner
SENIC	Georgia Tech	Devin Brown
SENIC	NCAT/UNCG JSNN	Steven Crawford
RTNN	NC State	Greg Allion Alternate: Saroj Dangi
RTNN	Duke	Primary: Talmage Tyler Backup: Jay Dalton
RTNN	UNC Chapel Hill	Amar Kumbhar Bob Geil
MANTH	Univ. Penn	David Jones Hiro Yamamoto
CNS	Harvard	Yuan Lu Backup: Jiangdong Deng
CNF	Cornell	Alan R. Bleier Backup: Amrita Banerjee Backup: John Treichler
KY MMNIN	Univ. of Kentucky	Brian Wajdyk
SHYNE	Univ. of Chicago	Peter Duda
MINIC	Univ. of Minnesota	Kevin Roberts
NNF	Univ of Nebraska-Lincoln	Anandakumar Sarella
TNF	UT Austin	Sarmita Majumder
NCI-SW	Arizona State Univ	Kevin Nordquist
SDNI	UC San Diego	Maribel Montero Backup: John Tamelier
nano@stanford	Stanford (SNSF Spilker)	Rich Tiberio Stanley Lin
NNI	Univ. of Washington	Shane Patrick

6.5. Etch Processing

The objective of the Etch Working Group is to provide an interactive forum for etch personnel from all the NNCI participating sites. This interaction includes but is not limited to the sharing of information regarding etch capabilities, established etch processes, processes under development, maintenance issues, preventative maintenance, baselining efforts, equipment modification, and the acquisition of new etch tools/technologies. Identification and documentation of the broad and complementary etch tools within NNCI allows us to effectively process wafers within the network to meet the diverse specifications of individual projects, and to provide back-up systems within the network to avoid any extensive downtimes in user processing. In addition to the above referenced tool set listing, we have composed a listing of common and various plasma etch technologies along with the network sites and specific platforms that support those processes. This document of supported processes will also assist users who seek etch process capabilities when requirements cannot be satisfied at a specific university.

This year due to COVID-19 travel restrictions, the working group held a virtual workshop via Zoom on December 9, 2020. The workshop was very well attended with 35 participants from within and outside of NNCI. The NNCI sites in attendance were Cornell, Harvard, Stanford, UCSD, Minnesota, Arizona St., Louisville, Chicago, UNC-Greensboro, U. Pennsylvania, Virginia Tech, and U. Washington. Non-NNCI sites in attendance were Princeton, Yale, U. British Columbia, Michigan, MIT-Nano, Brown, Caltech, UC-Berkeley, and MIT-Lincoln Labs. The workshop was dedicated to the important topic of chamber conditions and how these conditions can directly affect etch process outcomes such as rate, selectivity, uniformity, and run-to-run consistency. Presentations on various etch processes and associated chamber conditions were given by technical staff from Cornell, Harvard, and Stanford. These include the following:

1. Chamber wall monitoring and cleaning strategies for Cl2 and HBr based silicon etching (V. Genova, Cornell CNF)
2. Chamber cleaning and conditioning for Si DRIE (L. Xie, Harvard CNS)
3. Chamber conditioning for III-V etching (U. Raghuram, Stanford SNF)
4. Chamber wall monitoring and cleaning strategies for metal etching (V. Genova, Cornell CNF)
5. Chamber cleaning for diamond etching (L. Xie, Harvard CNS)
6. Post etch wafer cleaning methods (U. Raghuram, Stanford SNF)

The current communication paths include a LinkedIn-NNCI Etch Group and an NNCI Etch listserv, where etch questions can be posed to the NNCI etch technical staff. There is also an Etch Working Group page on the NNCI website (https://www.nnci.net/working-groups). This page contains a news blog where announcements can be made as well as postings of interest to all etch personnel. Currently the page contains links to workshop and symposium presentations, as well as an NNCI etch tool listing and the new NNCI etch capabilities listing.

The plan for 2021 is to hold an on-site symposium in October at the University of Pennsylvania. This will be a two day event with invitees from within and outside of NNCI, including a vendor exhibit. The event will be co-organized by members from Cornell, Harvard, Stanford and Penn.

Members:

Cornell University (V. Genova, T. Pennell, J. Clark)
Harvard University (L. Xie, K. Huang)

Stanford University (U. Raghuram)
Georgia Institute of Technology (T. Averette, H. Chen, M. Thomas)
University of North Carolina (B.Geil)
UNC Greensboro (Q. Dirar)
University of Louisville (E. Moiseeva, J. Beharic)
University of Minnesota (T. Whipple, P. Kimani)
University of Nebraska (J. Hua)
University of Pennsylvania (M. Metzler, H. Yamamoto)
University of Texas-Austin (J. James, S. Majumder)
University of Washington (M. Morgan)
Arizona State University (S. Ageno, S. Myhajlenko)
UC San Diego (X. Lu, D. Prescott)
Montana State (J. Heinemann)
Virginia Tech (D. Leber, M. Hollingsworth)
U. Chicago (P. Duda, S. Kaehler)

6.6. Atomic Layer Deposition

The NNCI ALD Working Group is co-lead by Malcolm Hathaway from Harvard University and Michelle Rincon from Stanford. The ALD Working group met 15 times (approximately bi-weekly) throughout the year to discuss staff concerns and best practices regarding the COVID shutdowns as well as re-starts. The forum has been a valuable place for group members to exchange ideas and solutions for safe operations and training specifically around ALD as well as lab operations in general. We also were able to start a project that is part of a long-term vision for online training materials. The goal is that these animations would be used by staff during user training sessions as well as reside online as a reference and resource for researchers who are interested in depositing films. These animations are intended to not just teach researchers about what tools do, but to help highlight the pros and cons of different deposition methods and how the topography of their substrates should influence the methods they choose.

Members:

Location	NNCI Site	Name
Cornell	CNF	Vince Genova
Univ. of Louisville	KY MMNIN	Julia Aebersold
Univ. of Pennsylvania	MANTH	Meredith Metzler
Georgia Tech	SENIC	Gary Spinner
		Ben Hollerbach
		Hang Chen
Virginia Tech	NanoEarth	Don Leber
Arizona State Univ.	NCI-SW	Stefan Myhajlenko
Univ. of Washington	NNI	Darick Baker
		Fred Newman
North Carolina State Univ.	RTNN	Bob Geil
		Jun Yan
Northwestern Univ.	SHyNE	Anil Dhote
Stanford Univ.	nano@stanford	Michelle Rincon

Univ. of Texas	TNF	Sarmita Majumder
Harvard	CNS	Mac Hathaway
University of California-San Diego	SDNI	Xuekun Lu
		Bernd Fruhberger
Univ. of Minnesota	MINIC	Tony Whipple
		Paul Kimani
Penn State		Bangzhi Liu
UC Santa Barbara		Bill Mitchell
Univ. of Michigan		Matt Oonk

6.7. Photolithography

The NNCI Photolithography Working Group is composed of representatives from 12 NNCI sites, plus UC Berkeley, and is charged with sharing photolithographic techniques and processes with member sites and the larger research community.

The working group held a virtual meeting in August 2020, using a format similar to the previous years' in-person meetings. Each site first presented a short overview of the operational status of their fabrication facilities and of any new equipment they have acquired. The discussion then turned to sharing ideas about conducting one of the more challenging professional roles that nanofabrication research staff had to face in the pandemic - how to safely train new users on the operation of the complex lithography tools in their labs.

Representatives from Cornell, Stanford, and Penn described their efforts to create detailed equipment training videos for steppers and direct-writers, and other techniques to ensure that new researchers had been thoroughly prepared to use these tools with a minimum of close contact with others. Stanford volunteered to compile links of these training videos to help each site to use as-is or use as a template to develop their own. These video links were shared with the Training and Technical Content Development Working Group who are creating a database of training materials for all types of cleanroom tools.

Members:

Pat Watson, Penn
Allison Dove, UC-Berkeley
Ben Hollerbach, Georgia Tech
Garry Bordonaro, Cornell
Brian Wajdyk, Kentucky
Mark Brunson, Washington
Shivakumar Bhaskaran, Stanford
Curtis McKenna, Louisville
Christine Yi-Ju Wang, Harvard
David Jones, Penn
Emily Beeman, UC-Berkeley
Eric Johnston, Penn
Mark Fisher, Minnesota
Guixiong Zhong, Harvard
Jiong Hua, Nebraska
Jean Nielsen, Washington
John Tamelier, UCSD
Paul Kimani, Minnesota
Gyuseok (Q) Kim, Penn
Mahnaz Mansourpour, Stanford

6.8. Imaging and Analysis

While the Imaging and Analysis working group had planned to meet at the annual MSA meeting in 2020, this has been postponed due to the COVID-2 pandemic. A virtual meeting is planned for March 2021 to kick start the group discussion.

Members:

Site	Location	Contact
NanoEarth	Virginia Tech	Elizabeth Cantando
SDNI	University of California-San Diego	Ryan Nicholl
RTNN	NC State	Phillip Strader
TNF	University of Texas at Austin	Sarmita Majumder
MONT	Montana State	Recep Avci
nano@Stanford	Stanford University	Tobu Beetz
NCI-SW	Arizona State University-Eyring Materials Center	Shery Chang
MANTH	University of Pennsylvania	Matthew Brukman
NNF	University of Nebraska-Nebraska Center for Materials and Nanoscience	Lanping Yue
SHyNE Resource	Northwestern University	Ben Myers
CNS	Harvard University	David Bell

6.9. K-12 Teachers/RET, Students, and Community Outreach

The working group met three times since the last NNCI annual conference, in September and November of 2019 and May 2020. The working group attempts to meet regularly on the fourth Wednesday of every other month; no meeting was held in January, and widespread school closings prevented a meeting in March 2020.

Main activities during the past year included:

A. Ongoing planning for the NNCI web site Education Pages. Over the past two years this working group has discussed several ways to develop and expand the education content of the NNCI web site. Members have explored ways to easily aggregate and add new nanotech educational content to the site, and have looked at methods employed by other educational archive sites. This year, it was decided that the working group should primarily be an advocate for an improved web site, instead of getting involved with detailed content. The group began regular reviews of the Education Page content with the goal of offering suggestions for upgrades to the Coordinating Office. Among the suggestions:

- Use more images, less text
- Enable full search ability of content (this has been implemented)
- Use the NNCI Education web page as a portal to material on nanoHUB
- Add a News feature to the Ed page, which could feature what sites are up to with education and outreach programs

- To make the website more useful to teachers, have some teachers review the site and get their input on what they'd like to see.
- Drive more web traffic to the NNCI Education page by marketing it more during our outreach events across the network (this was curtailed by the end of live programming in March).
- Change the title of the Education page--the present title of the page, "Learn", is not very descriptive.
- Include video content on the activities page that would address some aspect of nanoscience in an engaging way (much of this has been developed and is available elsewhere). Could be on a technical topic or be instructions for the activities. This could be an opportunity for more collaboration between sites.

B. Examining Education and Outreach program evaluations:

- During the NNCI renewal proposal site visits, several sites received strong suggestions from reviewers that a more comprehensive evaluation program for E&O programs was needed. Some of these comments stated that sites should carry out long term tracking of students to judge the impact of E&O programs.
- Education Coordinator Quinn Spadola and the working group grappled with this question and attempted to identify evaluation strategies that could be adopted by individual sites and Network-wide.
- Several sites reported their efforts, successes, and failures.
- Sites were reminded to review the material on evaluation already developed by NNCI and NNIN and available on Dropbox
- The group agreed to continue working on evaluation planning and to share their results with each other.

C. Review of teacher training programs:

- The institutional shutdowns necessitated by the COVID-19 pandemic forced a wholesale pause of summer teacher training plans.
- The group discussed what sites would be doing this summer and beyond, sharing strategies for pivoting to virtual versions of teacher training and E&O programming in general.
- Sites are now engaged in expanding their virtual program offerings.

Members: Jim Marti, Chair (University of Minnesota), Maude Cuchiara (NC State University), Terese Janovec (University of Nebraska), Dan Ratner (University of Washington), Angela Hwang (Stanford University), David Mogk (Montana State University), Yves Theriault (UC San Diego)

6.10. Workforce Development and Community Colleges

This working group has been requested by the Evaluation and Assessment working group to help in its plans to conduct surveys for non-REU related undergraduate internship programs. The task will be to survey industry users and other mentors/supervisors of the interns. This will serve to evaluate performance of the interns and seek recommendations on how the sites can better prepare their student workers. Efforts to create the surveys are underway.

Regarding the potential collaboration with SEMI on workforce development for the electronics industry, no additional discussions have taken place this project year as SEMI concentrated on completing their initial competency models for various types of positions. This opportunity to collaborate will continue to be pursued during the renewal period of the NNCI (Years 6-10).

As for other activities related to workforce development and community college engagement during the past project year, the following listing contains highlights from a number of NNCI sites. The list is not meant to be comprehensive; still it is illustrative of the breadth and diversity in effort across the network in spite of limitations presented by the COVID-19 pandemic since the spring of 2020.

MANTH: Hosted a cleanroom window-tour for students interested in the new Intro to Nano course at the Community College of Philadelphia (CCP). Students that eventually enrolled were given hands-on experiences in the Quattrone Nanofabrication Facility. CCP's Dean and staff also participated in discussions on MANTH's NNCI renewal proposal.

MINIC: Students from St. Paul Community and Technical College completed 1-2 semester internships at the Nano Center. Two interns were trained to synthesize nanoparticles and apply them to cells, while the third student received cleanroom training for making and transferring graphene films.

MONT: Two site labs have hired undergraduates to work part-time. They receive in-depth, on-going training on lab instruments, and several have gone on to work for local companies. Continued working with Montana Manufacturing Extension Center to provide outreach to manufacturers to help grow and innovate local industry.

nano@stanford: Three students from neighboring CCs (College of San Mateo, Foothill College) completed their internships at SNF and SNSF. They will transfer to UC Berkeley, San Jose State University, and Cornell for their 4-year degrees.

NanoEarth: Activities conducted by Virginia Tech staff included a Confocal Raman Imaging Workshop, a short course on Contaminants of Concern, and mentoring for Health Science & Technology Commercialization Fellows program. The site also launched the NanoTechnology Entrepreneurship Challenge – Multicultural and Underrepresented Nanoscience Initiative (NTEC-MUNI), in which one of the student-led teams was from Fayetteville State University, an HBCU. Its annual professional development workshop for high school science teachers was also reimaged into a month-long, virtual event throughout July.

NCI-SW: The site continued its collaboration with Rio Salado College (RSC) by conducting at Arizona State 9 different labs that are part of the curriculum for RSC's AAS degree in Nanotechnology. A total of 10 such lab sessions were conducted during the past project year for 7 students. The RSC program now has a total of 12 graduates, with 3 furthering their studies and at least 5 known to have found tech jobs.

NNF: Eight XRF lab sessions were held for 48 students from Central Community College (CCC). Another 30 were in 6 SEM lab sessions. Fifteen CCC under-grad students were also trained as hosts for the Travelling Nano Exhibit. NNF also partnered with CCC to host a Nano Workshop for 60 rural junior high girls, and a Nano Teacher Workshop for 30 rural schools.

RTNN: The site held its annual nano workshop for CC educators that included running processes in the cleanroom for the 14 attendees. It had a booth at the Fall STEM Day of Wake Technical Community College showing a photolithography demo. Portable SEM was incorporated into Biology Lab and Physics II lab courses at Durham Technical Community College, and STEM courses at Catawba Valley Community College, totaling 105 participants.

SDNI: Six remote SEM sessions were held for CC students and teachers at Miramar College, Imperial Valley College (IVC) and Southwestern College (SWC), totaling 133 participants. The site also hosted 11 students from SWC for hands-on activities involving quantum dots and graphene, and 65 students and teachers from IVC for an educational tour of site labs.

TNF: The site held a workshop on nanotechnology and robotics, and provided lab tours for STEM Explorer students from Austin Community College. There were also discussions with the students about careers in nanotechnology. It also hosted a Girls Day for 250 K-12 students.

Members: Ray Tsui, Chair (NCI-SW), Maude Cuchiara (RTNN), Kristin Field (MANTH), Angela Hwang (nano@stanford), Terese Janovec (NNF), Dave Mogk (MONT), Tonya Pruitt (NanoEarth), Dan Ratner (NNI), Trevor Thornton (NCI-SW)

6.11. Evaluation and Assessment

Following a request from education coordinators, interested sites met to discuss education and outreach evaluation feedback received during the renewal process. Some sites were struggling to determine which activities should be assessed and the best instruments for the type of activity. Evaluators in the network posted both a logic model and an impact chart in the shared NNCI Evaluation and Assessment Working Group folder to help coordinators better work through if an activity should be assessed and the best method for it. The impact chart helps coordinators determine the types of outcomes they could aim for based on the amount of time spent with participants. The logic model documents help guide them through the types of questions and outcomes they should measure.

After meeting with the workforce development working group lead, the working group broadened the scope of the survey they plan to distribute to sites. Draft surveys for student assistants and interns in facilities (non-REU students) and their mentor has been developed by Mary White (NCI-SW). It is currently out for comment to the working group. The group anticipates sharing it with sites early in 2021.

Members: Quinn Spadola, Chair (SENIC-GT), Ray Tsui (NCI-SW), Carolyn Plumb (MONT), Tonya Pruitt (NanoEarth), Ana Sanchez Galiano (KY MMNIN), Mary White (NCI-SW), Dan Ratner (NNI)

6.12. Technical Content Development

The Technical Content Development working group consists of three NNCI sites: RTNN, MANTH, and nano@stanford. Our goal is to develop and share educational materials to support existing users, potential users, and non-traditional users to lower the barriers to entry in our facilities and improve foundational knowledge. Two sites, RTNN and nano@stanford, have continued to create online resources to support the education of users as well as growth of the user base, while MANTH has focused on creating resources to be shared on their online repository.

Over the course of the past year, the working group has created a catalog of existing training videos and background information on tools, leveraging the network with educational content and resources, and developed guides on creating online resources (media production, copyright, managing digital content, etc). The working group also led a webinar focused on how to develop and disseminate online content, specifically for training, in May 2020. We have also developed a toolkit to help NNCI sites develop their own training content, as well as a library of source materials that will be shared across NNCI.

RTNN continues to maintain their Coursera course. More than 20,000 people have engaged with the course and over 5,500 have completed all course materials. The course has maintained its high ratings with 4.8/5 stars on Coursera. We supplement Coursera's evaluation by surveying all learners who complete the course. >89% of respondents noted that they were likely or very likely to recommend the course to others. 79% of respondents noted that they had a better knowledge of the capabilities of RTNN's facilities. Since the pandemic, RTNN has made introductory and training videos that are housed on individual facility YouTube channels. RTNN will continue producing new training videos to enable new users to learn how to operate equipment safely during the pandemic. We will also expand our Coursera course by creating new application-focused content (e.g. creation of a microfluidic device).

Nano@stanford has been continuing to add and improve the educational training modules on Lagunita (edX based platform) that will be open and free to use by the public, similar to RTNN's Coursera course and training content. The platform moved to edX in 2019, which has seen significant growth in usage during the pandemic. We have implemented new content, such as a full XPS remote training, lithography training, and soon an electron beam lithography training module. We hope to continue to enhance the collaborative nature of NNCI and universally support sites with their respective training. It is clear that online training is a pivotal part of all sites, especially due to these unprecedented times.

Members: Angela Hwang, Chair (Stanford), Maude Cuchiara (RTNN), Eric Johnston (Penn)

7. NNCI Network Promotion

7.1. Marketing and User Recruitment

Marketing and user recruitment strategies vary widely across the NNCI network, based on particular site local and regional needs and situations. During the January 2017 NNCI Conference, a breakout session on marketing and user recruitment identified a number of strategies as a way to help sites develop their plans to increase facility usage and those were provided in previous reports. A follow-up breakout session on this topic was held at the October 2019 NNCI Conference and the updated discussion is provided below. While much of the focus is on recruiting new external users, many of the approaches and best practices apply to internal users, particularly non-traditional users, as well. Some sites have staff with external user engagement as a primary job responsibility, while other sites do this on a more ad hoc basis. Previous NNIN sites generally seem to have a more mature marketing strategy based on previous trial and error, although most new sites have significant pre-NNCI experience with external users as well. Challenges to any marketing strategy include the often significant time lag between when a certain marketing tactic is employed and when actual usage may happen. This can make it particularly difficult to gauge the effectiveness of various approaches. Certain NNCI sites also possess geographic advantages and a built-in clientele of tech companies, start-ups, and other academic users, while other sites need to work hard to engage non-traditional users. Finally, IP concerns and overly burdensome access agreements can often discourage new users.

User Marketing and Retention Breakout Session (NNCI Annual Conference, October 25, 2019)

<u>Discussion:</u>

Facility managers were surprised to hear over and over users comment, "I didn't know this (*fill in the equipment/capability)* existed on campus." As well as ignorance to facility existence!

We should be doing continuous internal marketing including:

- Brown bag seminars
- Posters around campus
- Departmental seminars throughout institution
- Take 10 minutes in departmental faculty meetings
- Facility tours
- Send info posters to pertinent student groups

There was a discussion on billing and how sites handle delinquencies:

- Pre-payment for start-ups with no track record

Sites had some of the same challenges that impact usage:

- Needed equipment upgrades
- Down time (opportunity to refer other NNCI sites)
- Space needs
- Staff retention/turnover
- Cap rates on student time in facility. PIs will send only one student to reach the fee cap quickly when more students could be trained in a facility

- Some sites had reviewer comments to target diverse users in specific community groups (Hispanic/Latino, Native American).

Sites also had some very unique challenges:

- How to be sensitive to a neighboring facility that is 30+ years outdated and struggling? How can this site be complimentary and not competitive?
- Paperwork process for external users that can take 2-4 months before external users can get in the facility.

Ideas for increasing external users:

- Some sites have a position that at least a fraction of FTE is devoted to external user development.
- Give and go to talks at industry symposia
- Join local industry groups, attend their meetings
- Focus on SBIRs; find recent awardees; incubate current SBIR grantees to apply for addition funding and have them write the facility into proposals.
- Give and attend seminars/brown bags at neighboring institutions, community colleges
- Facility open houses for industry/Industry summits your institution
- Watch key accounts and investigate any major changes in usage. *Ex: Why hasn't company XYZ been for the last several months?*
- Find business incubators and see if your institution has something similar
- Short courses (both for internal and external users)
- Alumni associations donor resources (funding)
- Talk with deans and department heads
- Undergraduate interns from other institutions paired with research at your institution
- Contact economic development offices, manufacturing extension services, chamber of commerce
- Note that building these external relationships takes time and persistence

<u>Action Items:</u>

- A user marketing/retention working group would useful.
- Sites should post APPLICATIONS of tools on websites, which would make it easier for potential user to understand what they could accomplish rather than just a list of tools.
- We should share examples of "unusual/out of the daily scope" usage and applications so sites could be thinking about how to approach users/departments that are not normally in our facilities. For instance, MONT has new users from the entomology and art departments.

The consensus of the sites is that the role of the Coordinating Office in marketing and user recruitment efforts should include the following:

1. *Represent the network at national conferences.* While normally the Coordinating Office would have hosted a booth at conferences such as TechConnect or MRS, this activity was suspended in 2020 due to pandemic-related travel restrictions.

2. *Provide an NNCI website with tools and expert databases.* At the January 2017 NNCI Conference, there was significant discussion about the website and a desire to present a more applications-focused user experience. During the first year of its existence (2017), the website contact forms generated approximately 25 inquiries related to becoming a new user, education/outreach, or other general information, and this increased to 75 inquires during 2018-19 but decreased in 2020. Any potential users are referred to NNCI sites for follow-up, and we have recently begun tracking of outcomes in order to assess the efficacy of this user recruitment mechanism. More discussion of the website is provided below.
3. *Create an NNCI email list.* During 2017, a listserv was created for subscription by all interested NNCI site staff to share information on site activities, as well as provide another mechanism for sites to solicit assistance on technical and user support matters. Currently there are more than 120 subscribers to this email list with more than 70 announcements or discussions initiated in this forum yearly. Furthermore, an option to create an email list for individual working groups was offered, and both the etch and lithography groups have used this successfully. Other working groups have their own lists, not created by the Coordinating Office.
4. *Create an NNCI newsletter for periodic distribution by all sites.* This is currently under discussion.

7.2. NNCI Website

During the first year of the NNCI Coordinating Office, one of the main activities was the creation of a web portal (www.nnci.net) to provide a comprehensive list of tools and experts available within the network for both user recruitment and support. The design of a new, comprehensive website was predicated on the desire to accommodate the different needs of users, potential users, the public, and NNCI staff. The design concepts and structure of the website were reported in detail in the Year 1 report with additional upgrades made during Year 2. Additional features and content have been added during Years 3-5.

The NNCI Introduction Video was produced at the end of 2017 and publicly released in February 2018. It was posted to the NNCI home page with the 2019 upgrade. The YouTube URL is https://youtu.be/72ZXh-ESt3U. As of Dec. 31 2020 the video had been viewed more than 1500 times.

Since the original launch new content has been uploaded regularly including:

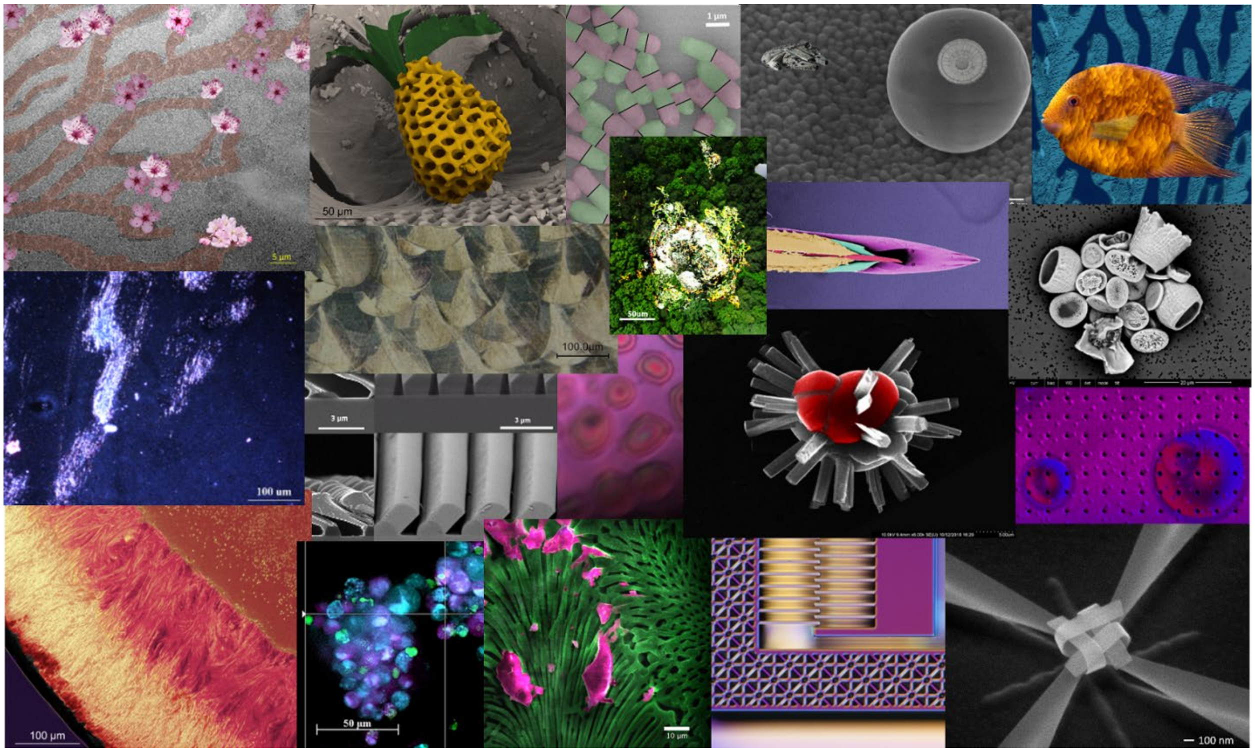
1. News items on the blog
2. NNCI Annual Reports
3. NNCI Annual Conference agendas and presentation materials
4. NNCI On the Road (list of upcoming NNCI site presence at meetings and conferences)
5. K-16 Educator Resources
6. Technical Resources, including Remote Work Contractors and Seed Grant Opportunities.
7. Home page news spotlights
8. Backend improvements, changes, and bug fixes

In particular, during the past year (Year 5), the following improvements and upgrades were made to the NNCI website:

1. Events page: This page was created as part of the staff exchange program (Section 9.2), to provide a centralized listing of events held by NNCI sites that staff may attend. When travel was restricted in March 2020, all of these events were either canceled or converted to online formats.
2. Tools and experts updates: In 2019 each NNCI site was asked to provide a list of experts and tools on the website, to reflect changes since 2016. During 2020, all of this information was updated.
3. Education and Outreach pages re-design: Previously dispersed content was grouped into a single page "Resources for Educators" and a permanent page for the "Plenty of Beauty at the Bottom" image contest was added.
4. Resources for Educators page: This new page contains a searchable K-16 curriculum materials database (created using the existing content), opportunities at NNCI sites, virtual/at home resources for teachers and parents (created in response to the COVID-19 pandemic), demo guides, information sheets, and reference sheets.
5. "Plenty of Beauty at the Bottom" page: A new page for the 2020 image contest and winning entries. This will be archived and used to host subsequent contest images as well (see more information below).
6. Resources pages re-design: Following the format of the Education pages, this material was grouped into categories of Technical Resources (working groups, computation, online training materials, research communities), Other Resources (adding regional networks to the previous content), News, and Events
7. Site page updates: After the successful renewal funding was announced, all sites were requested (Nov. 2020) to provide updates to their site information reflected in their proposals. This can include changes to leadership and staff, partners, facilities, access procedures, and other information.
8. Regional Network page: As described in Section 9.2, several NNCI sites have developed regional networks of facilities for collaboration and mutual support.
9. Research Community page: This new NNCI initiative is a new, external facing network-wide activity and is described in more detail in Section 9.2.

Since December 2016, the website contact forms have received nearly 250 inquiries (1 per week on average). In all cases these were forwarded to the appropriate site for action on technical requests, or to the Coordinating Office education and outreach director for answering questions related to those matters.

In celebration of National Nanotechnology Day (October 9, 2019), the NNCI website hosted the first "Plenty of Beauty at the Bottom" image contest. Images featured in this contest were produced at one of the 16 NNCI sites during the previous year. This contest was repeated in 2020, with public voting open during Oct. 5-12, 2020 in categories "Most Stunning", "Most Unique Capability", and "Most Whimsical". These images (and winners) are now archived as part of the Education pages on the website.



Google analytics for www.nnci.net indicate that in calendar year 2020 there were more than 46,500 visitors to the website, a 30% increase over the previous year. A large spike in visitors was observed in October, primarily to participate in the image contest voting. For the year, 90% were new visitors with 50% from the United States. There were more than 104,000 page views, which is a 10% increase from the prior year. The average session duration was slightly less than 2 minutes, with an average of 1.8 page views/session, a small decrease compared to 2019. During this time period, the top ten pages visited are shown in Table 8 below. Significant differences this year include large numbers of views of education-related pages ("what is nano" and "how small is nano" pages), consistent with previous year's observations, and decreases in views of the image contest and REU pages (likely due to cancellation of the 2020 program).

Table 8: NNCI Website Page Visits (2020)

Page	# Pageviews in 2020	%Change from 2019	% Pageviews in 2020
/	12,610	**-1.36%**	12.12%
/careers-nanotechnology	9,918	**6.26%**	9.54%
/how-small-nano	8,070	**372.21%**	7.76%
/what-nano	7,905	**127.68%**	7.60%
/plenty-beauty-bottom	3,676	**-28.75%**	3.53%

/research-experience-undergraduates	3,596	**-30.43%**	3.46%
/nature-helps-nanotechnology	3,538	**52.96%**	3.40%
/search/tools	3,378	**88.93%**	3.25%
/sites/view-all	3,172	**-15.10%**	3.05%
/about-nnci	2,125	**-7.89%**	2.04%

Since the NNCI website's debut in late 2016, the growth in annual visitors and pageviews is shown in Figure 6 below.

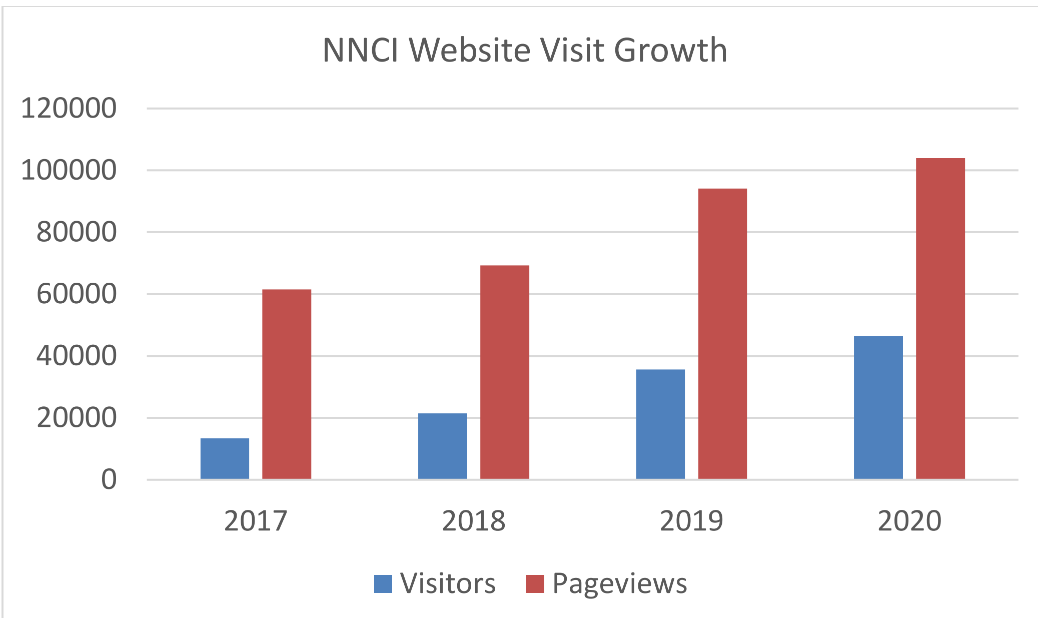


Figure 6: Growth in Annual NNCI Website Usage

Site acquisition (how visitors get to the website) is primarily through four routes: organic search, direct, referral from another website, and social media (see Figure 7). The organic search rate of 67.2% continues to increase (63% in 2019, 56% in 2018, and 42% in 2017) indicating that the website is gaining traction and appearing more frequently in online search results.

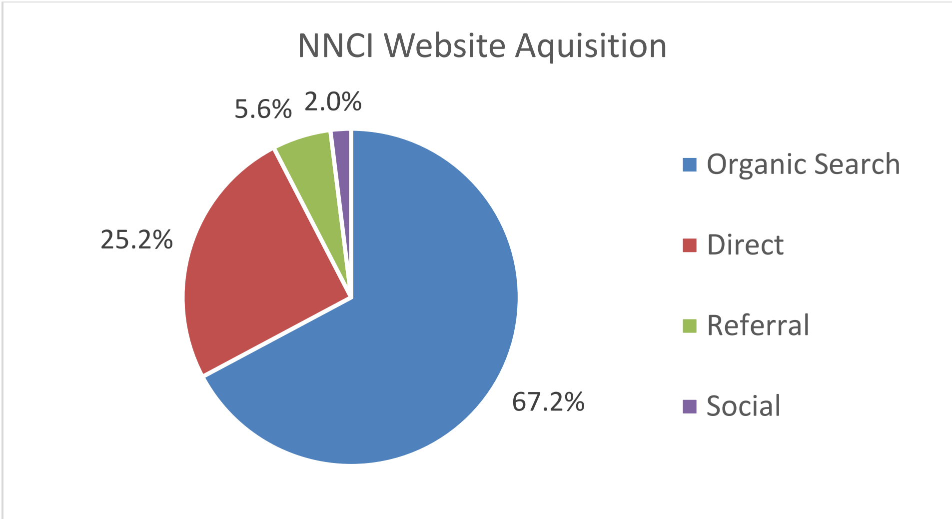


Figure 7: Site Acquisition (how visitors get to the website) for www.nnci.net (2020)

The global geographic distribution of visitors to the website is illustrated by the map in Figure 8 below. The top five locations of visitors are USA (50.15%), India (11.17%), Philippines (8.31%), China (3.40%), and Canada (2.11%). The next five countries with 1% or more of visitors each (approximately 500 visitors) are United Kingdom, Sri Lanka, Japan, Australia, and Iraq.

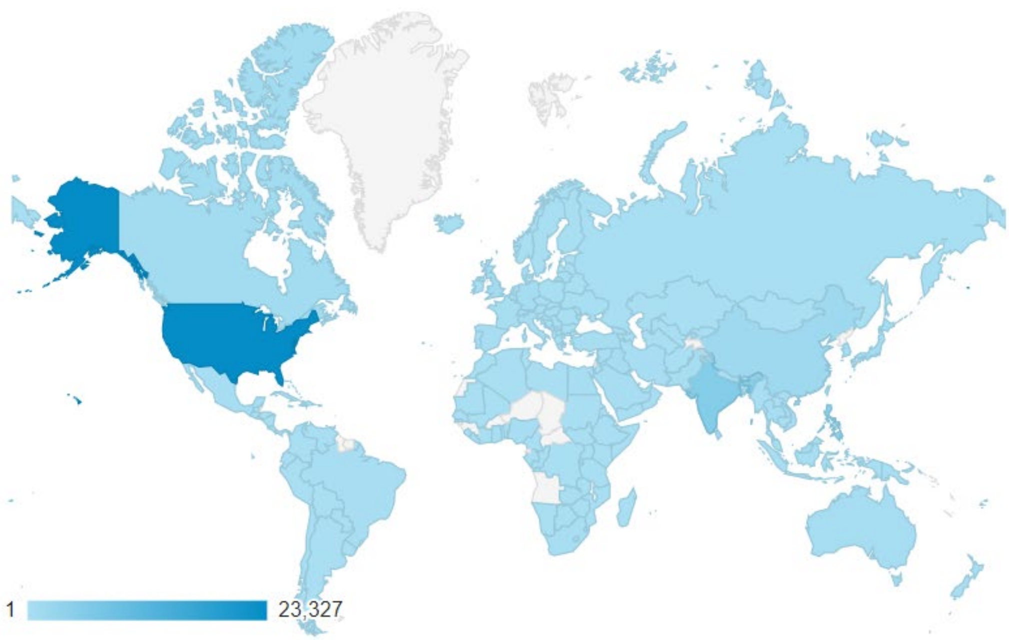


Figure 8: Geographic Distribution of Visitors to www.nnci.net (2020)

A Google search analysis indicates that searches resulted in nearly 3.3 M *impressions* (how many times an NNCI website page appeared in the search results) and 45.4K *clicks* (when someone selects an NNCI website page) during the 2020 calendar year. Both of these metrics are improvements over 2019 where we registered 1.4M *impressions* and 34.5K *clicks*. While overall this resulted in a 1.4% *CTR* (click through rate) and an average *position* (position of the particular page in the search results list) of 16 (21 in 2019) in the results list, the top query terms (Table 9) produced much better performance including many searches with nnci.net pages in the top 5 positions and CTR >10% (bold entries). While it is obvious that "nnci" and "national nanotechnology coordinated infrastructure" would produce the most direction to the NNCI website, most of the other queries are generic questions about nanoscale materials and structures as well as interest in careers/jobs in the field.

Table 9: Google Search Queries (2020)

Query	Clicks	Impressions	CTR	Position
nnci	**2,981**	**8,661**	**34.4%**	**1.2**
what is nano	1,129	30,867	3.7%	4.7
nanometer	550	364,985	0.2%	9.6
examples of nanostructures	**520**	**2,279**	**22.8%**	**1.6**
what are other examples of nanostructures	**412**	**2,503**	**16.5%**	**1.9**
nano	399	370,277	0.1%	11.5
how big is a nanometer	325	25,336	1.3%	5.2
nanotechnology careers	**250**	**2,485**	**10.1%**	**2.9**
what are other examples of nanostructures?	**207**	**1,345**	**15.4%**	**2.1**
how small is a nanometer	201	10,780	1.9%	3.8
nanotechnology in nature examples	**186**	**477**	**39%**	**1**
nanostructures examples	**162**	**1,156**	**14%**	**1.8**
national nanotechnology coordinated infrastructure	**161**	**316**	**50.9%**	**2**
nanotechnology in nature	**159**	**1,226**	**13%**	**2.7**
careers in nanotechnology	**145**	**979**	**14.8%**	**3**
what is a nano	141	7,187	2%	5.5
nanometer is an	131	6,345	2.1%	3.5
example of nanostructures	**130**	**816**	**15.9%**	**1.6**

nanotechnology jobs	126	6,505	1.9%	10.4
water molecule size	114	8,030	1.4%	6.6

7.3. User Satisfaction Survey

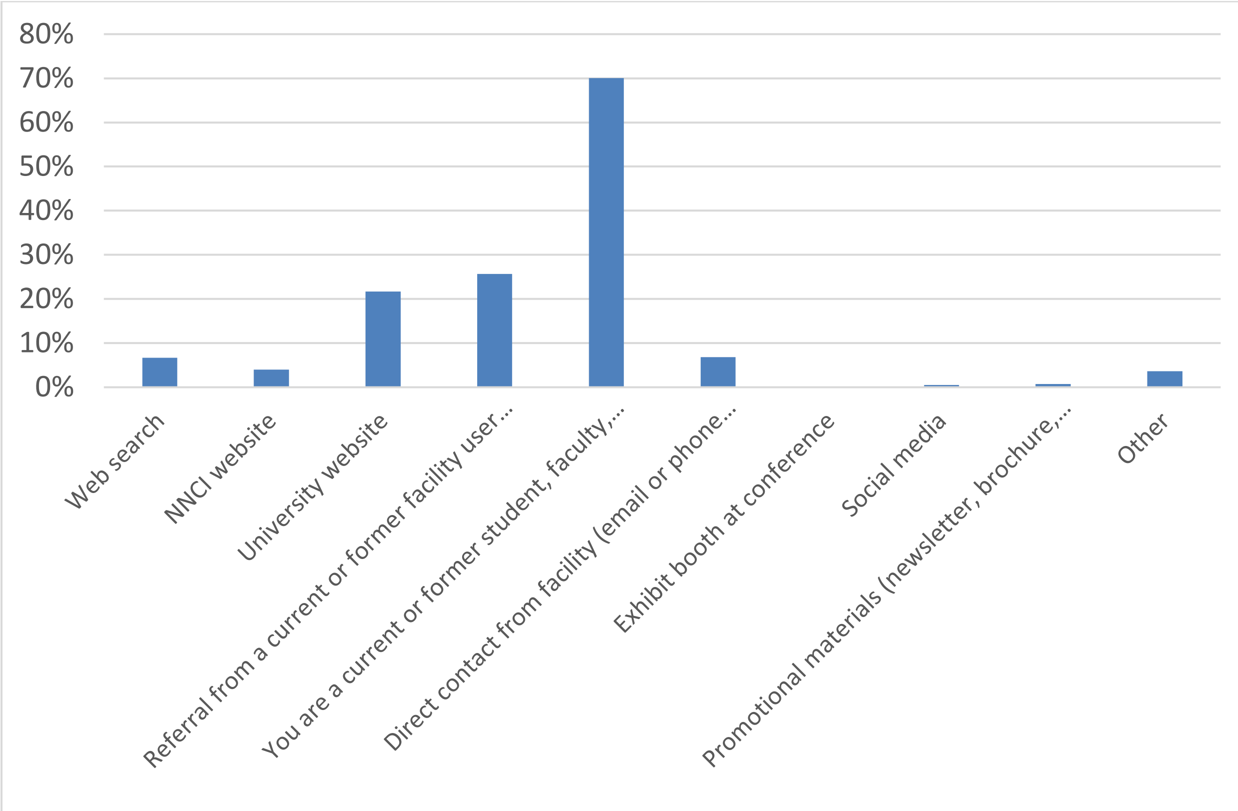
As a result of site director discussions, as well as recommendations from the Advisory Board, the Coordinating Office created a User Satisfaction Survey for implementation throughout the NNCI network. Using a *Survey Monkey* platform, the survey was first made available to sites for forwarding to their user bases during the fall/winter 2017. After receiving nearly 700 responses from 10 sites that participated and combined with the responses from five sites that had already developed their own internal surveys, the results (N>1300) were reported in the NNCI Year 2 Annual Report. Based on the first year of the common survey, the Coordinating Office solicited suggestions for modifications to the survey questions and a number were received and implemented for the 2018 survey which generated 638 responses from 8 sites that participated and an additional 747 responses from the remaining 8 sites which conducted internal surveys over a similar time period. These separate surveys did not all use the same questions as the common version on Survey Monkey, but responses were added to the overall results when possible.

For the 2019 NNCI User Survey, significant changes were implemented based on recommendations from professional evaluators at Arizona State University (Mary White) and Montana State University (Carolyn Plumb). This same survey was used for 2020, with the addition of a new question regarding use of resources specific to the COVID-19 pandemic. All sites were encouraged to use the common survey vehicle when possible, and 14 sites had respondents to the common survey while the remaining two sites provided their own data for inclusion (N=1334). Not all data were combined from the survey data submitted by these sites, so the N is reduced for those questions. The site-specific filtered results, with comments, were provided to individual sites for identification of action as needed.

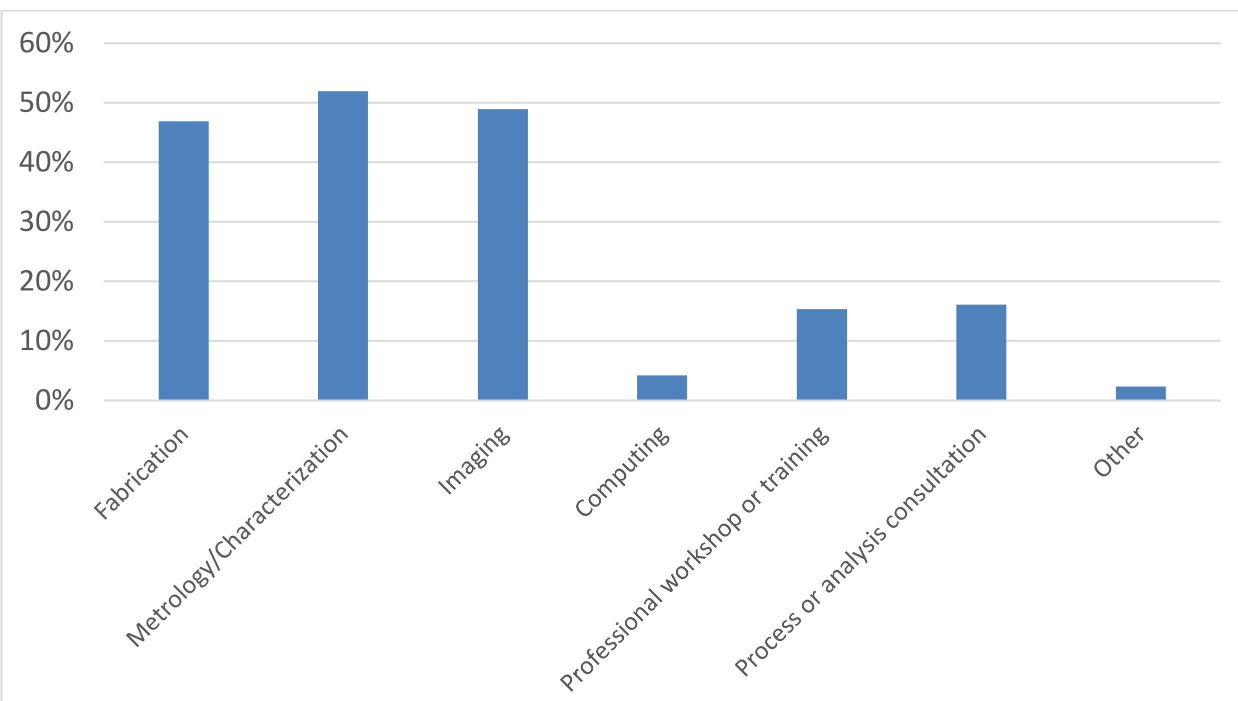
<u>The NNCI facility that was primarily used during the previous 12 months.</u>

The number of responses from each site varies from 7-337 (mean=83.4). In this year's survey, users were not asked if they used more than one NNCI facility during the past year although we know anecdotally that this number typically is around 5% of users.

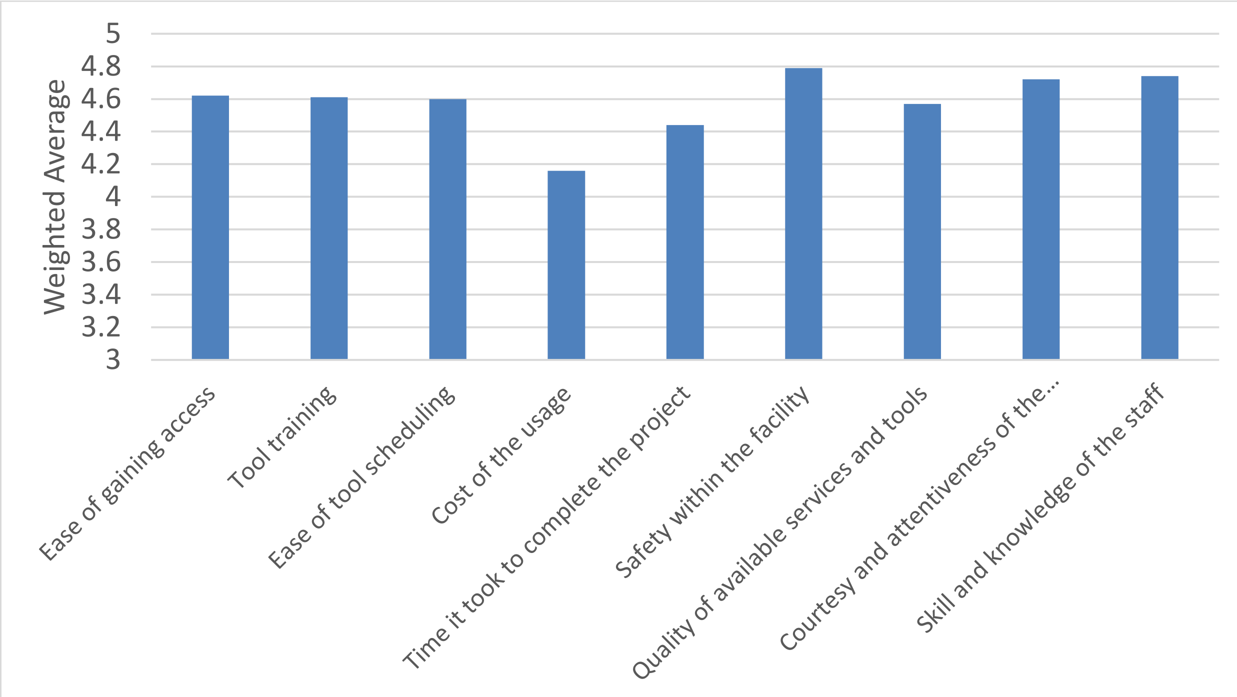
How did the user find out about the NNCI facility? (N=821)



Which services were used at the NNCI facility? (N=1330)

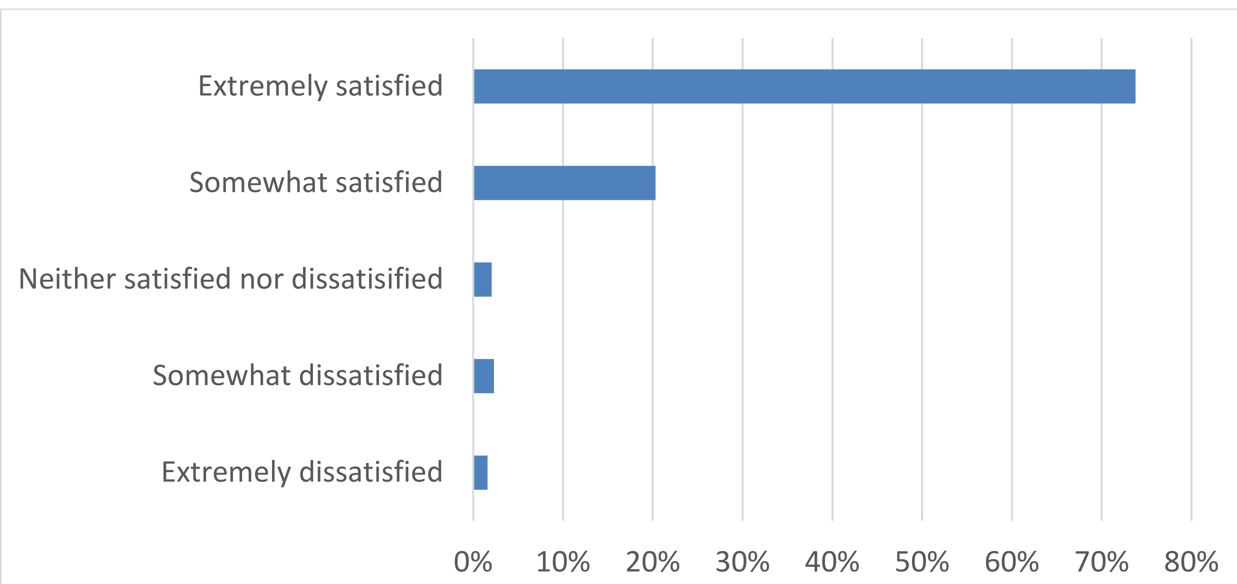


Regarding this NNCI facility, rate your satisfaction with the following (N=819; Scale=1-5 with 1=extremely dissatisfied, 5=extremely satisfied)



Rate your overall satisfaction with this NNCI facility (N=1334)

For all NNCI sites, the average overall satisfaction rating is 4.56/5. For the common survey (N=823), the detailed ratings are as indicated below, with 94% of respondents indicating either somewhat or extremely satisfied.



Would you recommend this NNCI facility to a colleague? (N=1225)

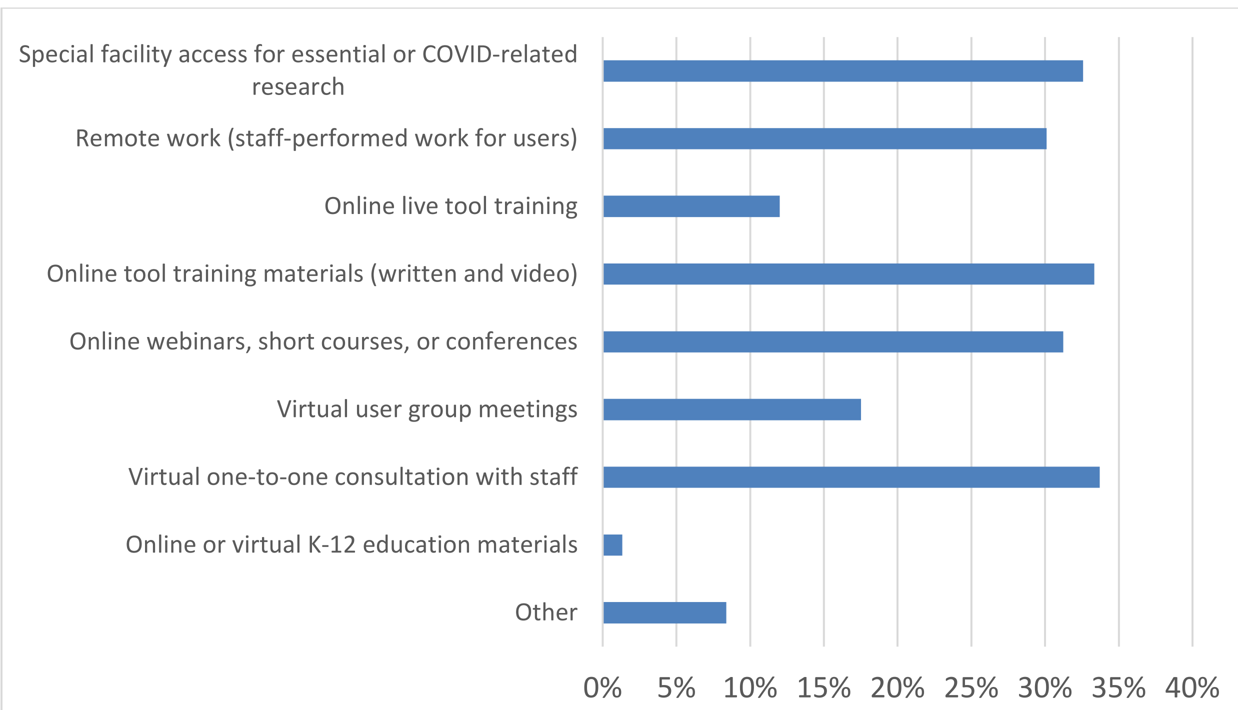
Yes: 96.9%

No: 3.1%

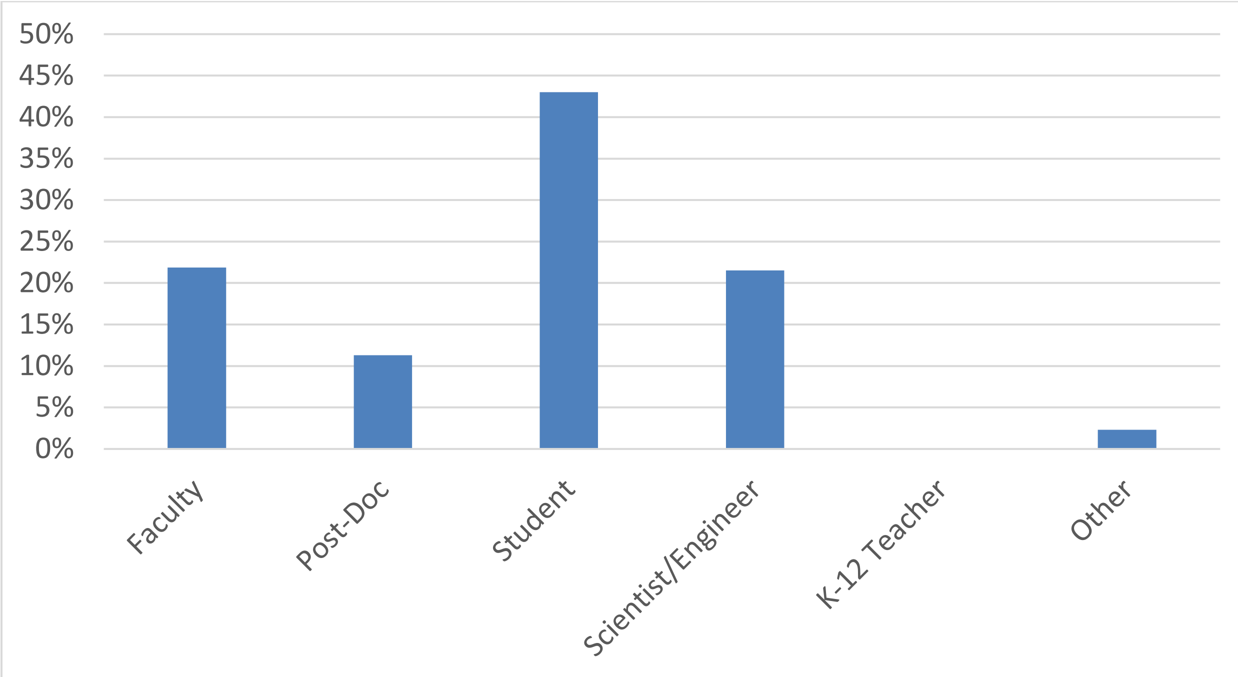
If you have any recommendations for specific new tools or services at this NNCI facility, please indicate them.

More than 170 suggestions were received and provided to the sites. Examples include characterization tools like XPS, XRD, SIMS, FIB-SEM, TEM, and fabrication tools such as maskless lithography, stepper, ion milling, epitaxial growth, and redundant RIE systems. In addition, users suggested more bench space, wet bench resources, and glove boxes as well as additional staff assistance.

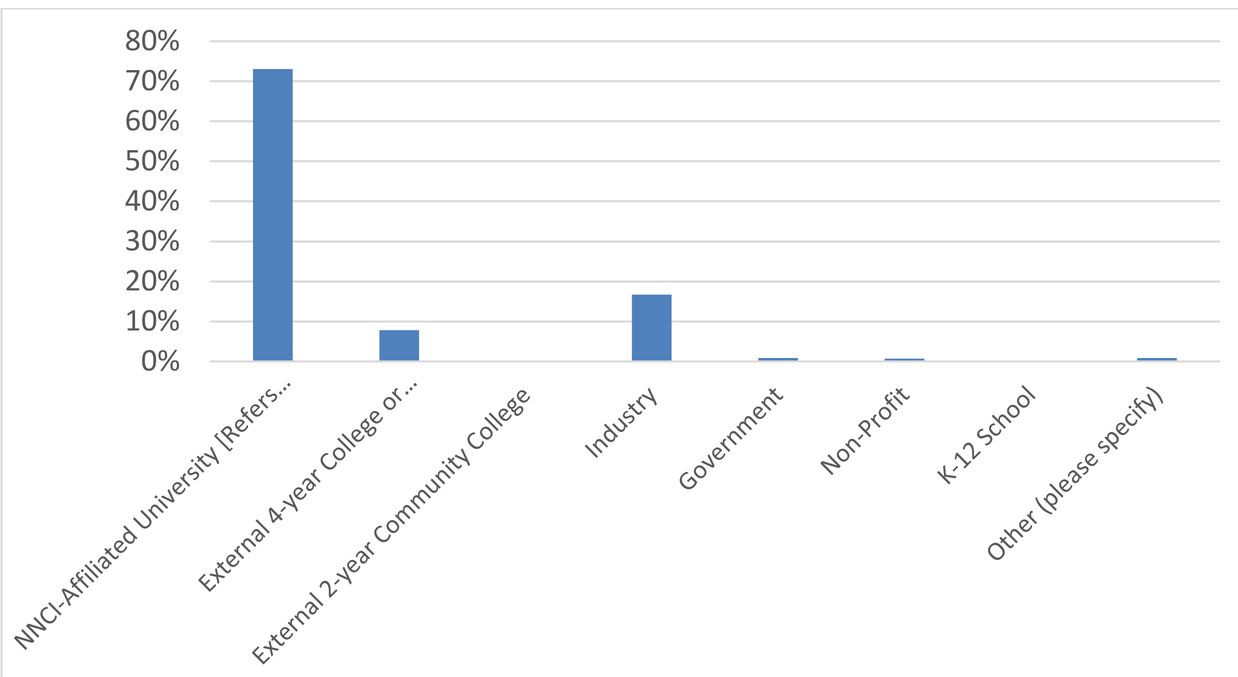
Which of the following resources offered by NNCI facilities did you use during the COVID-19 facility closures and current reduced operations periods? (N=525, this question was only asked on the common survey)



User Position (N=823, this question was only asked on the common survey)



User Affiliation (N=823, this question was only asked on the common survey)



Note that this distribution closely mirrors the actual user affiliation distribution for the NNCI network as a whole (see Section 10.1, Figure 19) suggesting that the survey is probing a reasonable cross-section of NNCI users.

In addition to responses to the survey questions noted above, more than 70 individual free-text comments were provided, both positive and negative, and a selection of these is provided here (specific facility names removed):

We are highly recommending the core facilities capabilities and services to our business partners and hope to use them for continuing work.

Honestly, this facility is great. I am at a university where research is expected but facilities for my type of research are non-existent. I knew about the facilities at … before accepting my current job and played a big role in accepting the job. I would honestly be in trouble without ….

The NNCI facility has great potential to serve the local communities. For it to be effective, it needs drastic changes in management and it should treat users as valued customers.

Gaining access was a bit difficult, but understandably due to the COVID situation. I believe that is improving and the staff has been amazing.

I have always had amazing experiences with the … staff. They are uniquely qualified, capable, warm, responsive, and informative. I could not have done a large chunk of my thesis work without their expertise and support, not just because they are exceptionally knowledgable, but also because they are patient, kind, and just fun to be around.

Excellent in all respects but the quality and responsiveness of the staff deserve an even higher rating!

The staff are amazing and work hard with the tools they have. The problem is that the tools are getting old and really need replacement. I would love for them to get more funding to do so because that is the barrier for this fabrication facility to be a better research fabrication facility.

The … staff and facility are amazing. They were so helpful in getting me set up so that I could continue my essential research during the main campus closure.

The facility is run efficient, friendly, and competent. I could not think of a better way to do it, have recommended it to my colleagues, and will use it again.

Staff attentiveness and responsibility are appreciated. Response COVID has been as good as can be expected, given the circumstances. Tool reliability is a continuing issue, exacerbated by COVID challenges.

The students and faculty members at … are very fortunate to have this facility. It plays a critical role in maintaining our level of competitiveness in science, engineering and innovation on an international scene with ever increasing competition in deep tech technologies. Our future national sovereignty and economic power will critically depend on our ability to maintain state-of-the-art equipment and expertise provided by such NNCI facilities.

8. NNCI Annual Conference (October 2020)

In the proposal for the Coordinating Office, it was suggested that "A flagship event for the NNCI network will be the annual ***NNCI Conference***, which will be held at different network sites and will not only highlight the research supported by the NNCI facilities, but also provide a venue to share best practices as a result of the work of various working groups and committees." It was further detailed: "The Coordinating Office will work with the site directors to organize the annual ***NNCI Conference***, which will be held each year at a different NNCI site. The conference attendees will include the site directors and other site management personnel, the External Advisory Board, as well as NNCI site staff who are members of the working groups. As mentioned above, individual working groups might organize parallel sessions where findings in the specific topical area can be shared with other interested NNCI staff. We envision a 1.5-2 day meeting, that includes half-a-day of network overview and site presentations, half-a-day of user presentations, possibly in parallel sessions, and at least a half-a-day of time for dedicated panels on E&O, SEI, computation and select working groups (safety, vendor relations, etc.). The goal is to have a working meeting that strengthens the network and its sites, helps with future planning and is not just a review. As an example, each year's conference could have a dedicated panel on "Emerging Research Areas", using invited talks to stimulate discussion among the NNCI sites on promising future research directions and the tools required to support these. We also envision that satellite events, such as an SEI Conference, could be organized in conjunction with the annual NNCI Conference. Poster and presentation awards as well as certificates for certain panel participation may be a way for student and staff development, respectively, as part of the annual event."

While originally intended as an in-person meeting at Northwestern University, it became clear that travel would be restricted during 2020, so the fifth annual NNCI Conference was organized by the Coordinating Office in a virtual format and held October 26-27, 2020 (12-4:30 pm each day). The 2-day event had a registration of 214, including senior representation from every site (all 16 site directors); 7 of 8 advisory board members; 9 NSF officials including Dr. Larry Goldberg, Dr. Kershed Cooper, and Dr. Carmina Londono; Dr. Lisa Friedersdorf, Director of the NNCO; as well as two invited speakers (see screen shots below). At its maximum, actual attendance was approximately 175 people.

The invited lectures were used to highlight the issue of diversity within NNCI as well as the emerging research area of quantum science.

- Dr. Christine Grant (Associate Dean of Faculty Advancement, College of Engineering and Professor of Chemical and Biomolecular Engineering, NC State University): "Creating NNCI Inclusion – From Ideas to Action"
- Dr. Celia Merzbacher (Deputy Director, Quantum Economic Development Consortium, SRI International): "The Nano-Quantum Superposition"

The agenda also featured:

1. Brief remarks from Dr. Larry Goldberg (NSF Program Manager for NNCI) and Dr. Lisa Friedersdorf (Director of the National Nanotechnology Coordination Office).
2. Presentations by the Director and the three Associate Directors of the Coordinating Office with an NNCI Overview and Reports on Education & Outreach, Societal & Ethical Implications, and Modeling/Simulation.

3. Short site reports from each of the 16 NNCI sites. To assist with the organization and flow of these reports, each site was requested to present a brief summary of the new programs they plan to offer as part of the NNCI Years 6-10 renewal. To assist attendees, supplementary information including site user statistics, research, education, SEI, and computation highlights, and impact were provided as PowerPoint files in an online accessible format.

4. Six breakout groups in 2 sessions moderated by NNCI leaders:

   - Measuring NNCI's Impact (Jan Youtie, David Berube)
   - Operations during the COVID-19 Pandemic: Lessons Learned (Mary Tang, Ron Olson)
   - Ideas for International Collaborations and Interactions/AccelNet (Steve Koester, Vinayak Dravid)
   - NNCI Beyond 2025 (Trevor Thornton, Mark Allen)
   - Diversity, Inclusion and Equity (Liney Arnadottir, Chris Ober, Heather Rauser)
   - Staff Professional Education and Training (Angela Hwang, Maria Huffman)

   Each of the sessions was recorded and access provided to attendees for review after the conference. In addition, each session leader was asked to provide a written summary for distribution, and some of those are included in Appendix 13.2.

5. Research communities provided summaries of their planned activities:

   - Nanotechnology Convergence
   - Nano Earth Systems
   - Nano-Enabled Internet-of-Things
   - Quantum Leap
   - Understanding the Rules of Life

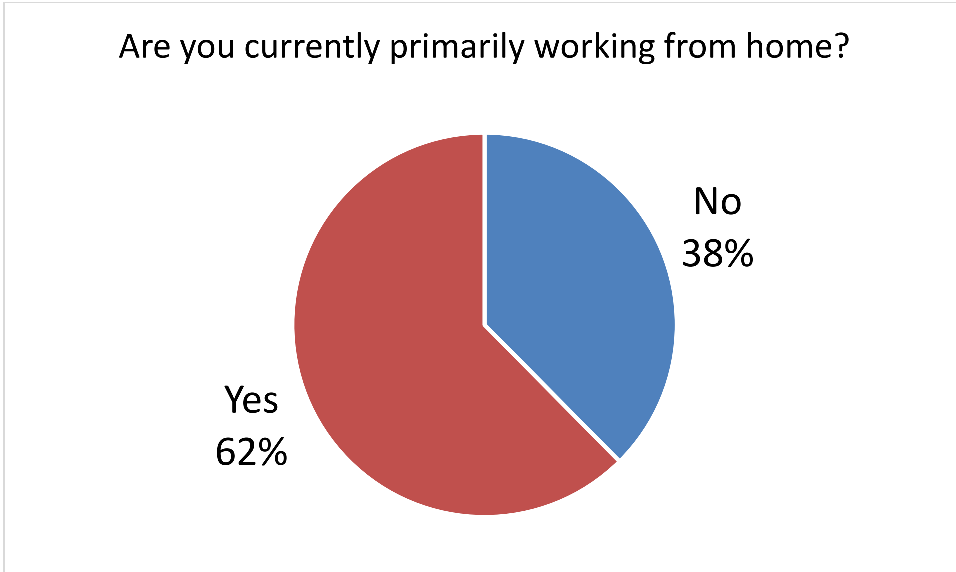
6. A separate meeting of Education and Outreach Coordinators was held the week before the main meeting and a separate meeting of SEI coordinators was held the day after the main meeting.

7. Staff awards were presented with details provided in Section 9.3 below.

8. A private meeting of the External Advisory Board. These discussions resulted in a written report to the Coordinating Office which is attached here as Appendix 13.1.

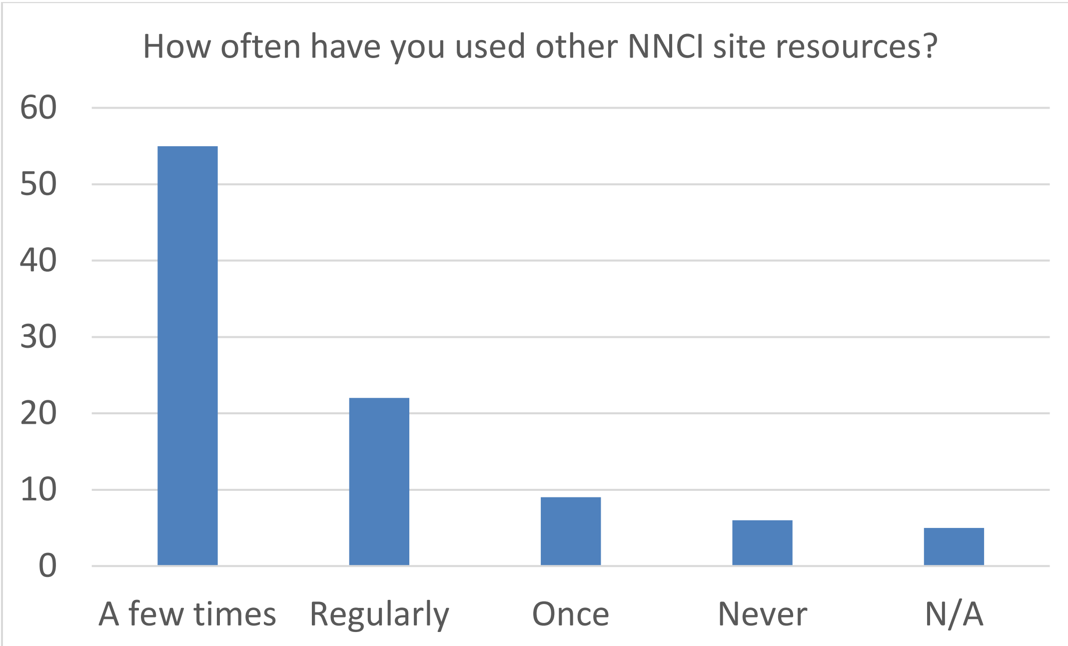
Taking advantage of an interactive feature available on Zoom, the Coordinating Office conducted live polling during the conference asking the following questions with responses provided:

Are you currently working primarily (>50%) from home?

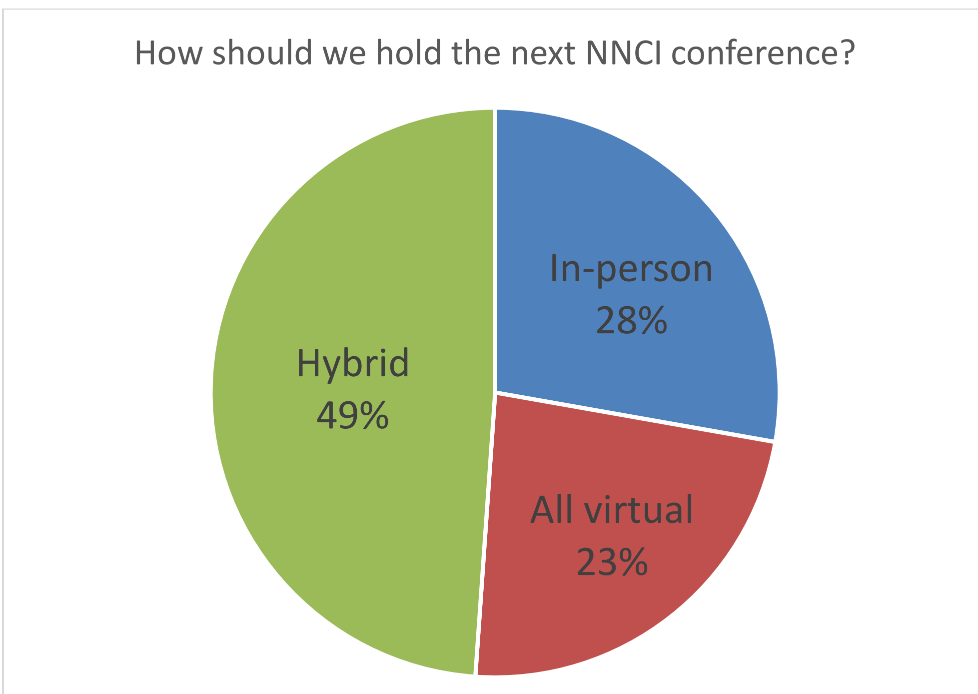


What are the greatest challenges facing your site at this point (may select multiple answers)?

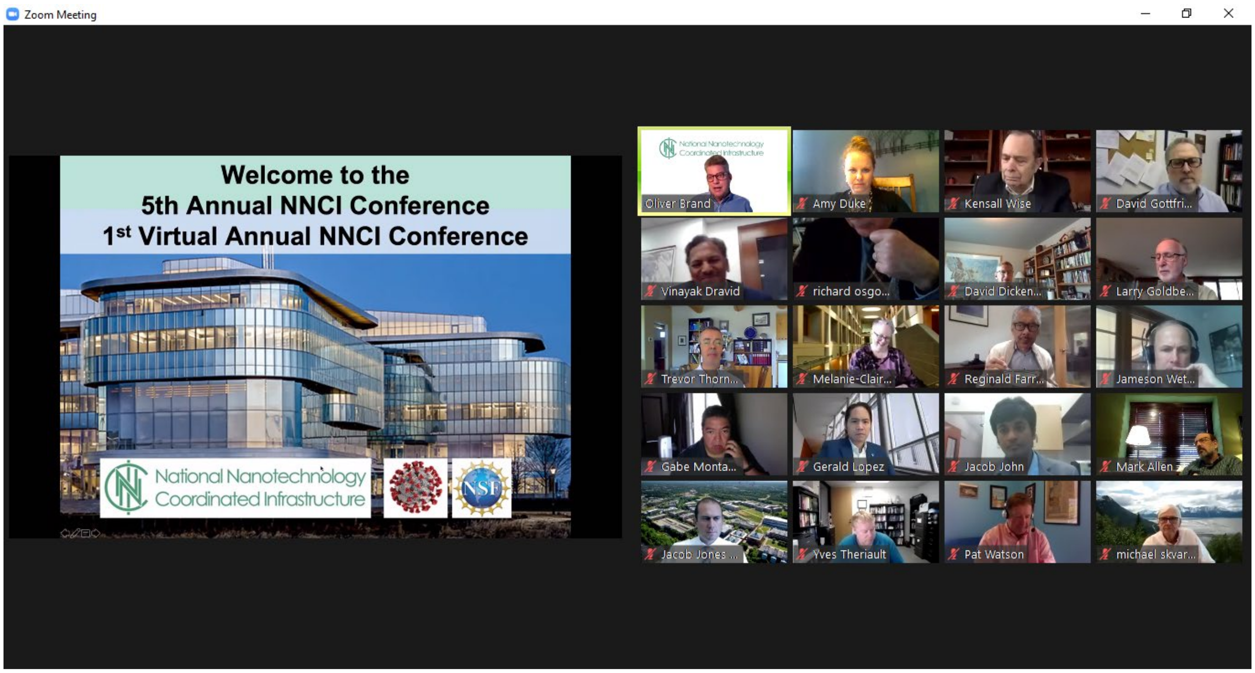
How often have you been able to take advantage of any resources or activities created or hosted by other NNCI sites?

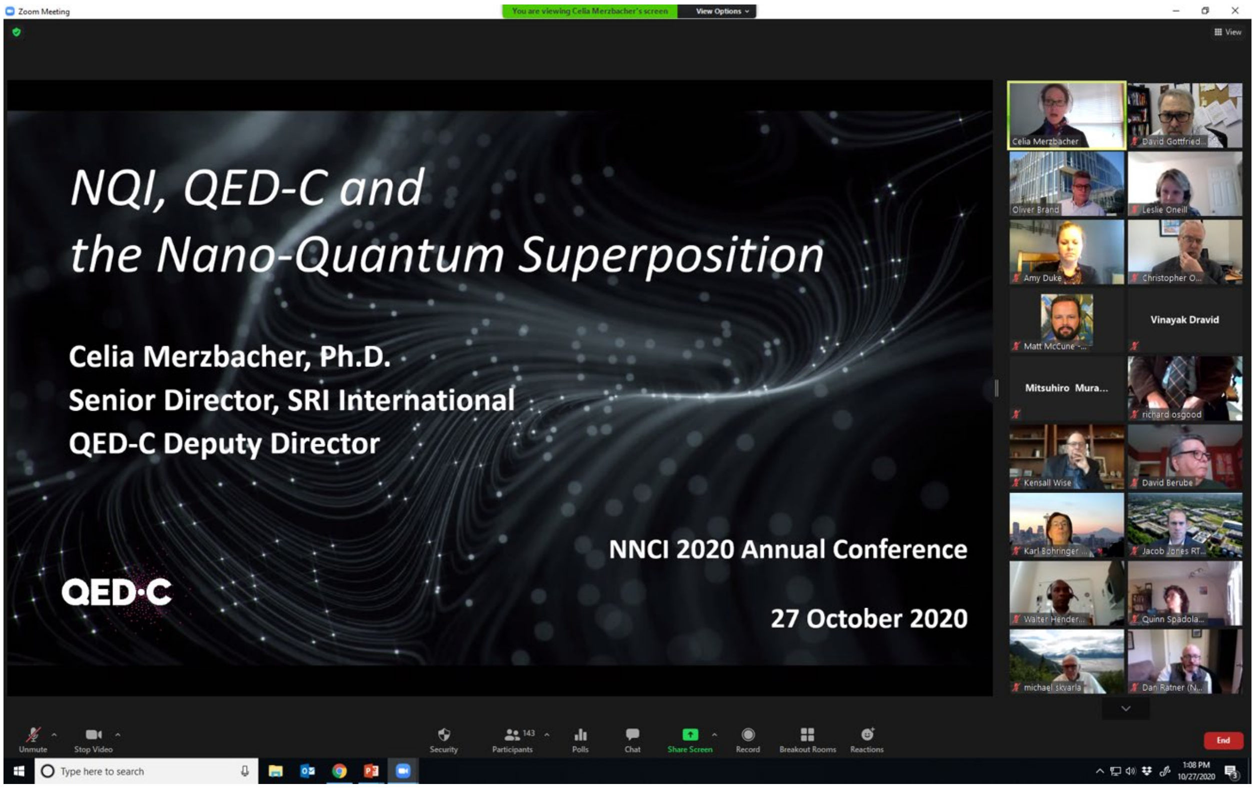


How should we hold the next NNCI annual conference?



The Coordinating Office presentations, site reports, and Research Community summaries are provided, along with the full meeting agenda, on the NNCI website at http://www.nnci.net/nnci-annual-conference.





The next NNCI Annual Conference is scheduled to be held at Northwestern University (SHyNE) in November, 2021.

9. Network Activity and Programs

9.1. Cooperative Network Activity

The NNCI sites and Coordinating Office have continued to make a concerted effort to develop and engage in activities that demonstrate the network "whole being greater than the sum of its parts." These activities include the following: (1) activities where all (or nearly all) NNCI sites participated, (2) activities between sites or with multiple NNCI site partners, and (3) activities where a single NNCI site acted on behalf of the entire network. Below are provided examples of such activities during this past year of the NNCI program.

Network-Wide Activities

1. Participation in monthly NNCI site director meetings
2. Participation in monthly NNCI education and outreach coordinators call
3. Chairing and membership of Subcommittees
4. Leading and membership of Working Groups resulting in shared reports and best practices
5. Participation in National Nanotechnology Day Activities. Twelve NNCI sites submitted entries for the "Plenty of Beauty at the Bottom" image contest in 2020. RTNN held a special "Take-out Science" episode and invited participation from all NNCI sites.
6. Attending NSF Nano Grantees Conference (December 2019). The December 2020 conference was cancelled, but several sites and the Coordinating Office submitted presentations for an online perspective "Nanotechnology Frontiers at 20 years of the National Nanotechnology Initiative: From October 1, 2000 to September 30, 2020." http://www.nseresearch.org/2020/
7. Attending NNCI Annual Conference (October 2020)
8. Providing content for the NNCI website
9. Participation in the NNCI Outstanding Staff Awards program
10. Discussions between site staff on equipment repair and maintenance issues
11. Promotion of NNCI, network events, and opportunities (workshops, job postings, etc.) through electronic communications and other marketing
12. User referrals to other sites, via NNCI email list or responses to NNCI website contact form
13. Leadership of and participation in the NNCI Research Communities (see more information below)

Multi-Site Activities

1. Hosting and participation in NNCI supported workshops and technical events (host site in parentheses), not including individual seminars and webinars:
    a. Oct. 2019: NNCI ALD/MOCVD/MBE Symposium (CNS) – Attended by members of the ALD Working Group

b. Dec. 2019: Fabrication of Wide Bandgap Power Devices Short Course (RTNN)
c. Dec. 2019: Nanomagnetism Symposium (NNF) – Five NNCI invited speakers were from the Univ. of Kentucky, Univ. of Minnesota, and Univ. of California-San Diego.
d. Dec. 2019: NNCI Etch Symposium (CNS) – Attended by members of the Etch Processing Working Group and the Equipment, Maintenance, and Training Working Group
e. April 2020: E-beam Lithography Webinar for NNCI Staff (virtual) (Stanford and SENIC)
f. April 2020: Annual TERS Workshop (virtual) (Stanford)
g. April 2020: NNCI Facilities Recovery and Operations working group workshop focused on safe reopening of shared facilities during the COVID-19 pandemic (virtual) (Stanford, CNF)
h. May 2020: NNCI Technical Content Development Webinar (virtual) (Stanford, MANTH, RTNN)
i. September 2020: SDNI-NNCI Education Symposium (virtual) with the theme "Integration of Nanotechnology Content with Current State-Wide K-12 Science Curricula: Challenge and Strategies" (SDNI)
j. Dec. 2020: NNCI Etch Symposium (virtual) (Cornell)
k. Jan. 2021: Advanced Lithography Unsymposium (virtual) (Stanford)
l. Stanford organized and hosted 2019 Metrology Symposium
m. KY-MMNIN hosted virtual Fisher Scientific Apreo SEM Workshop

2. User project support: User projects continue to be triaged and referred to and between NNCI sites where work can be done more efficiently. This process, driven and aided by direct cross-network staff technical interactions, an email listserv, and NNCI website contact forms, has become an important dynamic within the network which allows for maximizing the network's resources for the nation's benefit. This has been especially important this past year due to limitations imposed by pandemic restrictions. Examples include:
   a. In order to continue vital research programs due to the March 2020 shutdown, MANTH staff worked with four groups at Penn to find alternative laboratories to do their work. Critical help was provided by 4 NNCI sites (NanoEarth, KY-MMNIN, SDNI, and MINIC) allowed the users to continue to conduct their research.
   b. MONT users were also users of MINIC and NNI, while MONT also sent samples to NanoEarth for FIB lift-out, and MONT served users from NNI.
   c. NNI (WNF) manager of business outreach and customer development Jason Tauscher has been involved in remote projects with SDNI with MANTH (as well as Oregon State and Simon Fraser University).
   d. RTNN referred many of users and contacts to other NNCI sites. This is not limited to users looking for a tool. Many learners from the Coursera course have contacted RTNN to find more online resources and these have been referred to Stanford's online course, which provides further detail and offers more intensive training videos.

   e. SDNI directs users to other NNCI sites to assist their projects for resources unavailable at UCSD.

3. Staff technical interactions:
   a. SDNI has built relationships with NNI, MONT, NCI-SW, Stanford, SENIC, SHyNE, and MANTH to work on joint process development, direct users to resources, and to exchange know-how and best practices. SDNI has hosted visits by leadership from other network sites and also visited several other sites. Examples include discussions with the NNI related to an Electron-Beam Lithography project and working with SHyNE on a challenging dry etch project related (NASA/Jet Propulsion Lab).
   b. NNCI sites collaborated and share information related to activities in response to the COVID-19 pandemic, lab shutdowns, and restarts (more information in Section 9.4). Some examples of this include:
      i. Cooperative reusable mask order (CNF)
      ii. MANTH sold PPE and consumable materials to the MINIC to help them maintain adequate consumables for researchers during the shutdown.
      iii. MANTH worked with two vendors and five NNCI Sites to develop and supply a washable facemask.
      iv. MANTH designed, ordered, solicited donations, and built a social distanced cleanroom gowning room. These designs and procedures were shared with other NNCI members.
      v. NNI discussions with Harvard CNS about COVID-19 rules/guidelines for electron microscopy areas.

4. Joint proposals:
   a. The NSF "AccelNET: Global Quantum Leap" proposal was led by Steven Koester (MINIC), with core participation by SENIC, CNF, and SHyNE and collaboration with NNI, CNS, and RTNN. The proposal was funded and will establish an international network-of-networks linking the NNCI to quantum networks in Asia and Europe
   b. SENIC lead a successful multi-site proposal to NSF for a Research Experiences for Teachers site with three other NNCI partners (MINIC, NNF, and SHyNE). These four sites from across the NNCI network will support 20 high school/community college faculty each year in a 6-week summer research experience, with follow-up support during the school semesters. This was cancelled summer 2020 due to Covid-19 and will start in 2021.

5. Sharing of best practices:
   a. Assessment and evaluation tools and activities (RTNN, NCI-SW, MONT)
   b. Seed grant programs such as Kickstarter (RTNN) and Catalyst (SENIC)
   c. Regional facility networks such as Northern Nano Lab Alliance (MINIC), Southeastern Nano Fabrication Facility Network (SENIC), and Mid-Atlantic Region Cleanroom Facility Managers (MANTH). The NNI and MONT sites have started a joint effort to

create the Northwest Nanotechnology Laboratory Alliance (NWNLA), a regional platform for exchange on laboratory experiences and best practices.

d. Middle School Teacher Workshop: This program has been expanded by Stanford by implementing a parallel program at SENIC and seeding foundation for future program expansion at SDNI, NanoEarth, MINIC, and NNF. SDNI has participated in 3 other sites' programs (Stanford, SENIC, and NanoEarth). SDNI provided remote access to its SEM to all attendees participating in those summer schools in 2020. NanoEarth organized a professional development workshop for high school teachers in partnership with Virginia Tech's nanoscience degree program. Nano@Stanford and NanoEarth have started sharing their program materials with the goal of broadening and strengthening modules that other NNCI sites can choose from when implementing professional development workshops with their state standards in mind.

e. 4-H Outreach: CNF, NNF, NanoEarth, and MONT are collaborating on 4H outreach initiatives, sharing activities and best practices. Material to engage 4-H Youth already exists within NNCI; using the 4-H mechanism to deliver content and training is a scalable opportunity.

f. Education and outreach coordinators with an emphasis on Native American outreach have agreed to meet separately to coordinate on Tribal outreach activities (organized by NNI).

6. Participation in SEI Programs:

   a. The SEI program has hosted a half day workshop as part of the NNCI annual conference in 2019 and 2020 to share best practices, and the SEI leaders at the different sites have met to discuss issues and give each other feedback.

   b. ASU Winter School on Responsible Innovation and Emerging Technologies: Dr. Jameson Wetmore and colleagues from the NCI-SW SEI User Facility hosted the annual Winter School in January 2020. This year 14 students from 10 different countries participated in the week-long program.

   c. Associate Director for SEI Jamey Wetmore (CO and NCI-SW) traveled to NNCI sites and (especially subsequent to the COVID-19 pandemic) participated in online workshops to inject SEI into the education training programs being developed by the NNCI CO and other NNCI sites.

      i. Oregon State University (NNI) half-day workshop with engineering graduate students focused on thinking about SEI in their own laboratory work. He followed that up with a talk to around 60 people, "Nanotechnology at the Start of the Millennium: A look back at the excitement and fear," as part of OSU's Department of Chemical, Biological, and Environmental Engineering Seminar Series.

      ii. Assisted Quinn Spadola (CO and SENIC) with the "Teaching Nano & Emerging Technologies Webinar Series" and a special taping entitled "Teaching the Social Implications of Nanotechnology to High School Students" https://www.nano.gov/TeacherNetwork.

iii. Presented "Introduction to "You Decide" and teaching the social side of nanotechnology" at Nanoscience Summer Institute for Middle School Teachers, an online professional development program hosted by the Stanford site.

7. To support RTNN outreach efforts in rural areas, they often collaborate with volunteers from JSNN, part of the SENIC site.
8. Many learners from RTNN's Coursera course have contacted them to find additional online resources. These individuals have been directed to Stanford's online course (housed on Lagunitas, an EdX platform), which complements the RTNN course well as it goes into further detail and offers more intensive training videos.
9. NCI-SW, RTNN, NNF, SDNI, Stanford, and SENIC participate in the Nanotechnology Applications and Career Knowledge (NACK) Network's Remote Access Instrumentation in Nanotechnology (RAIN) coordinated by Penn State University.
10. MONT EAB members include Mark Allen of MANTH and Mike Hochella of NanoEarth.
11. RTNN actively shares information from other sites on their website, newsletter, and social media platforms. This includes information on programs like "Science Outside the Lab", job postings, and workshops/seminars.
12. RTNN collaborates on the "Take-out Science" program with SDNI, nano@Stanford, and NNI to develop and produce content.
13. SDNI and nano@stanford are collaborating for the grant period 2021-2025 to pursue mutual efforts that began in 2019. To date, these California sites have shared respective educational program frameworks as well as nanotechnology curricula, exchanged Remotely Accessible Instrument for Nanotechnology (RAIN network) sessions, attended each other's RET programs, and intend to merge frameworks and contents for future program and curriculum development.

<u>Site Activity on Behalf of the NNCI</u>

1. CNF publishes "Nanooze", and, in addition to direct distribution to classrooms, distributes it to all NNCI sites for use in their outreach activities.
2. Georgia Tech (SENIC) maintains the current NNCI website. RTNN receives requests from the Spanish language "Contact Us" form and responds to all inquiries made via this method.
3. CNF manages the iREU program that affords a second year research experience abroad from among the highest rated REU interns from the previous summer. CNF has submitted an NSF proposal for continued iREU funding.
4. CNF and Georgia Tech (Coordinating Office) have conducted longitudinal tracking of NNUN/NNIN/NNCI REU students since 1997.
5. Hosting of NNCI Annual Conference (virtual) by Georgia Tech (Oct. 2020)
6. NNCI hosted a conference exhibit booth at the inaugural MRS User Facility Row in Dec. 2019 with assistance from SENIC, CNS, SHyNE, CNF, KY-MMNIN, RTNN, and NNF.

7. SDNI collaborated with the NNCI Coordinating Office and the NACK Network to increase outreach. SDNI, NNCI and NACK worked together to submit workshop proposals for the 2019 Society for the Advancement of Chicanos & Native Americans in Science (SACNAS) National Diversity in STEM Conference, which took place in Honolulu, Hawaii in the Fall of 2019.
8. NanoEarth continues its partnership with Jim Metzner with 10 new shows developed for "Pulse of the Planet" this year about nano-related research and technology, and how it is changing the world. "Pulse of the Planet" highlights the most interesting projects from external users, local site researchers, and impactful research at other NNCI sites with those individuals personally interviewed for each episode. This year's episodes featured Greg Lowry (Carnegie Mellon University), Paul Schroeder (University of Georgia), and Linsey Marr (Virginia Tech). "Pulse of the Planet" is heard on over 265 NPR radio stations by 1.1M listeners per week; additionally, these 10 new shows were downloaded over 22,000 times during Jan-Sept 2020.
9. KY MMNIN hosts the UGIM website and several NNCI staff are members of the UGIM Steering Committee (Aebersold (KY MMINI), Cibuzar (MINIC), Clay (MANTH), and Tang (Stanford)).
10. The SENIC SEI program is developing an impact toolkit that will be shared with all NNCI sites.
11. SENIC began organizing the staff exchange program at the beginning of 2020, however this was put on hold due to pandemic travel restrictions.
12. SDNI joined the Micro Nano Technology Education Special Interest Group (MNTeSIG), an NSF supported group, in 2019 and as an active member SDNI networked and shared resources and ideas to promote nanotechnology education to classrooms nationwide.
13. KY-MMNIN gave a presentation about the NNCI and their site at the virtual 2020 KY Automotive Conference.
14. David Gottfried (CO and SENIC) and Matt Hull (NanoEarth) are partners in the EU Horizon 2020 funded project NanoFabNet and Quinn Spadola (CO and SENIC) is a partner in a sister project SUSNANOFAB. Both projects aim to develop hubs for sustainable nanofabrication.

9.2. New Initiatives

As part of the NNCI site renewal process (Years 6-10) during 2020, all sites proposed new programs and activities that build on their previous successes and demonstrated needs in their respective communities. Table 10 lists the major new initiatives by site as presented during the October 2020 NNCI Annual Conference. In addition, a new network-wide program on Research Communities was created for participation by <u>all</u> NNCI sites, and this is described in more detail below and not included in the table. Other programs such as Summer Teacher Workshops, Regional Networks, Seed Grants, and SEI research/education were added by many sites.

Table 10: New Initiatives within NNCI (Years 6-10)

Site	Program	Technical	Education	Outreach/ Societal	Tech Transfer
CNF	Partnership with Morgan State University (HBCU)	✓	✓	✓	
	Expanded 4-H Program		✓	✓	
	New Facilities (3D Fabrication and Visualization)	✓			
	Startup Partnership				✓
CNS	Enhanced CNS Scholars Program		✓	✓	
	Growth of Startup Outreach			✓	✓
	Expanded Research Experience for Veterans (REV)		✓	✓	
KY-MMNIN	Extended 3D Capabilities	✓			
	New Site Research Focus	✓			
	Collaboration with FAMU-FSU (HBCU)		✓	✓	
	New REU Program		✓		
	New Regional Nano Network	✓		✓	
	Middle School Teacher Training		✓		
	Seed Programs at UofL and UK	✓		✓	
MANTH	Growing Capacity	✓		✓	
	Expanded Partnership with Community College of Philadelphia		✓	✓	
	Improved Technology Translation Activities				✓
MINIC	Added Characterization Facility	✓			
	Expanded Capabilities for Quantum Information Research	✓			
	Nanoscience Summer Institute for Middle School Teachers		✓		

	Research Experience for Teachers (RET)		✓		
MONT	EMPOWER Scholars Program		✓	✓	
	4-H Program		✓	✓	
	Northwest Regional Lab Network	✓		✓	
Nano Earth	Agricultural Engagement (including 4-H)	✓	✓	✓	
	Educational Module Development & Remote Training	✓	✓		
NCI-SW	Northern Arizona University Partnership	✓	✓	✓	
	New Advanced Electronics and Photonics Facility	✓			✓
	Compact Free Electron Laser	✓			
	SEI Research Community			✓	
	Southwest Regional Network	✓		✓	
NNF	New Education Activities (Engineering Days, 4-H)		✓	✓	
	Community College Partnerships		✓		
	Teacher Development Workshop		✓		
NNI	Updated Focus Area: Photonic and Quantum Systems	✓			
	Advanced Prototyping Cleanroom				✓
	Northwest Regional Lab Network	✓		✓	
	Seed Funding Program	✓		✓	
	Tribal School Partnerships		✓	✓	
RTNN	Expand Kickstarter Seed Grants	✓		✓	
	Create new MOOC Modules		✓		
	RTNN Affiliates Network	✓		✓	

	Increase Partnerships within Research Triangle Region	✓	✓	✓	✓
	Rural Community Focus		✓	✓	
	Community College Focus		✓	✓	
	Improved Communications			✓	
	New SEI Research			✓	
SDNI	Expand Access to Advanced Characterization Tools	✓			
	New Education Initiatives		✓		
	Convergence Research Initiatives	✓	✓		
SENIC	Added Tools and Research Capabilities	✓			
	Enhanced Relationship with Oak Ridge National Lab	✓	✓	✓	
	Technical College Interns	✓	✓	✓	
	Research Experience for Teachers (RET)		✓		
	New SEI Activities			✓	✓
SHyNE	Expanding SHyNE SEED Funding	✓		✓	
	Data Science Initiatives	✓			
	Regional Coordination	✓			
	Expanded REU and RET		✓		
Stanford	Evaluation of MS Teachers Summer Workshop		✓		
	SEI Ambassador Program		✓	✓	
	Engagement with Stanford Ethics, Society, and Technology Hub			✓	
	Development of EdX Training Content for NNCI	✓	✓		
TNF	Partnership with Austin Community College for REU		✓	✓	

	New Computation Efforts (Webinars)	✓	✓		
	Network-Wide SEI Workshop		✓	✓	

a. Staff Exchange Program

The Global and Regional Interactions Subcommittee suggested in 2019 the creation of an NNCI Staff Exchange program. Most if not all of the NNCI sites offer a variety of short courses, workshops, symposia and other events open to users and the wider research community. These events cover a wide range of topics including specific fabrication or characterization equipment, nano-scale topical areas (e.g. quantum, bio-medicine, etc.), education and outreach strategies, and facility management and operations. The idea of the Staff Exchange program was to create a clearinghouse for these programs, make them available for staff across the network, and provide a cost-sharing mechanism for travel support. As a secondary goal, such a clearinghouse on the NNCI website would also serve as a single access point for non-NNCI participation in these educational opportunities.

In early 2020, an NNCI Events web page was created as a tool for NNCI sites that provided scheduling and information for events throughout the network. This web page was flexible and could be updated as needed as dates and details change throughout the year using an online link to a Google form. Once these events are available, sites would be able to request (through another online form) up to $1000 in travel support for one staff member per year to attend one of these NNCI programs.

Shortly after the program was launched in February 2020, the COVID-19 pandemic caused a complete cancellation of all in-person programs. Instead, the events page was used to list remote training modules, webinars, and recorded seminars/webinars. Once travel is possible, the Events Page/Staff Exchange will be re-started.

b. Regional Facility Networks

Initiated by efforts at MINIC and MANTH, a number of sites within the NNCI have established informal networks of regional fabrication and characterization facilities to provide mutual assistance, develop best practices, and provide staff networking opportunities. The map below (Figure 9) shows the geographic distribution and regional clustering of these networks, along with a brief description of those currently established (NNLA, SENFN, Mid-Atlantic, and RTNN Affiliates) and those still in the development stage (SW-NLA, NWNLA, and Ohio Valley).

Figure 9: NNCI Regional Facility Networks

MINIC: The **Northern Nano Lab Alliance (NNLA)** is a regional network of university fabrication facilities. Its mission is to help each member improve their support of academic research in applied nanotechnology.

SENIC: The **Southeastern Nano Facility Network (SENFN)** was created in 2018 as a regional network of nanoscale science and engineering user facilities located in the SE United States. The objectives of this network are to share information on capabilities and events at each facility, discuss best-practice solutions to common challenges, and begin a process for informal staff-level technical exchanges.

MANTH: The **Mid-Atlantic Region Cleanroom Managers Workshop** began as a gathering of lab managers from the academic and government cleanroom facilities located in the triangle formed between Washington DC, Brookhaven National Laboratory in NY, and Pittsburgh, PA. The Singh Center for Nanotechnology Quattrone Nanofabrication Facility staff at MANTH created these semi-annual meetings in 2016 in order to share best practices for research cleanroom operations throughout the region.

NCI-SW: The **Southwest Nano-Lab Alliance (SW-NLA)** will disseminate best practices in cleanroom management, equipment purchasing/maintenance, and user training across the partner schools across the southwest. The association will meet annually for a one-day workshop that will rotate amongst the participating labs. The workshop will bring together at least two participants from each lab to discuss best practice for managing cleanrooms and associated multi-user facilities, on-going challenges, and future opportunities.

NNI and MONT: The **Northwest Nanotechnology Laboratory Alliance (NWNLA)** is a joint effort between the NNI and MONT sites to create a regional platform for exchange of laboratory experiences and best practices. Members of NWNLA include nanotechnology facilities in Idaho, Montana, Oregon, Washington, Wyoming, Alberta and British Columbia.

RTNN: The **RTNN Affiliates Network** connects RTNN facilities with other nano-focused university and government facilities in the Triangle. The goals of Affiliates Network are to (1) allow regional facility managers/directors to more readily connect researchers to complementary facilities needed to complete their nanotechnology research, (2) enable facility leadership and staff from across the Triangle to communicate timely information efficiently and effectively about instrumentation and other opportunities, and (3) develop strategic partnerships on emerging opportunities and technical needs that support the facilities or user base.

KY-MMNIN: The **Ohio Valley Regional Nano Network** (no members identified yet) has the objective of building a network of researchers from facilities throughout the Ohio Valley. The purposes of the network are to exchange information on operations and capabilities, host processing seminars, accelerate access to KY Multiscale core facilities, and encourage best practices and collaborative research.

c. Research Communities

Research Communities are groups of faculty, students, and staff from NNCI sites organized around a particular research topic, national priority, or grand challenge, many of them based on NSF 10 Big Ideas. In contrast to NNCI working groups which are focused on a particular tool or process with the objectives of sharing best practices, the Research Communities are more outward facing helping to develop products that benefit the larger scientific and engineering communities. The current Research Communities are shown in Table 11 along with the lead sites and participating sites. The Research Communities provided an overview of their planned activities at the 2020 NNCI Annual Conference, and these can be viewed at https://www.nnci.net/annual-conference-2020.

Table 11: NNCI Research Communities

Research Community	Leader(s)	Participants
Nanotechnology Convergence	Jacob Jones (RTNN)	NCI-SW, SDNI, KY-MMNIN
Nano Earth Systems	Trevor Thornton (NCI-SW), Mitsu Murayama (NanoEarth), and David Dickensheets (MONT)	nano@stanford
Nano-Enabled Internet-of-Things	Mark Allen (MANTH)	CNF, SENIC, NNF, KY-MMNIN
Transform Quantum	Andrew Cleland (SHyNE), Robert Westervelt (CNS), Steven Koester (MINIC)	TNF, NNF, NNI, MONT, RTNN, SENIC, CNF
Understanding the Rules of Life	Vinayak Dravid (SHyNE)	MINIC, NNI, MONT, CNF, MANTH, SENIC

Activities of the communities may include:

1. NNCI-sponsored symposia/workshops/webinars
2. Road-mapping exercises
3. Identifying future infrastructure needs

These groups will address questions such as (a) What infrastructure capabilities are needed to support the research topic? (b) What are the challenges of current fabrication infrastructure for the specific research area? In addition, they can provide opportunities for networking among faculty and students working on similar themes. They also can be used to convey information about tools, capabilities, and expertise within the wider NNCI network to researchers who may not typically look outside their own local site.

9.3. NNCI Outstanding Staff Awards

During 2020, the NNCI Coordinating Office organized the third year of the "Outstanding NNCI Staff Member" awards to acknowledge the significant efforts by NNCI site staff who endeavor to provide excellent service and support to all network users in three categories: Technical Staff, Education and Outreach, and User Support. In May 2020, nominations consisting of a 500-word narrative were solicited from site directors (maximum of one nomination in each category) and these were reviewed by the NNCI External Advisory Board. Nominations were evaluated based on the individual's activities that align with site/NNCI goals of providing facility access and/or education and outreach, as well as their impact on the site and the NNCI network. Each winner received an engraved desktop plaque and was recognized at the 2020 Annual Conference. Due the virtual nature of the Annual Conference, travel support will be provided to attend the Annual Conference in 2021 (if possible).

Education and Outreach

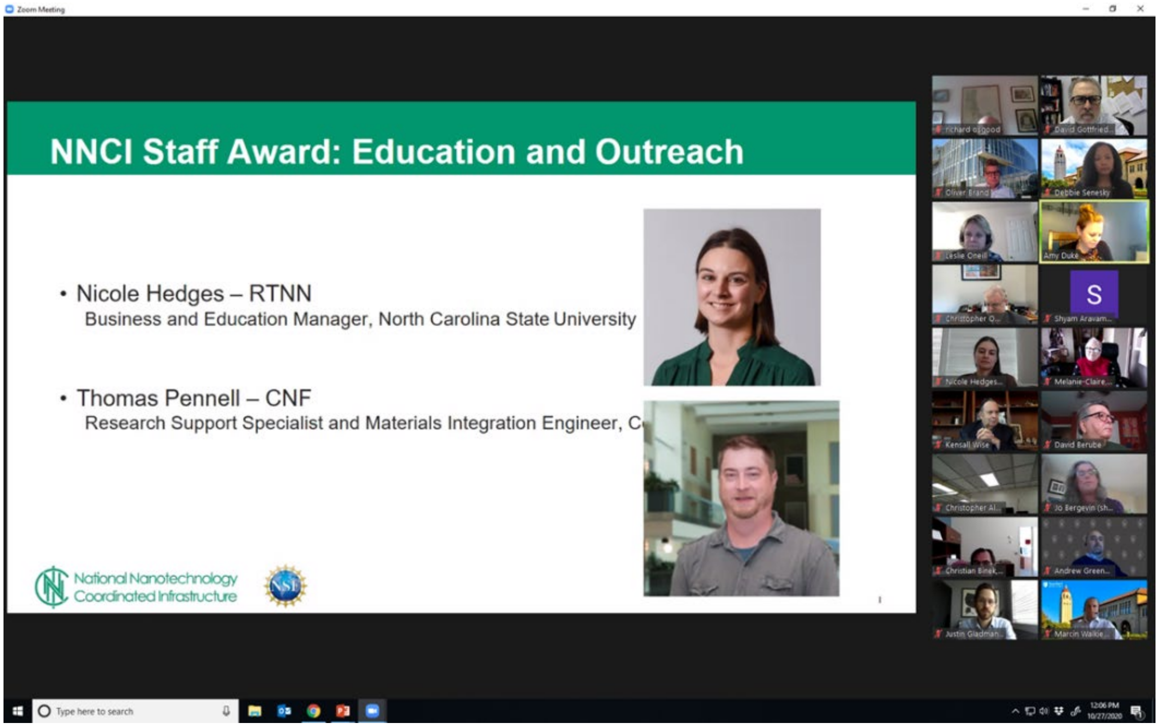
- Nicole Hedges (Business and Education Manager, RTNN (NC State Univ.)
- Thomas Pennell (Research Support Specialist and Materials Integration Engineer, CNF)

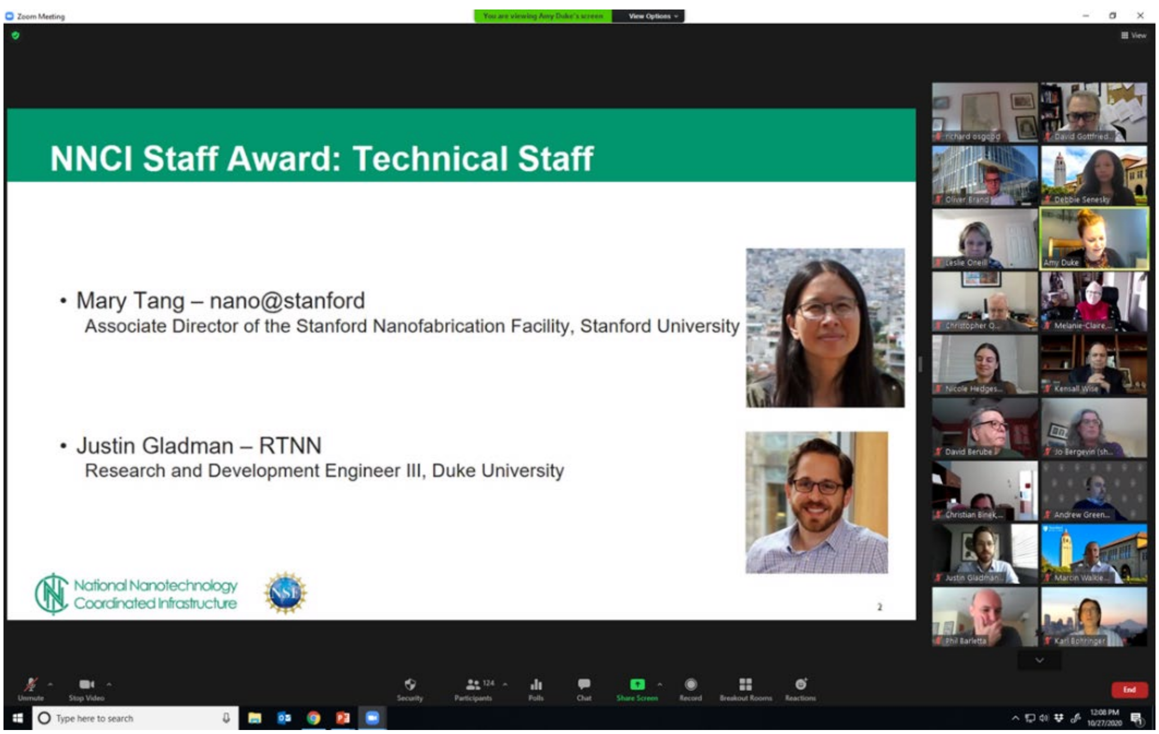
Technical Staff

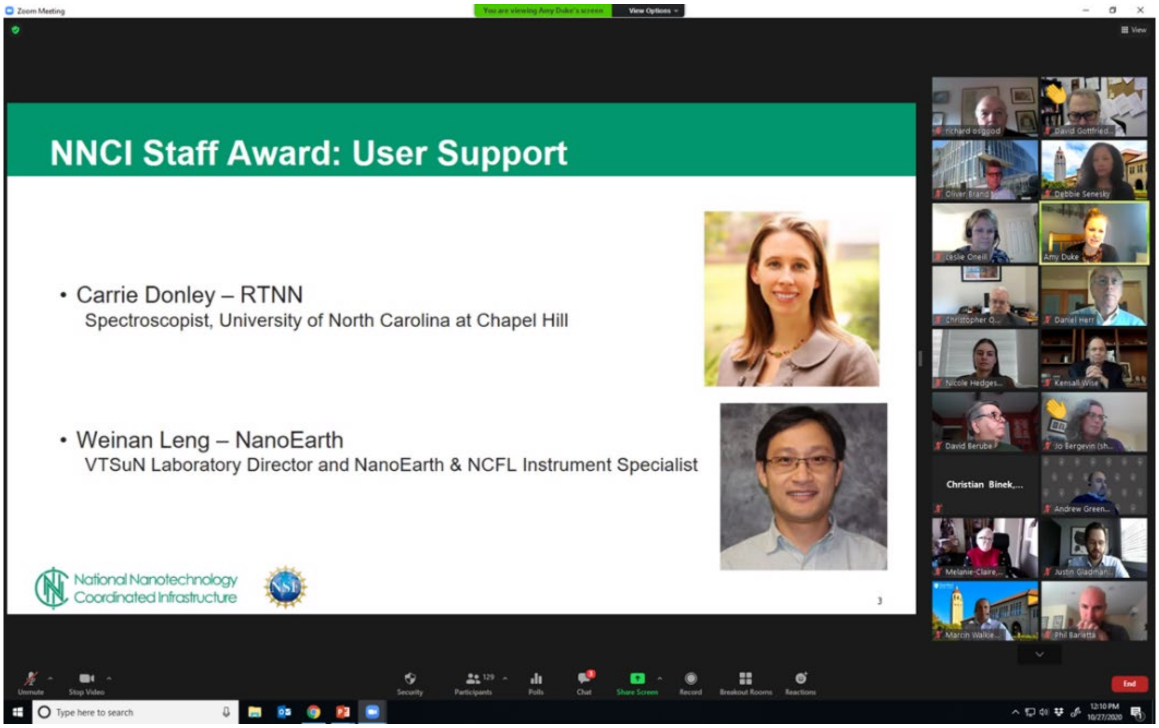
- Mary Tang (Associate Director of the Stanford Nanofabrication Facility, nano@stanford)
- Justin Gladman (Research and Development Engineer III, RTNN (Duke Univ.))

User Support

- Carrie Donley (Spectroscopist, RTNN (UNC-Chapel Hill))
- Weinan Leng (VTSuN Laboratory Director and NCFL Instrument Specialist, NanoEarth)


NNCI Staff Award: Education and Outreach
• Nicole Hedges – RTNN
Business and Education Manager, North Carolina State University
• Thomas Pennell – CNF
Research Support Specialist and Materials Integration Engineer, C
National Nanotechnology Coordinated Infrastructure


NNCI Staff Award: Technical Staff
• Mary Tang – nano@stanford
Associate Director of the Stanford Nanofabrication Facility, Stanford University
• Justin Gladman – RTNN
Research and Development Engineer III, Duke University
National Nanotechnology Coordinated Infrastructure



9.4. Responses to COVID-19 Pandemic

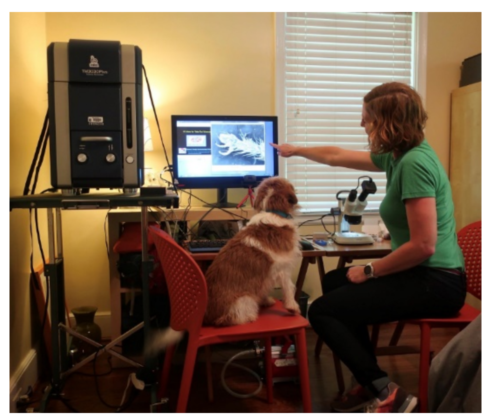
The global transmission of the novel coronavirus in 2020 and the resultant COVID-19 pandemic caused sudden and widespread upheaval to NNCI programs, events, and user facility operations. Among the immediate consequences were the near simultaneous closure of site facilities in mid-March. All NNCI programs (REU, RET, Teacher Workshops, Technical Workshops and Short Courses, Symposia, "Science Outside the Lab") were either cancelled outright, postponed to a future date, or moved to virtual formats. Finally, most, if not all, national, regional, and local scientific events and conferences (UGIM, APS, ACS, MRS) and teacher/student programs (NSTA, USA Science and Engineering Festival, local science festivals) where NNCI would have had a presence were either cancelled (spring/summer) or held in virtual formats (fall/winter). NNCI facilities began to re-open starting in June and continued to do so in stages over the next several months, with varying requirements for personal protective equipment, social distancing, research density, and new access procedures. Sites also made individual choices, often dictated by their local institutions, regarding access by external users and options for training.

Rather than remaining idle, NNCI sites quickly adapted to the new reality, implementing programs and processes to support users (both during and after the shutdown period), provide education and outreach resources, and also to take advantage of everyone's new online presence to create new and innovative opportunities. The list below provides a partial accounting of the variety of responses NNCI sites had in the face of this new challenge.

- The Coordinating Office created a new web page on the NNCI website (linked directly from a banner on the home page) specifically to document our site responses. https://www.nnci.net/blog/nnci-during-covid-19-pandemic

- Continuously-updated facility status information, both during the shut-down period and then as sites began to re-open.
- The results of a "Return to Operations" survey conducted by an ad-hoc task force that was made available as a sharing of best practices.
- Stories of research and other activities conducted at individual NNCI sites in support of the fight against COVID-19. https://www.nnci.net/nnci-activities-supporting-covid-19-efforts
- A link to the NNCI Events page which listed many of the now virtual programs (webinars) offered by sites and available to the greater research community. https://www.nnci.net/nnci-events
- A page of "Resources for Virtual Classrooms, Kitchens, Backyards, and Beyond" providing resources for children and adults, including videos, online magazines, podcasts, and activities that can be done from home using common items.

- One of the first actions taken by many sites was donation of their stocks of personal protective equipment (PPE) to local hospitals and health-care providers.
- Because of the need to share information and best practices, there was a noted increase in use of the nnci-general email listserv among NNCI site staff.
- Webinars specifically targeting NNCI staff were hosted by the Technical Content Development (April 1) and E-Beam Lithography (April 23) working groups. In addition, an ad-hoc task force, led by Mary Tang (Stanford) and Ron Olson (CNF), organized a workshop (April 21) and conducted a survey on best practices for return to operations of user facilities. As noted above, the results of this survey were also made available to other user facilities external to NNCI.



- Sites developed a variety of online education activities to help replace those events that were canceled. Examples of this include the RTNN "Take Out Science" and "Sciencing with Abby" programs and the SENIC NanoSIMST (Virtual Summer Middle School Teacher Workshop).
- Sites also developed online professional education opportunities for users and other researchers. Examples include the Technical Webinars and NanoFANS Symposium from SENIC and RTNN's Technical Short Courses. Most often video recordings of these events are archived and available online.
- After being canceled in 2020, the "Science Outside the Lab" program is planned to be offered as a virtual session during summer 2021.

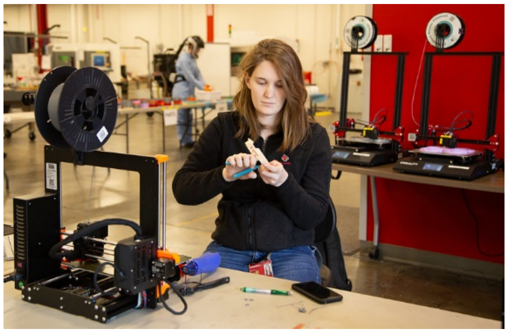
- Many sites offered online office hours and/or technical consulting opportunities for users and potential users.
- Sites developed new procedures and processes for new user orientation and existing user access and training, often developed in discussions with other NNCI sites but fulfilling requirements of their specific institutions.
- Many sites began to offer increased levels of remote work to accommodate the needs of external (and internal) users without the hazards of on-site access. This has been particularly important for external users who normally would need to travel to the host NNCI facility.
- Site annual meetings and the NNCI Annual Conference were adapted for a virtual format.
- During the shutdown period (March-June), many NNCI site staff were required to work from home, and this generated a number of suggestions for tasks that they could accomplish away from labs and offices:
    - Reading publications/literature review to deepen and/or expand knowledge base
    - Learning new or improving current skills with data analysis software
    - Learning new programming language
    - Updating website content
    - Updating instrument operating instructions
    - Writing new instructions for advanced analytical or process techniques
    - Creating new instructional training videos
    - Writing/reviewing papers or proposals
    - Attending virtual seminars
    - Creating and delivering webinars to share with users and/or NNCI staff
    - Reaching out (email, phone) to potential new users

In addition, many NNCI sites conducted unique or site-specific activity in response to the pandemic, and examples include the following, with additional stories found on the NNCI website.

- The Georgia Tech location of **SENIC**, along with lead institution Emory University, was awarded funding by the NIH as part of the Rapid Acceleration of Diagnostics (RADx) program. The Georgia Tech role is to serve as the engineering core, evaluating dozens of new designs for COVID-19 laboratory and point-of-care molecular (RNA) or antigen tests for robustness, technology readiness level, manufacturability, and usability.
- At **NNF**, a new partnership with Educational Talent Search (ETS) created virtual lessons and ETS staff training for After-School programs to underrepresented middle/high school students (50 junior high/25 high school students planned monthly). Existing distribution systems are used to send materials home with students for hands-on activities during the presentations. In addition, nanotechnology lessons were provided for 4H/Nebraska Extension Boredom Busters virtual series and NNF worked with the UNL Engineering

College to provide rural schools with virtual nanoscience lessons including hands-on materials.

- **Nano@stanford** assigned each research group or organization a staff person to help coordinate any resource needs that may be more challenging under pandemic conditions.



- The AMIST additive manufacturing facility at **KY MMNIN** took the lead on a regional effort to 3D print protective face-shields and swabs for coronavirus testing. Similarly, **NanoEarth** co-PI Marc Michel is using his expertise in inverse stereolithography, a type of additive manufacturing, to design and fabricate 3D-printed adapters that convert snorkel masks into reusable passive respirators with viral filters and to address shortages of COVID-19 test swabs.

- The New York Times described **NanoEarth**'s Deputy Director Linsey Marr as "one of the world's leading experts on airborne transmission of viruses" and has relied on her heavily for their coverage of the COVID-19 pandemic. In addition to performing research on the efficacy of homemade masks, she has been a key public-health figure in the fight against COVID-19 for numerous media outlets and has been active on Twitter to keep the public informed. She has been mentioned and quoted nearly 8,000 times in news from 96 countries reaching an estimated 18 million unique individuals.


The New York Times

The Scientist, the Air and the Virus

Most of us had never heard of aerosol science before the pandemic. Then Virginia Tech's Linsey Marr showed up and became our tour guide to the invisible world of airborne particles.

- **MANTH**'s response to the COVID pandemic began in early January. This site prepared by ensuring that they had several months of access to consumable cleanroom supplies. By March 2020, MANTH was stocked with sufficient consumable resources to run uninterrupted for 18 months. Many of the contacts and sources for these resources were shared with the rest of the NNCI via the Vendor Relations working group.

10. NNCI Network Usage

Individual NNCI site performance, and that of the network as a whole, can generally be assessed based on four major criteria: (1) ability to serve the greatest number and broadest set of researchers from academia, industry, and government, while keeping in mind site's capabilities and focus, (2) impact on the research enterprise and its economic importance in the commercial realm, (3) societal impact based on improved public awareness, diversity, and workforce development for nanoscale activity, and (4) contributions of sites to the NNCI network. Given these broad criteria, each site determines the set of metrics for their annual site report to NSF that best fit their own technical specialization (if any), regional user base and commercial interests, and any partnership arrangements. A non-exhaustive list of examples of potential metrics, many based on experience from NNIN, has been provided in previous reports.

NNCI sites collect statistical data about their users in an effort to assess the strength and success of the internal and external user programs. Research disciplines can be used to help track usage in non-traditional areas. Productivity is implied from annual assessment of user research publications, patents, and presentations that rely on use of the shared facilities and the research budgets enabled. It is more difficult to quantify the productivity of industrial usage, where publications are not the norm, but data on numbers of start-up companies, their financial well-being, patent applications and personnel hiring can be used as indirect measures. In addition, sites may decide to conduct regular user and/or PI satisfaction surveys as a means of assessing site quality and making adjustments to operations as needed (see Section 7.4 above). Education and outreach evaluation plans will provide assessments to guide program improvement as well as impact and effectiveness of programs. Finally, each site's contributions to creating a unified network that surpasses the sum of its parts can be assessed by participation of site personnel in network activities (see Section 9 above).

That being said, it is important that a common set of data for the NNCI network sites, as well as aggregated data for the network as a whole, be regularly collected. The NNCI Coordinating Office has established a *Metrics and Assessment Subcommittee* that has agreed upon a common set of site and network metrics, and the collected data are consistent with the user statistics developed under the NNIN program. The following are the definitions provided to all sites for creating a uniform set of metrics.

1. An on-site user is someone who physically comes to a site facility (or partner facility) to access the tool set. A remote user is someone who contracts to have processing and/or characterization done by site staff for them. In general, there should only be one remote user for any given piece of work. Faculty (both internal and external) and industry PIs, unless they actually do hands-on work themselves, should not be counted as users – only the students/researchers who do the work are users. Site staff should not be counted as users, unless they have a dual role and act as a student/researcher as well. All included facilities are OPEN, SHARED, USER facilities, where the tools are available to all researchers (internal and external) for hands-on use. Purely service facilities or individual PI labs should not be included. It is also important to not count users more than once for using multiple facilities of a single NNCI site. In short, every user in the cumulative user count corresponds to a single, unique individual. Even though summer interns/REU students are typically paid with internal funding and working on internal projects, these users are counted as EXTERNAL users as their home institution is another university/college, which is the primary factor that governs affiliation.

2. Stats are broken down by Affiliation, meaning the type of institution, and Discipline, meaning the area of research. Local Site Academic refers to users who are either students or employees of a site (or its partners). All other Affiliations are for external users. A Small Company is defined as one with <500 employees. Disciplines are often self-selected by the user, or perhaps by site staff. In the Discipline category "Educational Lab Use" is NOT intended to count students in a regular university class which uses the NNCI site facilities. Rather, this category is applied to users who attend workshops or short courses, created as part of a sites NNCI education and outreach, where hands-on work (attendees actually go into the lab) is part of the program.
3. Lab Time refers to actual time in the cleanroom OR tool time for all users during a given month. These should not be double counted. In other words, if a student is using multiple tools in the cleanroom, only the time in the cleanroom should be used. If a student is outside the cleanroom, but a process is still running, the tool time can still be counted. Most characterization tools, outside the cleanroom, are counted as straight tool usage time. For cases when users are logged into a cleanroom tool, but he/she is not inside the cleanroom (for example, during extended furnace runs), tool time is recorded.
4. Monthly Users are the total number of unique individuals who access a site in a given month. In this case, the total number may be different than the sum of On-Site + Remote if a user accesses the site via both methods in a given month.
5. Cumulative Users is the running total of all users since the beginning of the NNCI year on October 1. Each year on October 1, the cumulative count starts over with all users counted again.
6. Fees data are the revenue from all user fees for use of a site's facilities. This data does not include indirect charges (if they are assessed). If a site uses a cap on charges after a certain hour limit, only the actual fees charged are reported, but the actual hours used over the cap limit are reported in Lab Time.
7. New Users Trained refers to those users who are first time users (and typically attend a site's orientation program) in that month. In this section all users should only be included ONE TIME during the entire life of the NNCI program.

10.1. NNCI Aggregate User Data (Oct. 1, 2019 - Sept. 30, 2020)

Since each site provides its own usage data as part of their annual report and a subset of this data is provided in the site reports below (Section 11), we have not included exhaustive sets of individual site data here, but rather the aggregate for the NNCI network. In Table 12 below, we provide the NNCI totals, along with the average for the 16 sites, as well as the minimum and maximum values for the sites as an indication of the wide variation among the sites.

Table 12: Summary of NNCI Aggregate Usage Data (Year 5)

	NNCI Network	NNCI Sites Mean (Min - Max)
Unique Facility Users	10,501	656 (169 – 1,501)
Unique Internal Users	7,668	479 (121 – 1,320)
Unique External Users	2,833 27.0%	177 (47 – 511) 27.5% (12.1% – 48.2%)
External Academic	1,064	67 (9 – 342)
External Industry	1,529	96 (16 – 247)
External Government	182	11 (0 – 130)
External Foreign	58	4 (0 – 13)
Average Monthly Users	3,654	331 (48 – 605)
New Users Trained	2,813	176 (34 – 375)
Facility Hours*	767,225	47,952 (4,858– 139,175)
Facility Hours – External Users	197,368 25.7%	12,335 (1,463 – 45,519) 26.8% (5.0% – 60.2%)
Hours/User*	73	68 (29 –108)
User Fees Internal Users External Users	 $16.3M $13.1M	 $1.02M $0.816M

*Hours were collected as lab usage hours (time in the cleanroom), tool usage hours (when operated while not in the cleanroom), and tool usage hours for non-cleanroom tools. While we have conveyed this definition to the sites (see above), we have not made an attempt to standardize the data collected.

The data ranges presented above also need to be considered with some nuance and context as to the nature of the individual sites and their sometimes unique roles within NNCI. As has also been discussed previously, sites with large numbers of internal users and total users may have a lower external user percentage while still serving large external user populations.

A comparison of the network aggregate usage data for Years 1-5 is shown in Table 13 below. As can be seen, all metrics show significant decreases from Year 4 to Year 5, most in the range of 20-30%. Of course, this needs to be taken with the context that all site facilities were closed for several months during the COVID-19 pandemic. The changes in internal and external users and usage hours over the first five years of NNCI are illustrated in Figures 10 and 11.

Table 13: Comparison of Years 1-4 NNCI Aggregate Usage Data

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 4-5 Change
Unique Facility Users	10,909	12,452	13,110	13,355	10,501	-21.4%
Unique Internal Users	8,342	9,276	9,731	9,503	7,668	-19.3%
Unique External Users	2,567 23.8%	3,176 25.5%	3,379 25.8%	3,852 28.8%	2,833 27.0%	-26.5%
External Industry Users	1,413	1,669	1,870	1,961	1,529	-22.0%
External Academic Users	1,060	1,295	1,365	1,531	1,064	-30.5%
Average Monthly Users	4,429	4,911	5,001	5,292	3.654	-31.0%
New Users Trained	4,116	4,563	4,981	5,194	2,813	-45.8%
Facility Hours	909, 151	939,230	1,006,764	1,149,788	767,255	-33.3%
Facility Hours – External Users	173,511 19.1%	191,494 20.4%	228,441 22.7%	298,986 26.0%	197,368 25.7%	-30.9%
Hours/User	83	75	77	86	73	-15.1%
User Fees Internal Users External Users	 $20.6M $13.5M	 $23.0M $14.5M	 $23.6M $16.9M	 $23.2M $20.5M	 $16.3M $13.1M	 -29.7% -36.1%

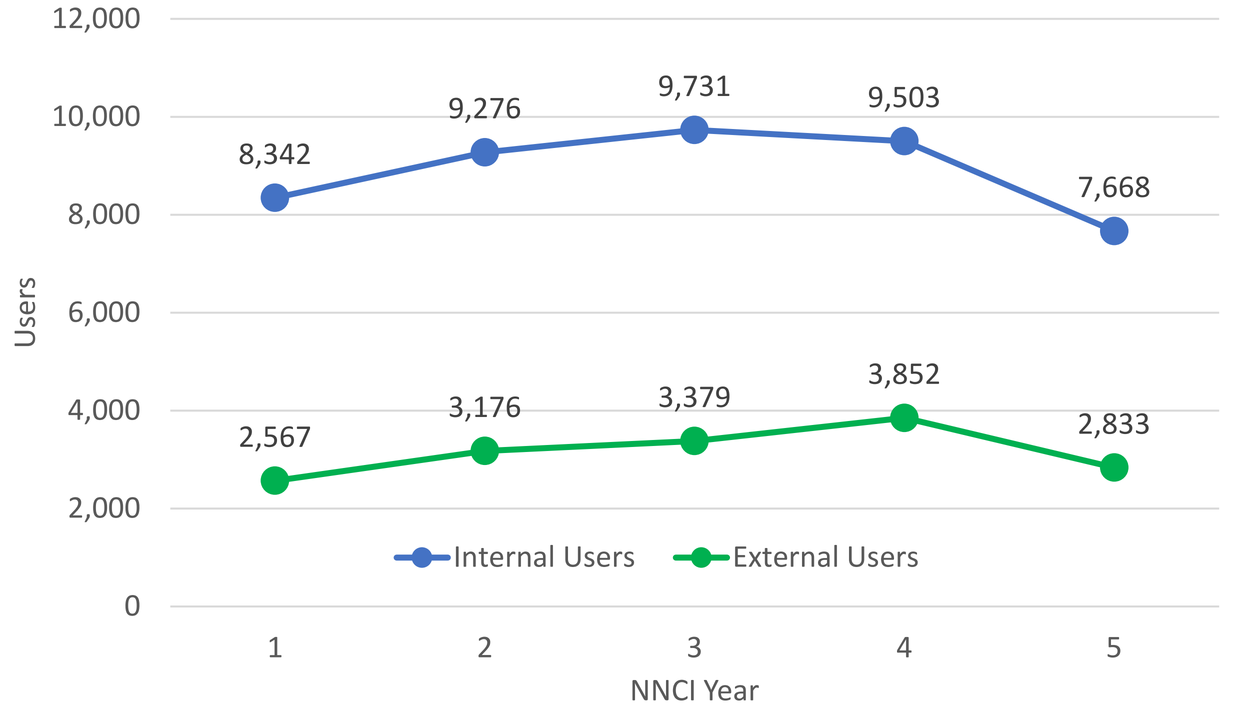


Figure 10: NNCI Users by Year

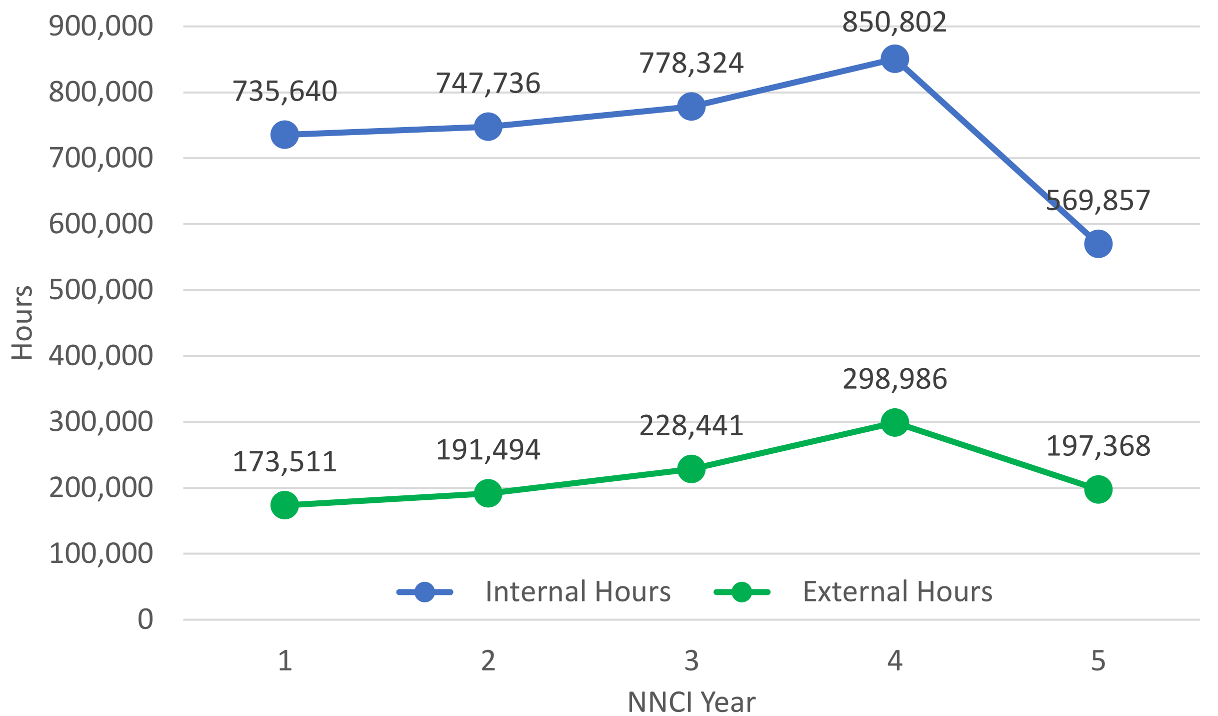


Figure 11: NNCI Usage Hours by Year

Even after re-opening of NNCI facilities during the June-August 2020 timeframe, many sites operated with reduction in usage capacity, limits on external usage, and/or eliminated training opportunities. The effects of the pandemic were most striking for external users (and training), nevertheless the fraction of users and hours from external sources, 27% and 26% respectively, did remain relatively constant over the course of Year 5 compared to Year 4 (See Table 13). A deeper analysis of the effects of the pandemic closures and recovery of usage is explored in the figures below. Figures 12 and 13 show the Years 4 and 5 monthly change in cumulative users and lab time, respectively, across all NNCI sites. It is clear that usage at the beginning of Year 5 was on a pace to match or exceed that of Year 4, but plateaued suddenly when facilities were shut down in March 2020 and only began to recover partially beginning in June. The cumulative usage in Year 5 is further dissected into internal and external users in Figure 14, where it is clear that recovery is slower for external usage perhaps due to the added burden of travel restrictions. This is further illustrated in Figure 15 which shows the percentage of cumulative external users by month. It is clear that in Year 4 (and previous years) the fraction of external users increases throughout the year, with a particular increase during the summer months likely benefited by REU students and other summer research users. During Year 5, of course, this summer effort was curtailed and the overall decrease in external usage is obvious. These pandemic effects on usage are amplified in Figure 16, which shows the total number of monthly users across the NNCI, and indicates that as of September 2020 (end of NNCI Year 5) monthly users have only reached less than 70% of the number from February 2020. Nonetheless, those users who have returned to the facilities since June are operating at their normal pace, as indicated by the data in Figure 17 (hours/user).

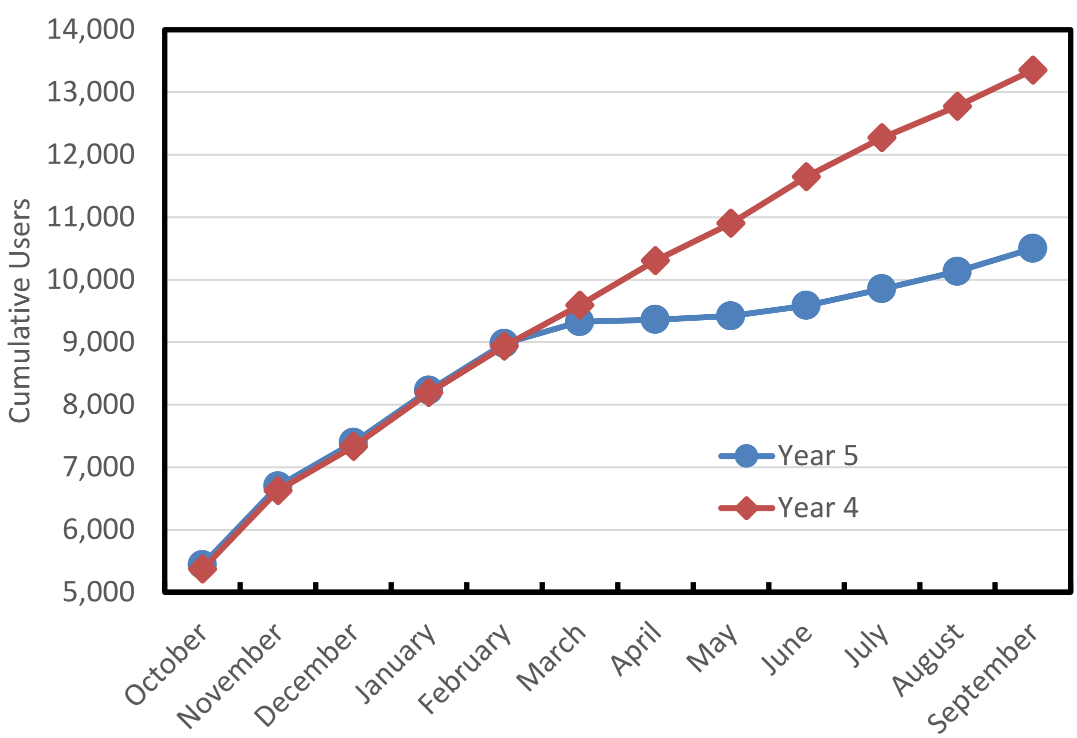


Figure 12: NNCI Cumulative Users by Month for Years 4 and 5

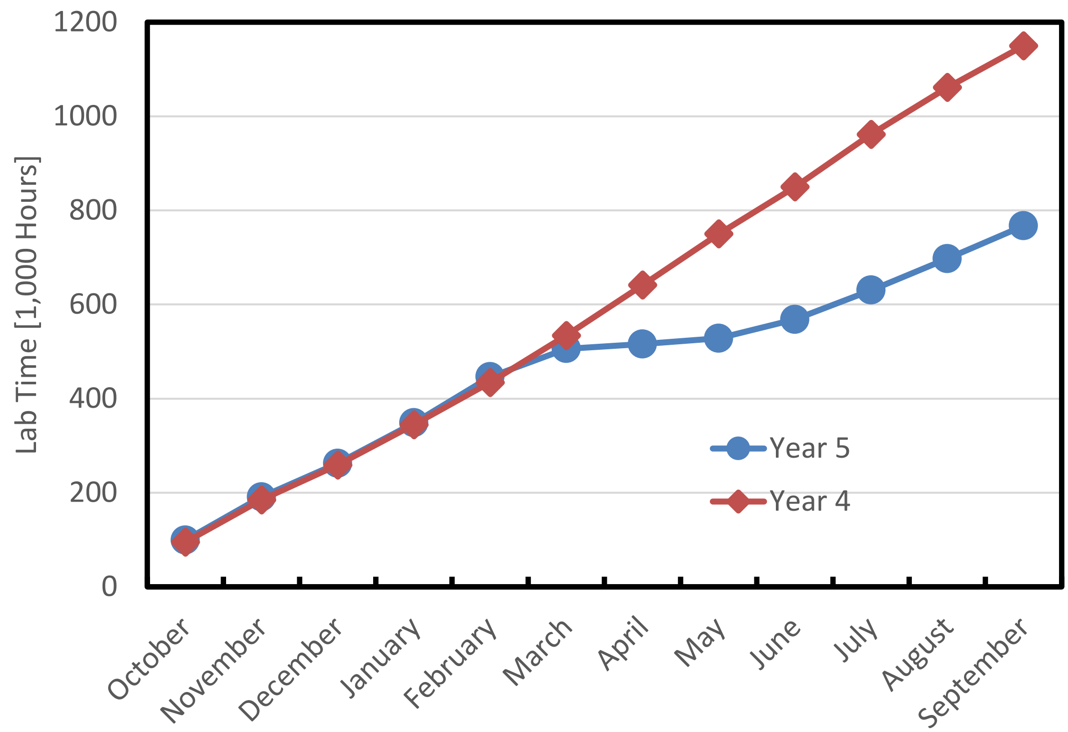


Figure 13: NNCI Lab Usage Time (1,000s of Hours) by Month for Years 4 and 5

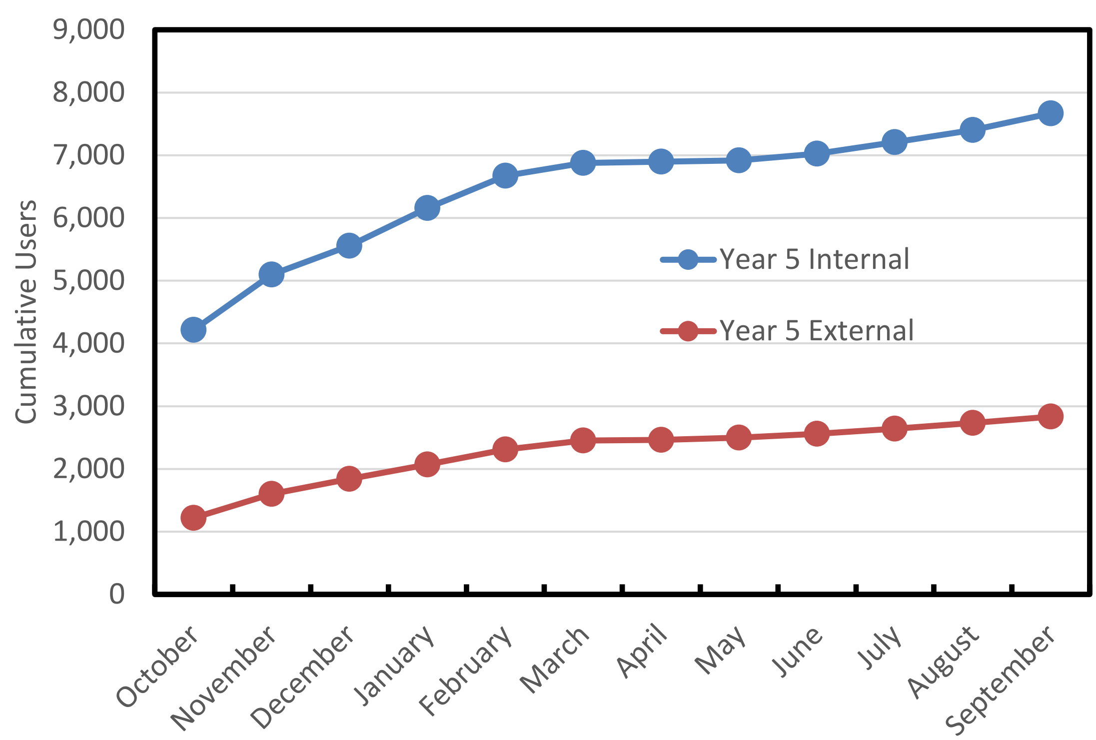


Figure 14: NNCI Cumulative Users, Internal and External, by Month for Year 5

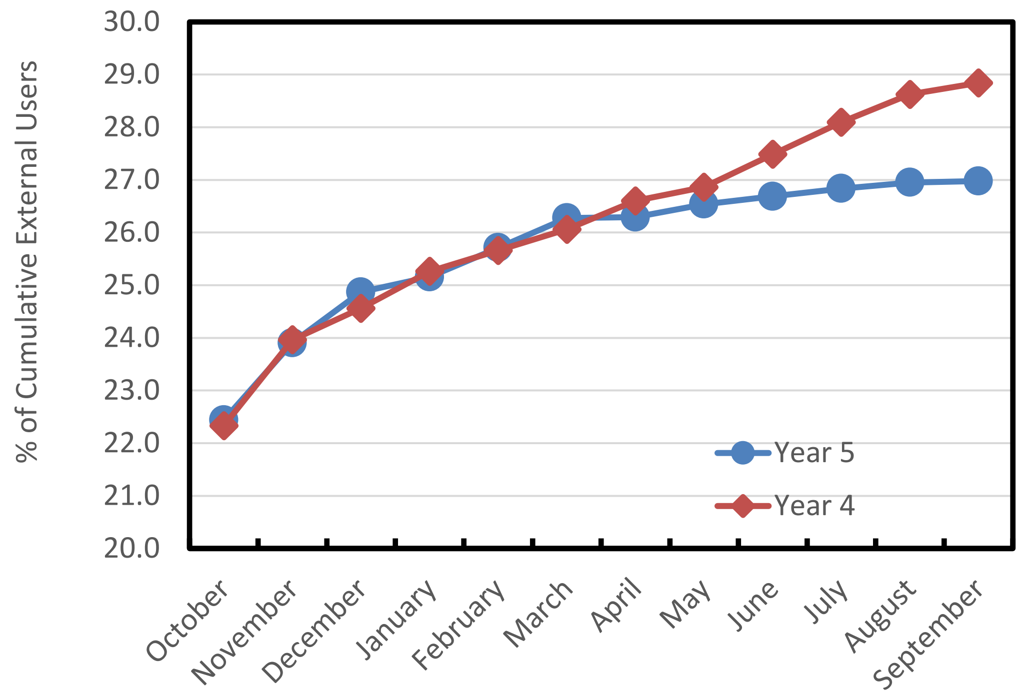


Figure 15: NNCI Cumulative External Users (%) by Month for Years 4 and 5

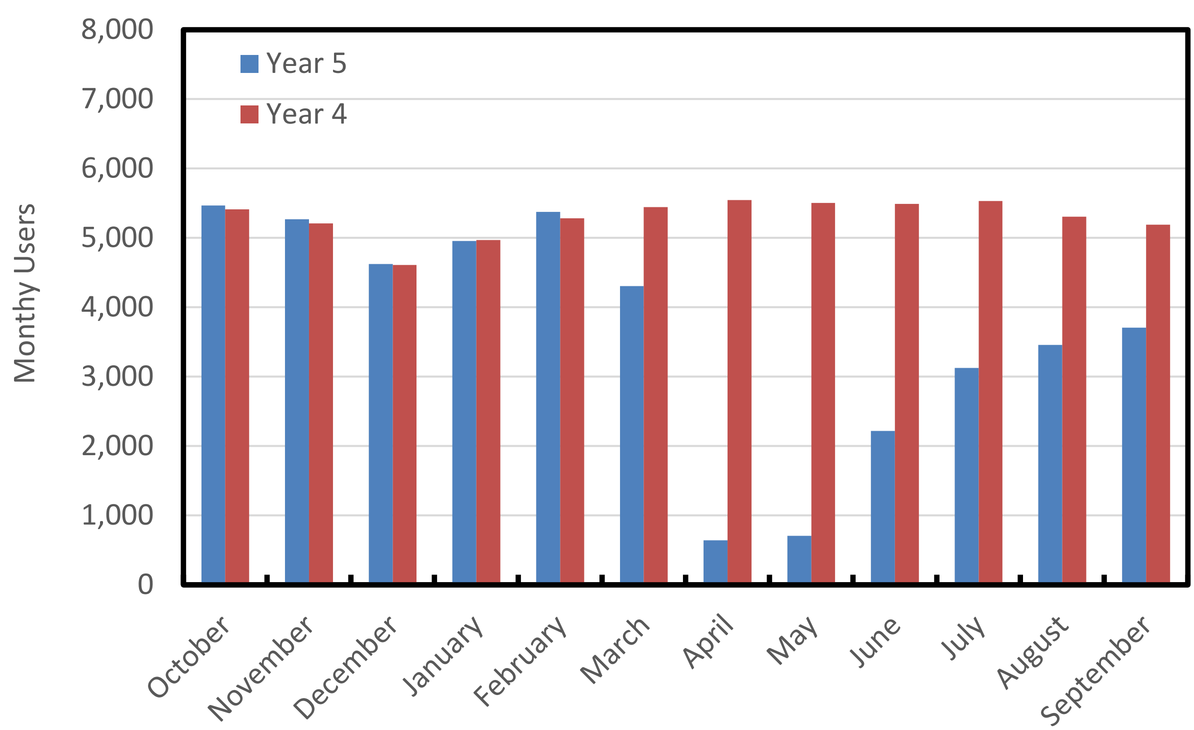


Figure 16: NNCI Total Monthly Users for Years 4 and 5

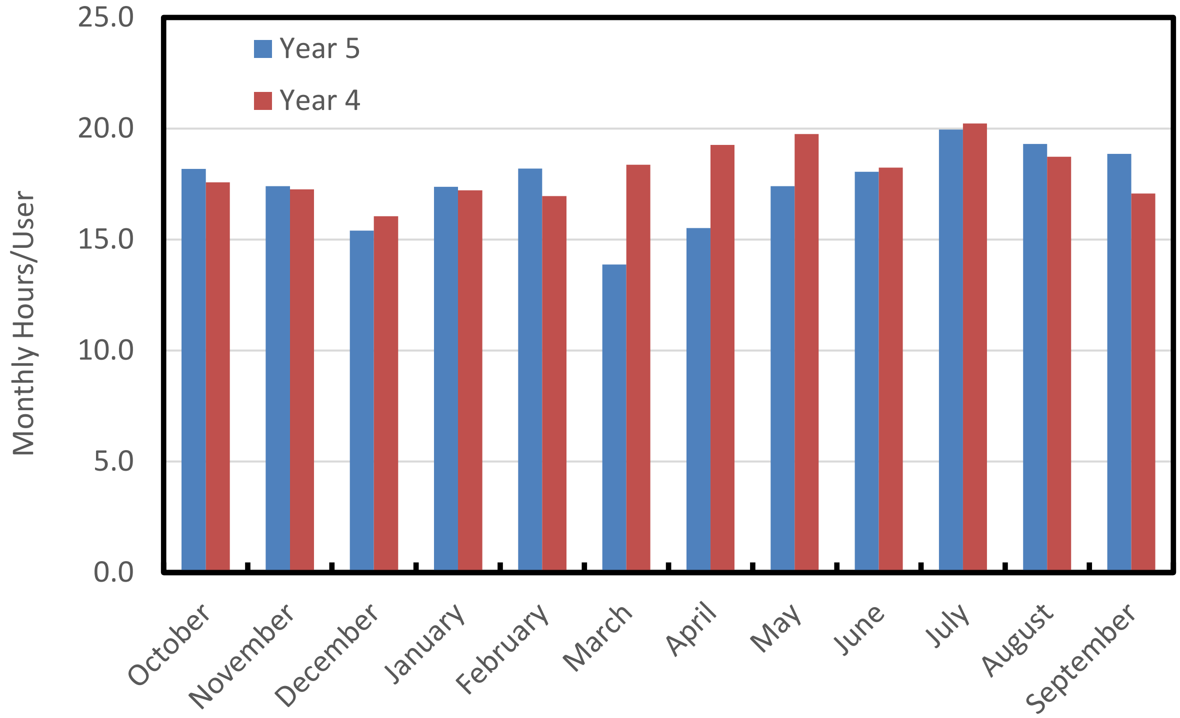


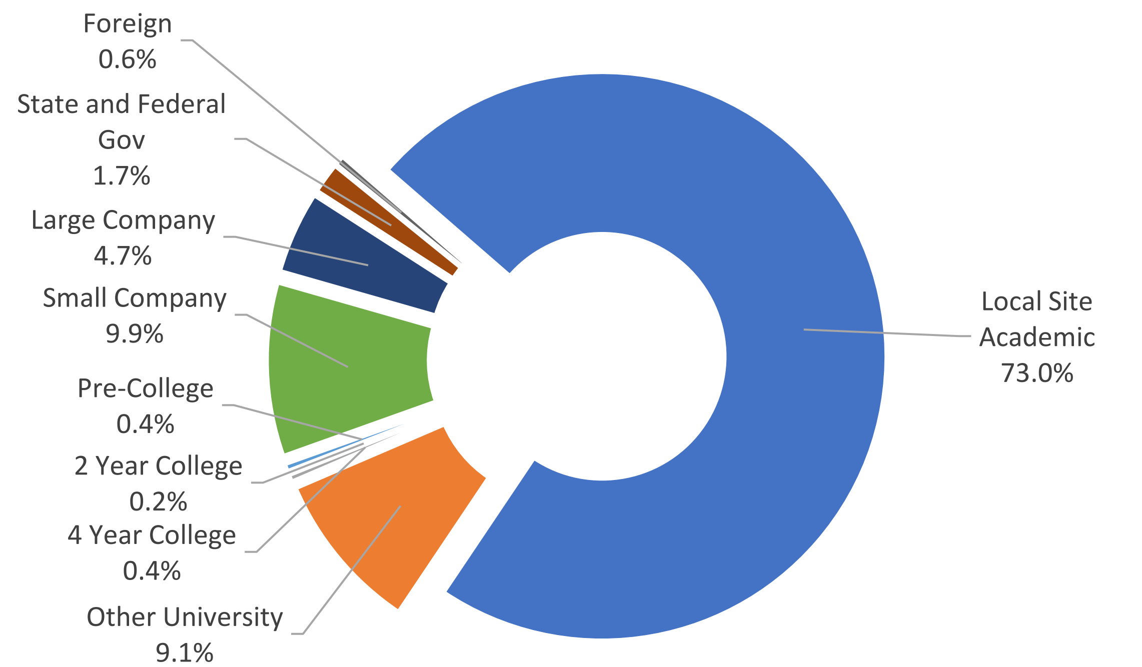
Figure 17: NNCI Total Monthly Hours/User for Years 4 and 5

The 2,800+ Year 5 external users come from 1,084 distinct external institutions (full list shown in Appendix 13.3), including 210 academic institutions (Figure 18), 573 small companies, 200 large companies, 27 US local/federal government organizations, 62 international institutions (from Europe, Asia, North America, South America, and Australia), and 12 other institutions (museums and non-profits, for example). This number does not include cases where an external institution (not necessarily the same PI or user) is working at multiple NNCI sites. It also does not include 112 companies that remain anonymous due to contractual requirements with one of the NNCI sites and may or may not overlap with those listed in the appendix.

Figure 18: NNCI Year 5 Academic Institutions (210 External)

Figure 19 show the breakdown of users and lab hours by affiliation for the entire network. Individual affiliation plots are shown for each site in the data of Section 11 below. While external users make up 27.0% of total users, external hours are 25.7% of total hours, a smaller discrepancy than observed in previous years. In any event, the difference is likely due to the proximity and ease of access of internal users to the facilities, which provides them opportunities for greater overall use, although the difference between percentage of external users and external hours is diminishing each year (see Table 13 above).

A comparison of Year 5 cumulative users (by affiliation) by site is provided in Figure 20 for all users and Figure 21 for external users only. Care should be taken when analyzing these data and particularly when comparing different sites. The NNCI sites are diverse: some are located in “nanotechnology” hub areas, others are not; some serve a general NSE user base with a broad tool set, others have a particular research focus; some were part of the NNIN program, others were not; some have a large number of facilities, tools, and staff, others do not. Thus, it can be difficult to draw conclusions from a site-to-site statistical comparison.



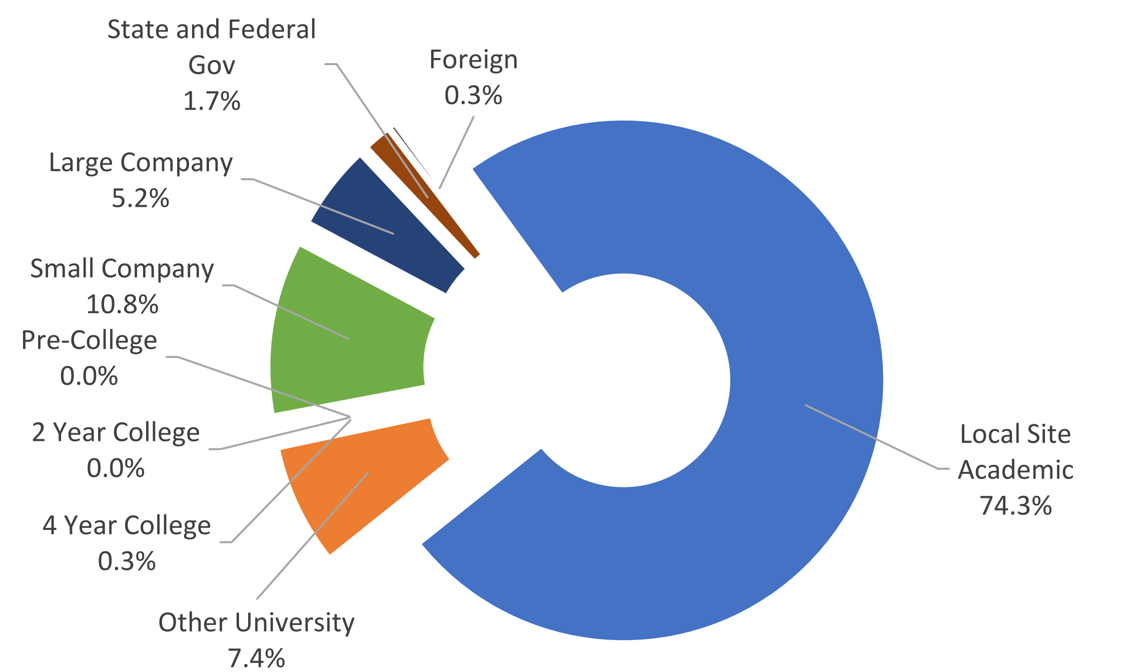


Figure 19: NNCI Users (top) and Usage Hours (bottom) by Affiliation (Year 5)

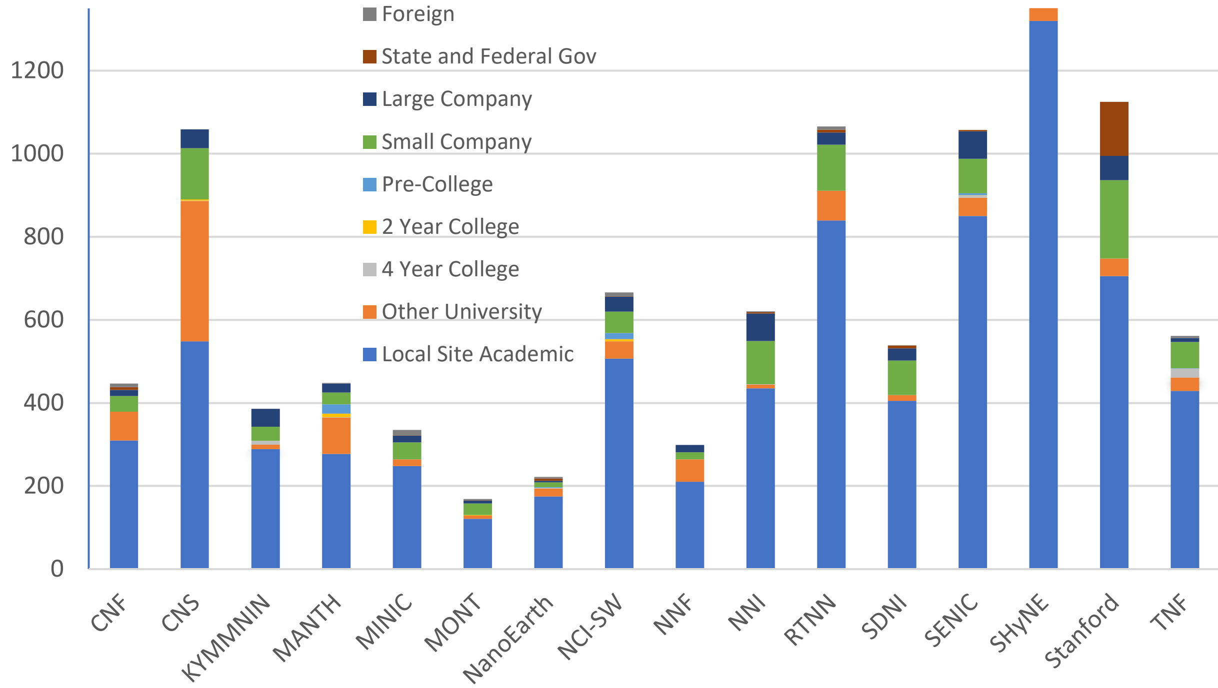


Figure 20: NNCI Cumulative Users by Site (Year 5)

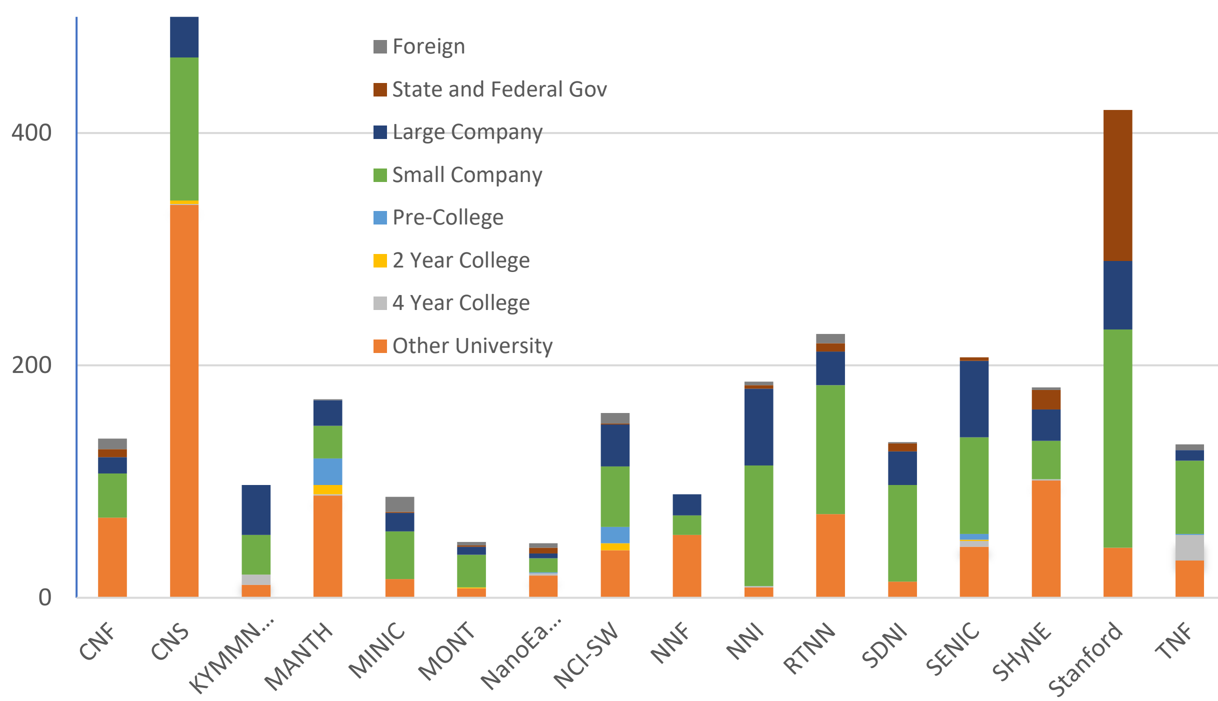


Figure 21: NNCI Cumulative External Users by Site (Year 5)

For academic institutions a network map showing the NNCI nodes and associated US colleges and universities (from 44 US states) is shown in Figure 22 below. The size of the NNCI node (blue circle) is proportional to the number of unique academic entities it has as users. Universities with projects at three or more NNCI sites (22 in Year 1, 35 in Year 4, and 25 in Year 5) are labeled in Figure 22, including one institution (UC-Santa Cruz) with projects at 5 different NNCI sites and 4 (MIT, Penn State, South Dakota School of Mines and Technology, and UCLA) with projects at 4 sites. Year 1 had 296 linkages between institutions, and this increased each year reaching 395 in Year 4, but has fallen to 307 in Year 5 due to the pandemic-related decrease in usage. In addition to the academic usage depicted by the figure, it was also observed that approximately 40 companies, government agencies, or foreign entities accessed facilities at multiple NNCI sites, although it cannot be determined if these resulted from the same or unique users or projects.

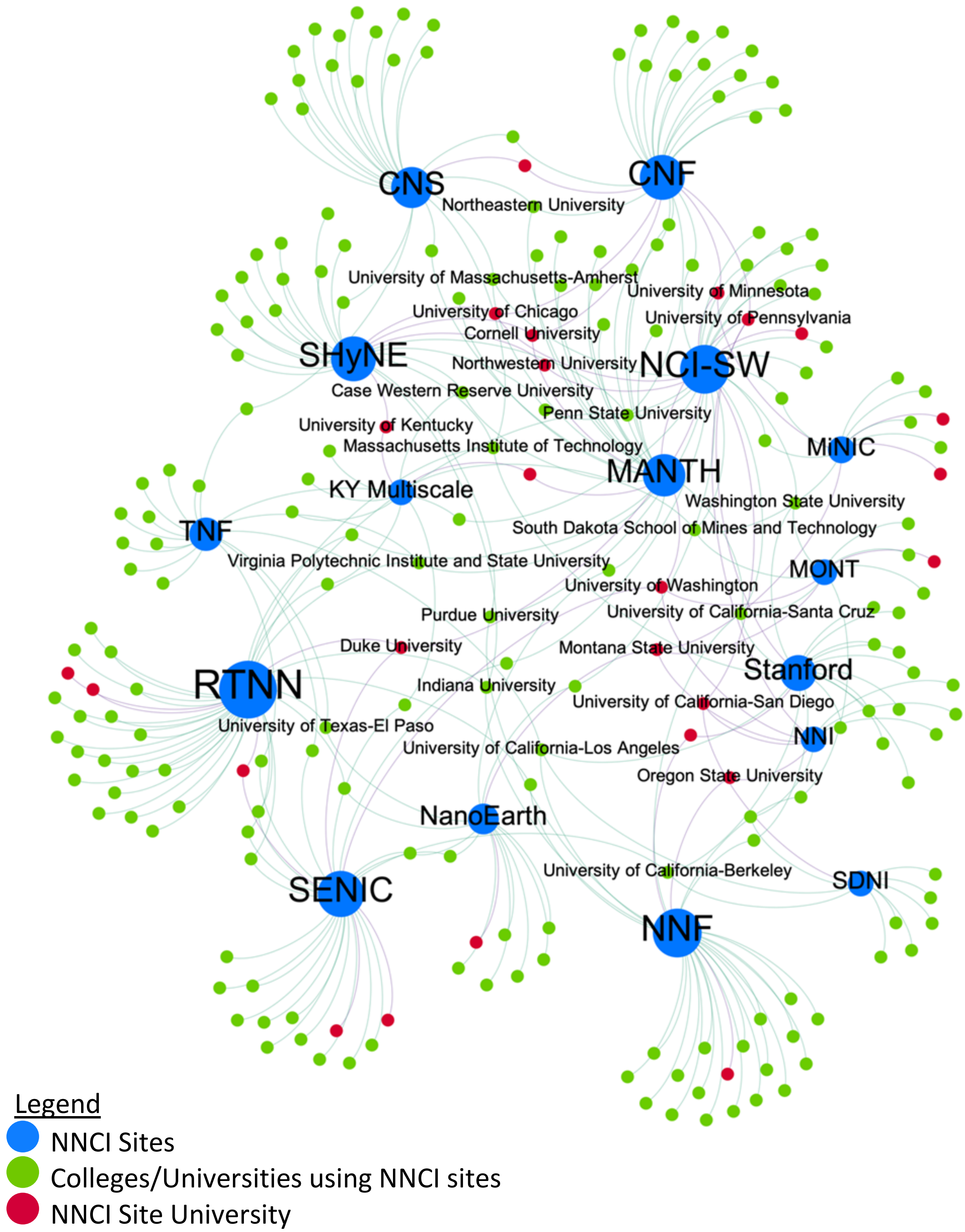


Figure 22: NNCI Academic User Network Map (Year 5)

10.2. Non-Traditional Users

One important, though difficult to define, metric is how well NNCI reaches and assists non-traditional users. In order to determine the best way to assess this aspect of NNCI activity, a breakout session on this topic was held at the 1st NNCI Annual Conference (January 2017), and a summary of that discussion was included as part of the Year 1 NNCI Annual Report (March 2017). In addition, the Building the User Base subcommittee has indicated that non-traditional users may come from the following categories:

1. Research areas that do not typically use nanotechnology facilities; these are identified using the disciplines described in more detail below.
2. Demographic groups, such as women and under-represented minorities; information on minority serving institutions is provided below.
3. Users from non-Research I educational institutions; data on 2-year and 4-year colleges are provide in the affiliation statistics above.
4. Small companies; data on small company users are provide in the affiliation statistics above.
5. K-12 students, community college students, and teachers; affiliation data is provided for pre-college users and more information about outreach to this category is provided in Section 4.1.

The charts below illustrate the usage of the NNCI network by users in specific disciplines (internal and external). It is worth noting that in many cases these disciplines are self-selected, may reflect the user's home department or their specific area of research, and these may be different from each other. Figure 23 illustrates the distribution by number of users in specific disciplines, while Figure 24 illustrates the usage hours by discipline. Furthermore, Figure 25 illustrates the average number of hours/user across the network based on the user's discipline, illustrating that the fabrication-heavy disciplines of electronics, MEMS, optics, and physics tend to require more lab usage by researchers. These distributions are similar to previous years, continuing the rapid growth in Geology/Earth Sciences users (5.1% in Year 5 compared to 2.4% in Year 1) and usage hours (5.6% in Year 5 compared to 1.2% in Year 2), and this is also reflected in the hours/user for that discipline. The annual changes in number of users in each discipline are graphically displayed in Figure 26 (with "Educational Lab Use", "Process", and "Other" removed for clarity).

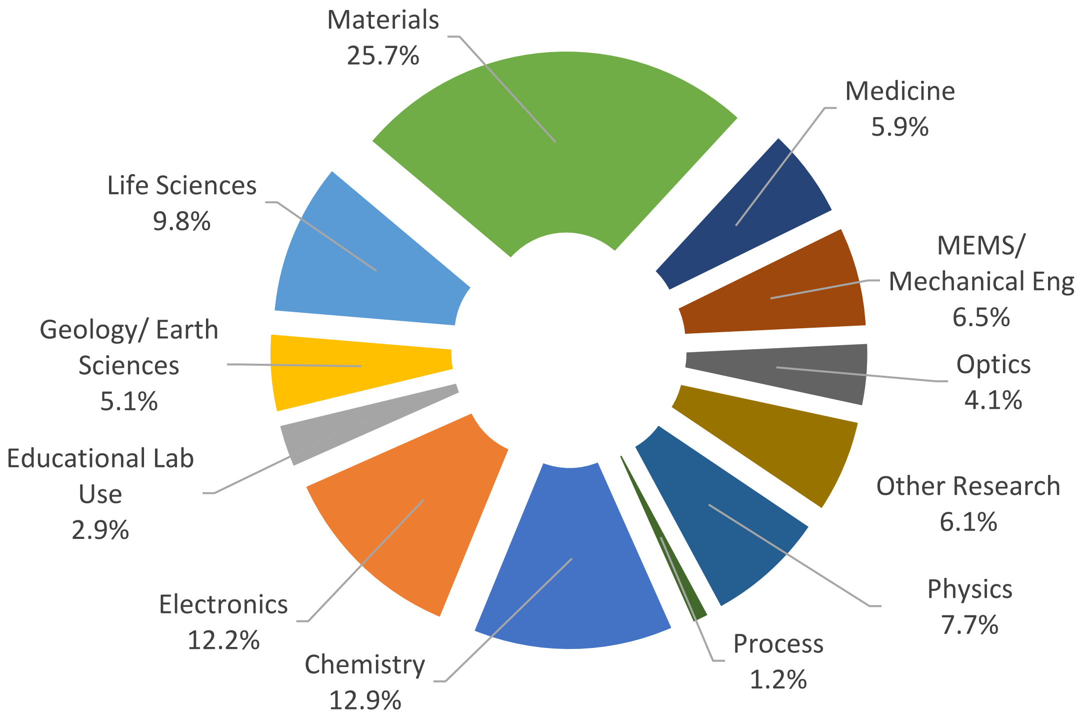


Figure 23: NNCI Users by Discipline (Year 5)

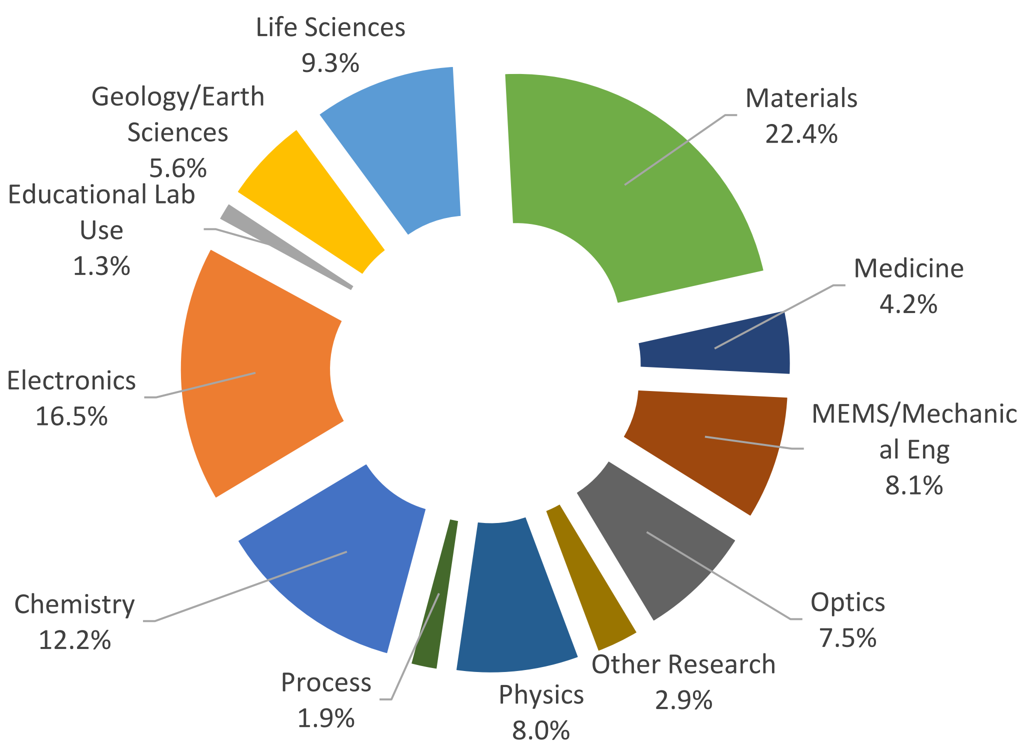


Figure 24: NNCI Usage Hours by Discipline (Year 5)

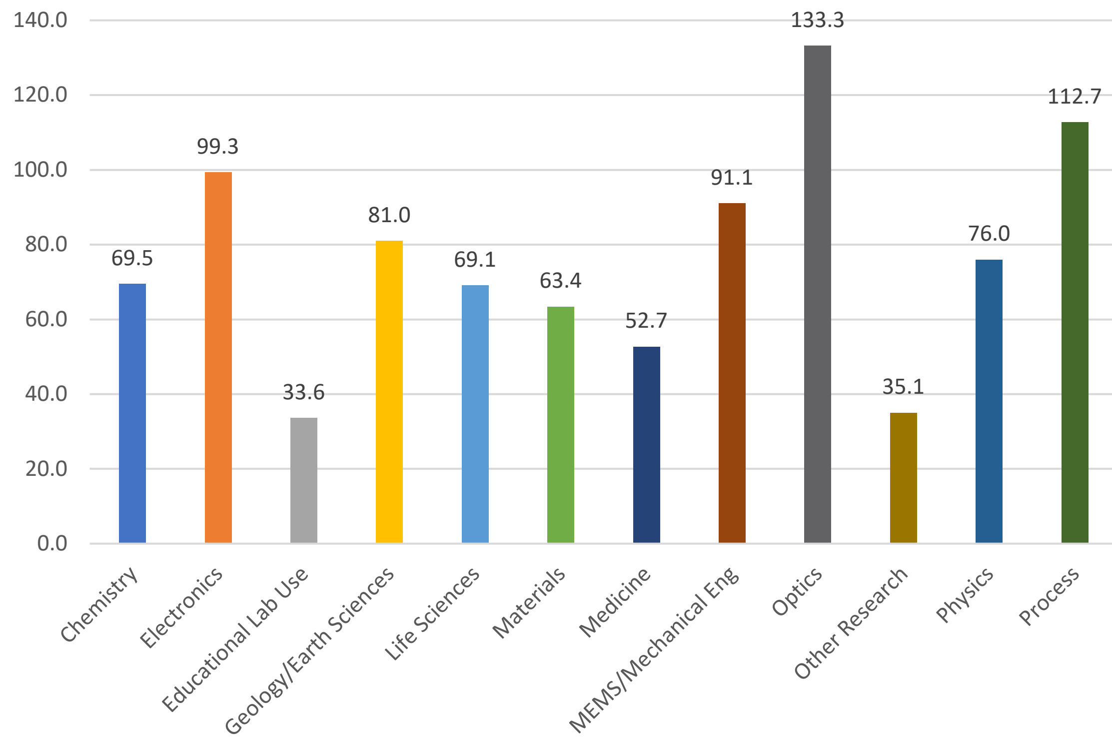


Figure 25: NNCI Hours/User by Discipline (Year 5)

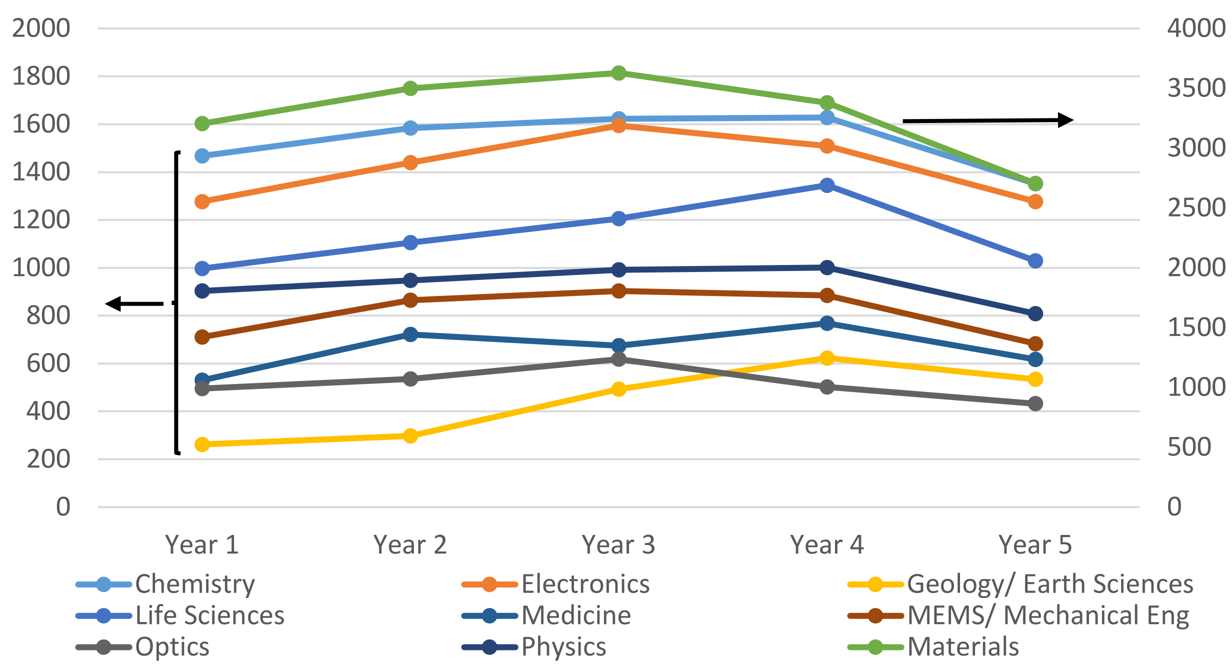


Figure 26: NNCI Yearly Users by Discipline ("Materials" indicated by the right Y-axis for comparison purposes.)

Beginning with the Year 1 annual report, and as a matter of convenience, we have defined "traditional" disciplines to include the engineering-related electronics, materials, MEMS, and process development disciplines, whereas "non-traditional" contains everything else (Educational Lab Use is excluded in this tabulation). Table 14 below compares the relative usage breakdown by number of users and hours for each year of NNCI. Using the above definition, the number of users was split evenly between traditional and non-traditional during the first three years, with a measurable shift in the usage hours from traditional to non-traditional during that same time period. However, during Year 4 usage by non-traditional users has increased significantly so that is now the dominant population of users, although the relatively proportion of non-traditional usage hours did decrease during Year 5.

Table 14: Usage by Traditional and Non-Traditional Disciplines

	Year 1	Year 2	Year 3	Year 4	Year 5
# of Users					
Traditional*	5386 (51%)	6063 (50%)	6384 (50%)	5997 (47%)	4791 (47%)
Non-Traditional**	5262 (49%)	6044 (50%)	6383 (50%)	6750 (53%)	5408 (53%)
Hours of Usage					
Traditional*	495,215 (55%)	506,393 (54%)	510,180 (51%)	543,838 (48%)	374,934 (50%)
Non-Traditional**	409,935 (45%)	424,855 (46%)	490,992 (49%)	588,980 (52%)	382,140 (50%)

* Electronics, Materials, MEMS/ME, Process

** Chemistry, Physics, Optics, Medicine, Life Sciences, Geo/Earth Sciences, Other

As indicated above, another measure of non-traditional usage within NNCI is to examine the diversity of users' home academic institutions, particularly those that serve under-represented minority populations as defined by the US Dept. of Education.

- As constituted, NNCI sites contain one *Historically Black College and University* (HBCU), North Carolina A&T State Univ. (SENIC), one *Minority-Serving Institution* (MSI), UNC-Greensboro (SENIC), and one *Primarily Black Institution* (PBI), Community College of Philadelphia (MANTH).
- Four other primary sites are recognized as *Emerging Hispanic Serving Institutions* (EHSI, 15+% Hispanic undergraduate students): Univ. Texas-Austin (TNF), Arizona State Univ. (NCI-SW), Univ. California-San Diego (SDNI), and Stanford (nano@stanford).
- During Year 5, external academic users came from 17 *Hispanic Serving Institutions* (HSI, 25+% Hispanic undergraduate students), 21 EHSI, 9 HBCU, and 10 *Asian-American and Native American Pacific Islander* institutions (AANAPI). Thus, 57 of the 210 (27%) US academic institutions using NNCI facilities serve under-represented populations.
- Examples of these institutions are: Cal State University-Bakersfield, Elizabeth City State University, Florida International University, Hampton University, Morgan State University, Phoenix College, San Jose State University, Tuskegee University, University of California-Davis, and University of South Florida.

More generally, the fraction of users from non-research academic institutions (4-year colleges, 2-year colleges, and pre-college) has remained steady through the first four years of NNCI at approximately 1% of all users.

10.3. Publications Information

The publications data shown below (Table 15) was collected by sites for the calendar year 2019. Due to the difficulty in getting compliance from users for this requested information, this should only be considered a lower limit of the actual publications data. In addition, no attempt was made to remove duplicates, where authors might have been from multiple NNCI sites. This represents a slight 2% decrease in total publications compared to Year 4 (2018 publications) with most of this due to fewer collect external publications and conference presentations (355 in Year 5 compared to 481 in Year 4) perhaps due to difficulties collecting information during the pandemic. Publications reported by each site range from 108 to 663. At the same time, a 22% increase was seen in patents/applications/invention disclosures for 2019 compared to 2018 and more than double the amount in 2016. In addition, due to extra efforts in improving compliance among users and PIs to properly acknowledge NNCI and NSF in publications using the appropriate grant numbers, Figure 27 below shows a significant improvement in this metric.

Table 15: NNCI 2019 Publications

Publication Type (CY 2019)	
Internal User (Site) Papers	2761
External User Papers	293
Internal User Conference Presentations	1069
External User Conference Presentations	62
Books/Book Chapters	39
Patents/Applications/Invention Disclosures	690
Total	**4914**

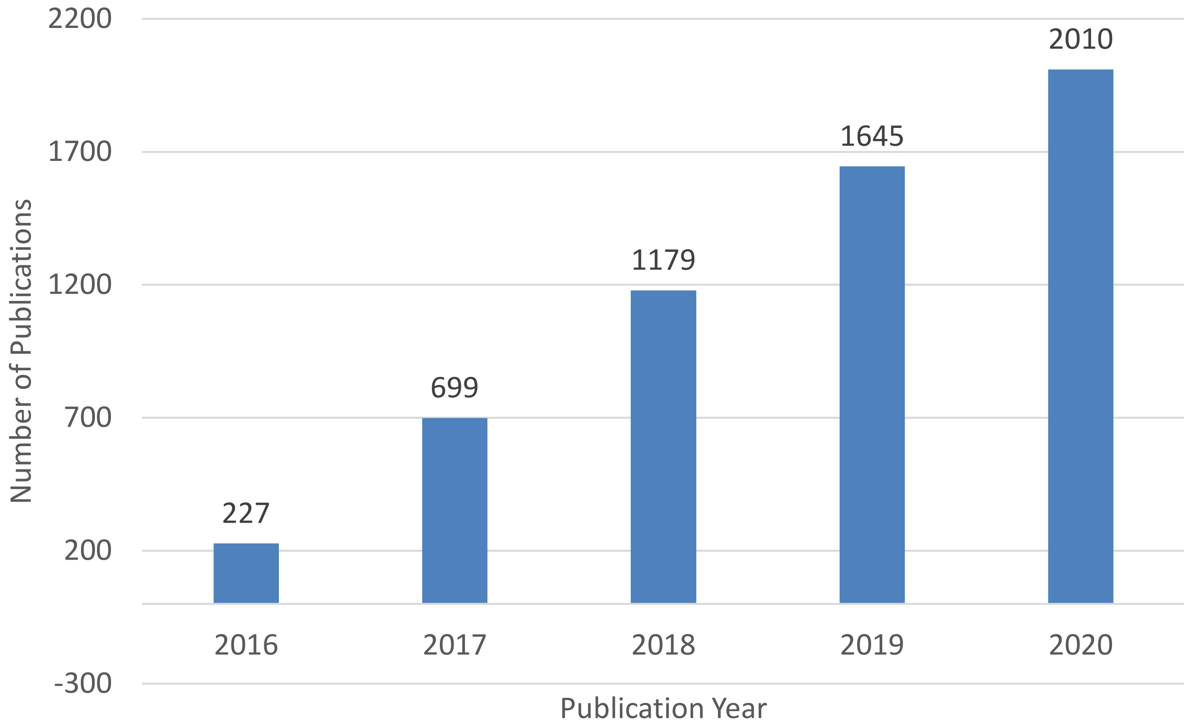


Figure 27: Number of Publications with NSF NNCI Award Numbers based on Google Scholar (NNCI-Award # or ECCS-Award #). Both 2015 and 2020 award #s were used. Search conducted 2/1/2021.

10.4. Supported Research Centers

During 2020, the Coordinating Office asked NNCI sites to provide a list of large, multi-PI and/or multi-institution research centers supported by their facilities as a way of demonstrating some of the academic (and even economic) impact of the NNCI program. This is likely not an exhaustive list (Table 16) but is provided to give some indication of the use of NNCI by these national centers. The host and supporting site are provided, but in many cases other sites are also participants in these centers. In addition, the funding source given may refer to a previous (graduated) funding mechanism, such as a legacy ERC which still exists.

Table 16: NNCI Supported Research Centers

Research Center	Supporting Site	Funding Source
Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST) Center	RTNN	NSF ERC
Advanced Technologies for the Preservation of Biological Systems (ATP-Bio)	MINIC	NSF ERC
Alliance for Molecular PhotoElectrode Design for Solar Fuels (AMPED Solar Fuels)	RTNN	DOE EFRC

Application and Systems driven Center for Energy-Efficient Integrated Nanotechnologies (ASCENT)	SENIC	SRC JUMP
Atlanta Center for Microsystems Engineered Point-of-Care Technologies (ACME POCT)	SENIC	NIH
Center for Biofilm Engineering	MONT	NSF ERC
Center for Bright Beams	CNF	NSF STC
Center for Cell Manufacturing Technologies (CMaT)	SENIC	NSF ERC
Center for Dialysis Innovation	NNI	NSF ERC
Center for Dynamics and Control of Materials (CDCM)	SDNI	NSF MRSEC
Center for Hierarchical Materials Design	SHyNE	NIST
Center for Hybrid Approaches in Solar Energy to Liquid Fuels (CHASE)	RTNN	DOE Energy Innovation Hub
Center for Integrated Quantum Materials (CIQM)	CNS	NSF STC
Center for Neurotechnology	NNI	NSF ERC
Center for Power Optimization of Electro-Thermal Systems (POETS)	Stanford	NSF ERC
Center for Quantum Networks	NCI-SW	NSF ERC
Center for Sustainable Polymers (CSP)	MINIC	NSF Chemistry Center
Chicago Quantum Exchange	SHyNE	
Cornell Center for Materials Research (CCMR)	CNF	NSF MRSEC
Cornell Center on the Physics of Cancer Metabolism	CNF	NIH
Cornell High Energy Synchrotron Source	CNF	NSF
Fundamental Understanding of Transport Under Reactor Extremes (FUTURE)	RTNN	DOE EFRC
Future Renewable Electric Energy Delivery and Management (FREEDM) Systems Engineering Research Center	RTNN	NSF ERC
Integrated Mesoscale Architectures for Sustainable Catalysis (IMASC)	CNS	DOE EFRC
Internet of Things for Precision Agriculture (IoT4Ag)	MANTH	NSF ERC
Kentucky Advanced Manufacturing Partneship for Enhanced Robotics and Stuctures (KAMPERS)	KY MMNIN	NSF
Kentucky IDeA Networks of Biomedical Research Excellence (KY INBRE)	KY MMNIN	NIH
Laboratory for Research on the Structure of Matter (LRSM)	MANTH	NSF MRSEC
Nanobiotechnology Center (NBTC)	CNF	NSF STC
Nanomanufacturing Systems Center (NASCENT)	TNF	NSF Nanosystems ERC
Nanotechnology Enabled Water Treatment Center (NEWT)	NCI-SW	NSF ERC

Platform for the Accelerated Realization, Analysis, and Discovery of Interface Materials (PARADIM)	CNF	NSF Materials Innovation Platform
Polarization and Spin Phenomena in Nanoferroic Structures (PSPINS), NNF, NSF MRSEC	NNF	NSF MRSEC
QISpin (Quantum Information)	SHyNE	AFOSR
Q-NEXT: Next Generation Quantum Science and Engineering	SHyNE	DOE
Quantum Energy and Sustainable Solar Technologies (QESST)	NCI-SW	NSF-DOE ERC
Rapid Acceleration of Diagnostics (RADx)	SENIC	NIH
The University of Kentucky Superfund Research Center (UKSRC)	KY MMNIN	NIEHS
UC San Diego MRSEC	SDNI	NSF MRSEC
University of Minnesota MRSEC	MINIC	NSF MRSEC
University of Washington Molecular Engineering Materials Center (MEM-C)	NNI	NSF MRSEC

11. NNCI Site Reports

NNCI sites were asked to provide summary information as part of this Year 5 report. Specific information requested included:

1. A brief narrative corresponding to the NNCI Year 5 (Oct. 1, 2019 - Sept. 30, 2020).
    a. Facilities, tools, staff updates during the year
    b. User base – marketing, outreach and support activities, including any specific research strengths or focus of the site
    c. Research highlights and impact – include brief mentions of any significant user accomplishments as well as scholarly and economic impact. Note: Research and education highlight slides are provided as a separate document.
    d. Education and outreach activities summary
    e. Societal and ethical implications activities (if applicable)
    f. Computation activities (if applicable)
2. A listing of all external user institutions for NNCI Year 5, separated as follows: Academic, Small company (<500 employees), Large company, Government, International, Other. See Appendix 13.3 for the complete listing. Due to disclosure limitations, some external users asked that their information not be shared, and the number of these are indicated in the appendix.
3. The number of publications in each category for calendar year 2019. The list of publications may have been part of each site's Year 5 report to NSF, but the data presented here (Section 10.3 above) are only aggregate numbers of publications for the NNCI network.
4. A list of site-site or network-wide activity, including proposals, facility operations, education/SEI programs, staff interactions, or other events. This is provided in Section 9 above.
5. User survey data, if the site did not participate in the common NNCI user survey for 2020. This data was added to the survey results presented in Section 7.3.
6. For this year's report, all sites were asked to provide information on their activities in response to the COVID-19 pandemic, and this was collated and presented in Section 9.4.

In addition, the user statistics for NNCI Year 5 (Oct. 2019-Sept. 2020) were collected from the sites and used by the Coordinating Office to generate both the aggregate network user activity described in Sections 10.1 and 10.2 above, as well as the individual site usage information shown after each site narrative below.

The reports below are presented as provided by the sites, with only minor editing for format.

11.1. Center for Nanoscale Systems (CNS)

This has been a very challenging 5th year for the Center for Nanoscale Systems as it has been for the nation. Covid-19 limited all research operations from March 2020 – July 2020 and our labs are still not back to full operations as of the end of the grant period. Moreover, we expect these conditions to persist through the end of the academic year (May 2021). In spite of this, PI Westervelt and co-PI Wilson, the Operational Director of the center, have been continuing the assessment, revamping, and augmentation of the tools and instrumentation available at CNS for advancing transformative Nano and Quantum science. There were specific new tools and techniques added this year which are outlined below. PI Westervelt and co-PI Wilson have also continued cultivating a cooperative, synergetic relationship with the Center for Integrated Quantum Materials (an NSF STC), with CNS serving as the primary experimental resource for many of the supported (CIQM) PIs, their students and postdocs.

Facility, Tools and Staff Updates

This year we have not added new permanent staff, but have expanded our instrumental research capabilities. The modest list of new instruments is detailed below; we do note essentially that we have experienced a 6-month vendor shutdown which is just getting lifted now, which has delayed installation and staff training. During the pandemic we importantly have expanded the capabilities available to remote train the user base, both in the nanofab and the other core instrumentation focused areas of the lab. Our team has developed training materials using *"StoryLine"* a course development software platform. In addition we have also completed a VR model of our complex to be used in training and for virtual tours of CNS.

Hitachi HF3300S 300kV TEM

https://my.matterport.com/show/?m=rVhrkRCTdHD

The new tools and/or instrumentation include:

Imaging and Analysis additions:

- Asylum Jupiter AFM
- Leica Ultracut – ARTOS 3D (cryo-Microtome)

Nanofabrication additions:

- Samco Oxygen Plasma Etcher

We are also finalizing the installation and training of the "Harvard Quantum Imager", an Hitachi 300keV aberration corrected electron microscope, which has an *ultra-high-resolution* energy filter and the capability of imaging magnetic materials with atomic-resolution. We have also ordered an NSF MRI-funded Low Energy Electron Microscope (LEEM) system which will be delivered next year (delayed by Covid-19). These new tools will expand our analysis and processing capabilities.

User Base

Our staff have initiated a number of protocol changes that have allowed us to safely re-open our labs to users, in *low density* operation in July. One caveat is we were allowed to use user experience as our trigger for access. This allowed us to open for both *internal and external* users. *We believed that it was really important for us to support our start-up user base; many of these small companies depend on our resources for their survival.* CNS has also continued to increase the usage by start-ups via direct interaction and partnership with technology incubators in the Cambridge area. This effort has more than doubled the usage by start-ups last fiscal year. As noted, we have tried to be a lifeline for these companies offering them access even under our trying conditions driven by Covid-19.

Research Highlights and Impact

Broadband electro-optic frequency comb generation in a lithium niobate microring resonator: Optical frequency combs consist of equally spaced discrete optical frequency components and are essential tools for next generation quantum optical communication, precision metrology, timing and spectroscopy. Here the Loncar team has realized an integrated EO comb generator in a thin-film lithium niobate photonic platform that features a large EO response, ultralow optical loss and highly co-localized microwave and optical fields, while enabling dispersion engineering. Their measured EO comb spans more frequencies than the entire telecommunications L-band (over 900 comb lines spaced about 10 gigahertz apart), and they show that future dispersion engineering can enable octave-spanning combs. Furthermore, they demonstrate the high tolerance of our comb generator to modulation frequency detuning, with frequency spacing finely controllable over seven orders of magnitude (10 hertz to 100 megahertz), and they use this feature to generate dual-frequency combs in a single resonator. Mian *Zhang, Brandon Buscaino, Cheng Wang, Amirhassan Shams-Ansari, Christian Reimer, Rongrong Zhu, Joseph M. Kajn, and Marko Loncar;* ***Nature Comm*** *(2019) 10:978;* ***Appl. Phys. Lett*****, *115*** *12108 (2019); doi: 10.1063/1.5118901*

Coherent control of a hybrid superconducting circuit made with graphene-based van der Waal heterostructures: Quantum coherence and control is foundational to the science and engineering of quantum systems. In van der Waals materials, the collective coherent behaviour of carriers has been probed successfully by transport measurements. However, temporal coherence and control, as exemplified by manipulating a single quantum degree of freedom, remains to be verified. Here the team demonstrates such coherence and control of a superconducting circuit incorporating graphene-based Josephson junctions. Furthermore, we show that this device can be operated as a voltage-tunable transmon qubit, whose spectrum reflects the electronic properties of massless Dirac fermions travelling ballistically. In addition to the potential for advancing extensible quantum computing technology, our results represent a new approach to studying van der Waals materials using microwave photons in coherent quantum circuits. *Joel I-Jan Wang, Daniel Rodan-Legrain, Landry Bretheau, Daniel L. Campbell, Bharath Kannan, David Kim, Morten Kjaergaard, Philip Krantz, Gabriel O. Samach, Fei Yan, Jonilyn L. Yoder, Kenji Watanabe , Takashi Taniguchi, Terry P. Orlando, Simon Gustavsson, Pablo Jarillo-Herrero and William D. Oliver;* ***Nature Nanotechnology*****, *14***, *pg 120-125, (2019)*

Education and Outreach Activities

The summer programs were cancelled in 2020. We did have a small number of Vet Interns who were supported during the academic year. This year, if possible, PI Westervelt and co-PI Wilson will again use the STC college network and several other vehicles to ensure a diverse candidate pool. PI Wilson recruited both at the NSBE and CARRMS meetings, events geared toward STEM development in the African-American community. We also expanded our recruiting activities this year to include the National Society of Black Physicists (NSBP) annual meeting. *(We note that CNS has become sponsor for a new student chapter of NSBP at Harvard)*. We, as noted, selected 3 REV interns, three of which are being supported doing continued work in the current academic year. Most of these students were selected from a pool at Bunker Hill Community College. BHCC has a very vibrant STEM focused directed at VETs. Our traditional REU program solicited summer research projects from the entire CNS user base (both internal and external). The goal is to foster new strong interactions between staff and research groups.

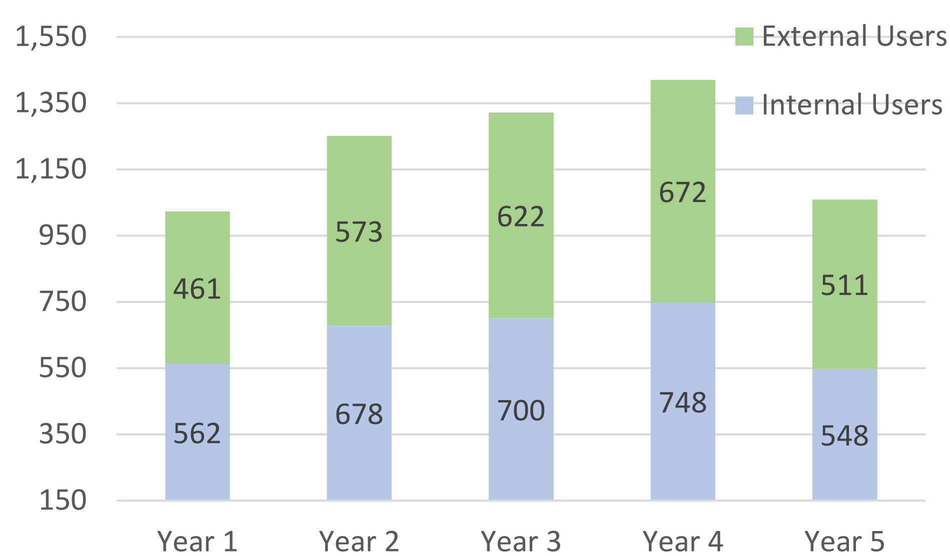
Our CNS Scholars program offers direct fabrication and instrumentation support for researchers from under-represented groups, small or minority serving institutions. The first submissions have focused on junior faculty and some post-doctoral support. We are only funding use with some materials and supply support. The current enrollees all submitted brief proposals, which were evaluated by CNS senior staff. This year we have more extensively advertised these activities. As noted we have continued our partnership with Harvard Catalyst. Catalyst provides seed support for projects in the translation biosciences. Currently we are not using NNCI funding to support any of these initial researchers but we anticipate possible inclusion of some of these bioscience teams in CNS Scholars.

The senior leadership team has also continued visiting current and potential users throughout the Northeast and the within the Cambridge area to assess overall user needs community-wide. One continuing initiative this year has been expansion of our engagement with the New England start-up community. Here, in particular, we have reached out to local high-technology incubators to understand their current organizational goals and to gain insight as input as we develop a long-term engagement plan and have started partnership activities, specifically with Greentown Labs and the Engine. Here we bill the incubators directly for their company's usage. The goal for the lab is to align our vision with the broader national nanoscience community.

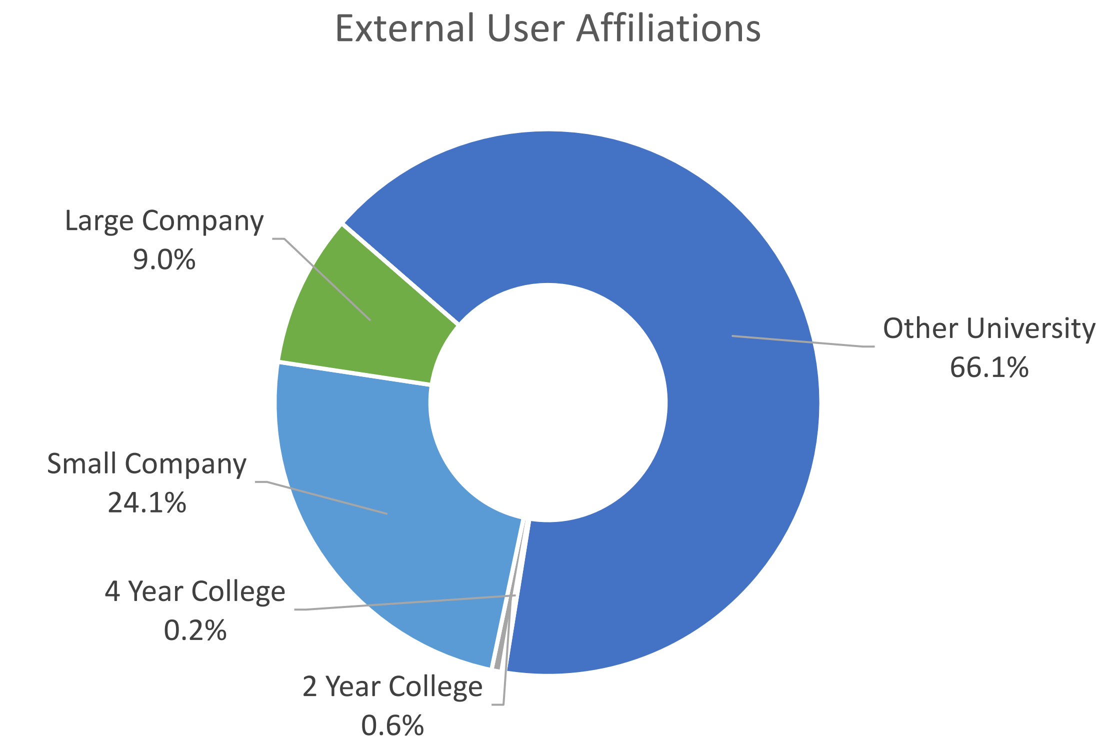
This effort has resulted in a substantial increase in usage from local start-ups. As noted, we had planned to hold our 2nd start-up "Boot Camp" this spring as a vehicle to teach the user base the promise and pitfall of Start-ups (derailed by Covid-19). The program goal being to bring together Entrepreneurs, Incubator and Venture Capital folks, IP folks, students and post-docs to allow an open dialog on creation of start-ups. The focus was to demystify the process and educate our userbase on strategies and pitfalls when starting a technology business. We had invited a number of our Start-up users, as well as local incubators, and a few local VCs and Angel investors, to a half-day forum and open discussion on "all things" relevant to the Start-up process. This event was to be open to the entire NNCI network. We expect/hope to re-boot this program in the spring of 2022.

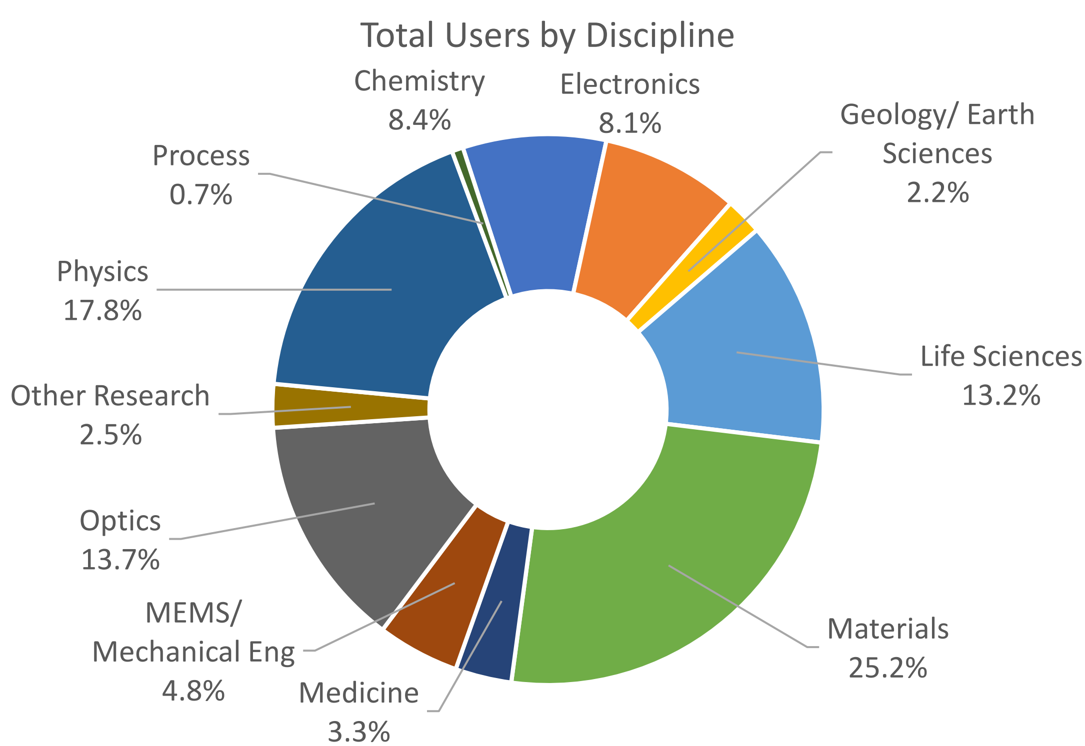
CNS Site Statistics

Yearly User Data Comparison					
	Year 1	Year 2	Year 3	Year 4	Year 5
Total Cumulative Users	1,023	1,251	1,322	1,420	1,059
Internal Cumulative Users	562	678	700	748	548
External Cumulative Users	461 (45%)	573 (46%)	622 (47%)	672 (47%)	511 (48%)
Total Hours	174,710	181,826	185,288	204,221	114,523
Internal Hours	124,256	133,020	126,662	117,615	69,904
External Hours	50,454 (29%)	48,806 (27%)	58,626 (32%)	86,607 (42%)	45,519 (40%)
Average Monthly Users	511	514	538	565	317
Average External Monthly Users	201 (39%)	196 (38%)	218 (40%)	250 (44%)	137 (43%)
New Users Trained	415	404	452	483	191
New External Users Trained	196 (47%)	200 (50%)	233 (52%)	240 (50%)	89 (47%)
Hours/User (Internal)	221	196	181	157	126
Hours/User (External)	109	85	94	129	89



CNS Year 5 User Distribution

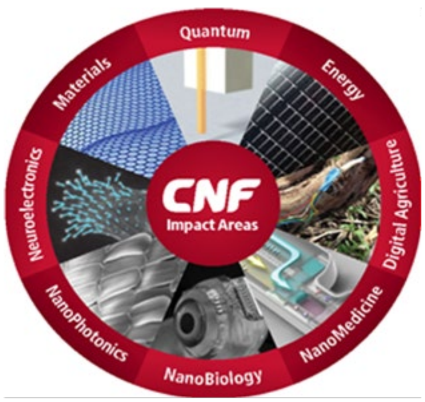




11.2. Center for Nanoscale Science and Technology Facility (CNF)

Facility, Tools, and Staff Updates

The Cornell Nanoscale Facility has provided key nanotechnology resources to the nation's users for over forty years. CNF serves as a nanofabrication-focused open resource to scientists and engineers with emphasis on providing complex integration capabilities. This is made possible by an expertly-staffed user program providing rapid, affordable, hands-on 24/7 open access to advanced nanofabrication tools.



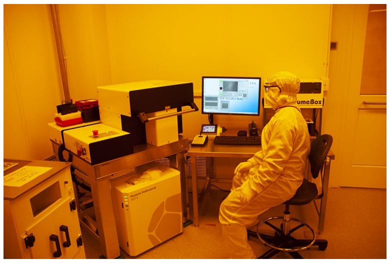
CNF areas of activity/expertise

Map of CNF users and NNCI sites

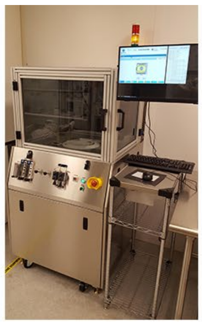
CNF houses, operates, and makes available to its users an almost unmatched array of nanofabrication and characterization equipment. Over 180 individual pieces of equipment with a replacement cost of over $100 Million. These include many resources that are unique to NNCI or are best of class in NNCI.

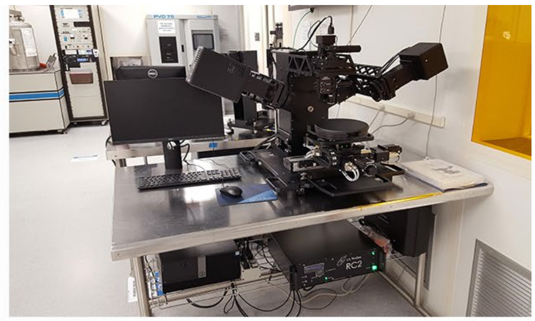
CNF steadily updates and expands its equipment base to maintain a broad set of state-of-the-art equipment and to address areas of growing interest. The following tools have been acquired or developed over the past year.

New CNF Tools	
AJA Orion 5 load locked sputter deposition (delivered) (3rd AJA sputtering system)	Yield Engineering Ecoclean: High speed resist stripping
Filmetrics F50 optical interferometric mapping system	Woollam RC2 spectroscopic ellipsometer
UHV load lock evaporator (ordered)	Woollam in situ spectroscopic ellipsometer
High speed, high resolution digital cameras for fluoresce microscopes	Hiden Langmuir probe for process development on ALE system
ICP PECVD	C&D Semiconductor automated lift off tool
Nanoscribe Photonic Professional GT2 3D Laser Lithography System (MRI 2019)	Plasma Therm Atomic Layer Etching System (ALE)
200 mm wet cleaning station	




Left: Nanoscripe Photonics GT2; Right, Plasma Therm Atomic Layer Etch system

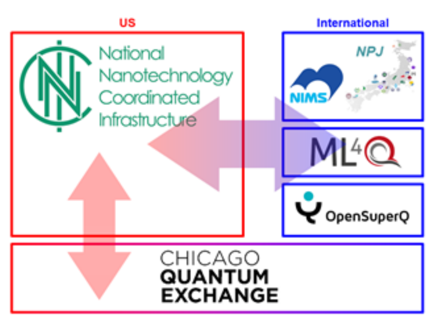


From Left: AJA Orion 5 sputtering system, C&D Systems automated lift off system, Yield Engineering Ecoclean stripper, Woollam RC2 spectroscopic ellipsometer

CNF is blessed with a very talented and experienced veteran staff; the median tenure of our staff is 18 years. During this year, one technical staff retired and one went on phased retirement (50%). The full-time position was replaced with a new hire. Two of our four administrative staff have retired; we are streamlining our operations and do not currently plan to fill those positions.

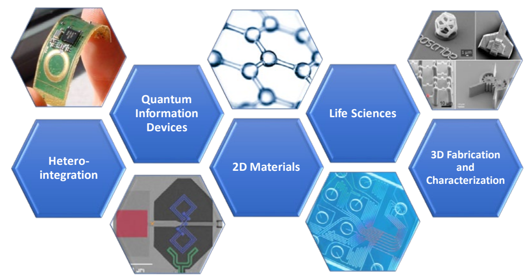
As part of the CNF NNCI renewal process, Prof. Claudia Fischbach-Teschl was appointed as Associate Director. Prof. Fischbach is a Professor of Biomedical Engineering and Director of Cornell's Physical Sciences Oncology Center (an NIH center). As Associate Director, she will assist CNF in meeting the needs of the life sciences community.

In 2020, CNF joined with several NNCI sites to propose AccelNet: Global Quantum Leap. AccelNet is an NSF program to form alliances between international research networks. For this program NNCI is joining with the Chicago Quantum Exchange in the US, the Nanotechnology Platform Japan, European OpenSuperQ, and Matter and Light for Quantum Computing (ML4Q) (Germany) to promote international cooperation, collaboration, and workforce development in the area of materials and devices for quantum information systems. This proposal, led by the University of Minnesota with NNCI partners Cornell, the NNCI Coordinating office at Georgia Tech, and the University of Chicago, part of the SHYNE NNCI node, has been awarded and began operation in Oct 2020, for 5 years. CNF acts as the primary interface to the Nanotechnology Platform Japan, based on its long experience with student exchanges with Platform.



Network linkages within AccelNet: Global Quantum Leap

Like almost all facilities in the US, CNF was severely affected by the COVID-19 pandemic. The facility and all of Cornell were shut down from mid-March through mid-June. All equipment was shut down. As a result, there was essentially no usage of CNF for half of March, and all of April, May, and June. Significant effort was expended in the down period to develop procedures to assure a safe reopening. Starting in mid-June, CNF executed a phased reopening, beginning with staff-only to restart the equipment, followed by gradual introduction of groups of prior users. During this restart period, CNF coordinated with other similar NNCI sites to share best practices. New training regimens were developed to account for new protocols and the restrictions of social distancing on direct person to person hands on training. By mid-August, CNF was open to essentially all prior users, with exception for those from states under NY State imposed travel restrictions. **New users** from NY state are also now being accommodated. At this time, CNF remains open to all New York state users. The deteriorating COVID situation, however, has required reinstatement of restrictions on out-of-state users.



CNF Strategic Areas

User Base

The CNF user base is distributed widely across nanotechnology areas, with particular historic concentration in the Life Sciences areas. As part of its strategic plan, CNF has highlighted several areas as Strategic Initiatives over the next decade. These include:

- **Heterointegration:** The ability to integrate microelectronics with MEMS, photonics, microfluidics, and flexible electronics/packaging is increasingly important to our user base. These include integration of novel materials such as graphene and other 2-D materials. CNF will continue to acquire equipment and expertise to serve this evolving area.
- **Quantum Materials and Devices:** Quantum information systems are a national priority and one of NSF's 10 big ideas. Both Cornell faculty and outside users make strong contributions in this area. CNF has joined with 3 other NNCI sites for **Global Quantum Leap**, an NSF AccelNet (network of networks) program, to make an impact on international information exchange and human resources.
- **2D Materials:** Cornell faculty provide significant support for 2-D materials research. CNF fully supports the activity of PARADIM, an NSF Materials Innovation Platform (MIP), with significant activities in materials discovery.
- **Life Sciences:** CNF has a long history of support for the Life Sciences. CNF leads NNCI facilities with percentage of users in the life sciences.
- **3D Fabrication and Characterization:** As part of its renewal proposal, CNF has established a partnership with an existing imaging facility within the Cornell Institute of Biotechnology and an existing 3D printing facility in Mechanical Engineering. Through the imaging facility we will be able to offer access

to x-ray micro-CT, super resolution microscopy, and advanced confocal microscopy. Through the mechanical engineering department, we will be able to access more than ten 3-d printers of various capabilities.

CNF will continue to invest in and promote these strategic areas while supporting users from all applications of nanotechnology.

Research Highlights and Impact

CNF exists to enable cutting edge research across the nanotechnology spectrum. Naturally, this includes significant contributions from Cornell research groups. We are, however, particularly proud of our support for non-Cornell research groups. These groups come to CNF by choice, sometimes in spite of similar facilities closer to home or even at their own universities. Throughout this award CNF has maintained the highest percentage of outside users of any site within NNCI.

Each year, CNF collects research reports for each project. These summary reports, each 2 pages, highlight the accomplishments by each user. There are compiled and nicely formatted and published as the **CNF Research Accomplishments**. The **CNF Research Accomplishments** are available both in print and electronically on the CNF web site, and have been attached to each annual report.

The impact of CNF research is particularly highlighted by the number of publications in "high impact" journals, e.g. *Science*, *Nature*, etc. Research Highlights from over one dozen recent user projects are provided separately.

In particular, CNF provides critical support for research within NSF's 10 Big Ideas, including Understanding the Rules of Life, Quantum Leap, and Convergence:

The research done by CNF users results in a large number of publications, presentations, and patents, too many to itemize individually via the report module. CNF collects publications, presentations, and patents on a calendar year basis from its users. We have made a diligent effort to have all publications properly acknowledge CNF and the NSF award number. And we have encouraged all users to report their publications to CNF, however, many do not. In any event, these numbers should be considered as the minimum documented impact of CNF research.

User publications are collected on an annual year basis. In calendar year 2019, research in CNF resulted in at least 234 Publications, 41 Presentations, and 117 Patents and Patent Applications. In addition, we have collected over 100 citations to date from 2020.

CNF continues to serve as an engine for economic development for small businesses. Over the course of NNCI, CNF has averaged 2.5 new startup company launches per year based on CNF developed technology; these include Xallent, Esper Biosciences, FloraPulse, Ultramend, Jan BioTech, Heat Inverse, JR2J, White Light Power, Odyssey Semiconductor, GeeGah, and OWIC. In addition to CNF inspired startups, CNF provides access to critical nanotechnology to support an extensive group of both small and large companies involved in the commercialization of nanotechnology. During the recent year, this included 32 small U.S. companies and 9 large U.S. companies. The flexibility of CNF's tool set and CNF's low barriers to entry (legal, technological, and financial) make an ideal environment for rapid technology development.

Education and Outreach Activities

Over the years, CNF has developed a broad range of education and outreach activities. In a normal year CNF would host over 150 visits, events, and tours, directly reaching (in person) over 3000 people. Unfortunately, the COVID crisis forced cancellation of all events from March on. This included our longstanding and critical the summer activities, REU, International REU in Japan, our 4-H Career Explorations, and the June instance of our Technology and Characterization Short Course. We will resume these activities after the crisis has passed.

CNF was able to conduct its annual meeting in September via Zoom with presentations and posters by CNF users. Presenting the keynote addresses were Dr. Larry Goldberg, NSF program manager, and two distinguished CNF user alumna, Lidija Sekaric, Ph.D., National Business Director, Distributed Energy at Siemens and Nancy Stoffel, Ph.D. Flexible Hybrid Electronics Lead, GE Global Research.

Lidija Sekaric, Ph.D., National Business Director, Siemens

Annually, as part of our annual meeting, CNF presents the Whetten Memorial Award which recognizes young women scientists whose work and professional lives exemplify a commitment to scientific excellence, interdisciplinary collaboration, professional and personal courtesy, and exuberance for life. The 2020 award was presented to two outstanding Ph.D. students, Marissa Granados-Baez, University of Rochester, and Christine Harper, Cornell.

Christine Harper (left) and Marissa Granados-Baez (right)

Under NNCI, CNF has partnered with NY 4-H to assist with STEM-based content for a mutually beneficial outreach relationship. 4-H provides an extensive network at state and national levels for platforms, logistics, and dissemination of outreach to youth aged 8–18. As noted earlier, our main interactions with 4-H were a temporary victim of COVID in 2020. Under the CNF NNCI renewal proposal, CNF will be partnering with NNCI sites at Virginia Tech, U. Nebraska, and Montana State (NNCI Land Grant schools) to share our experiences with 4-H and make a larger impact with the rural K-12 community.

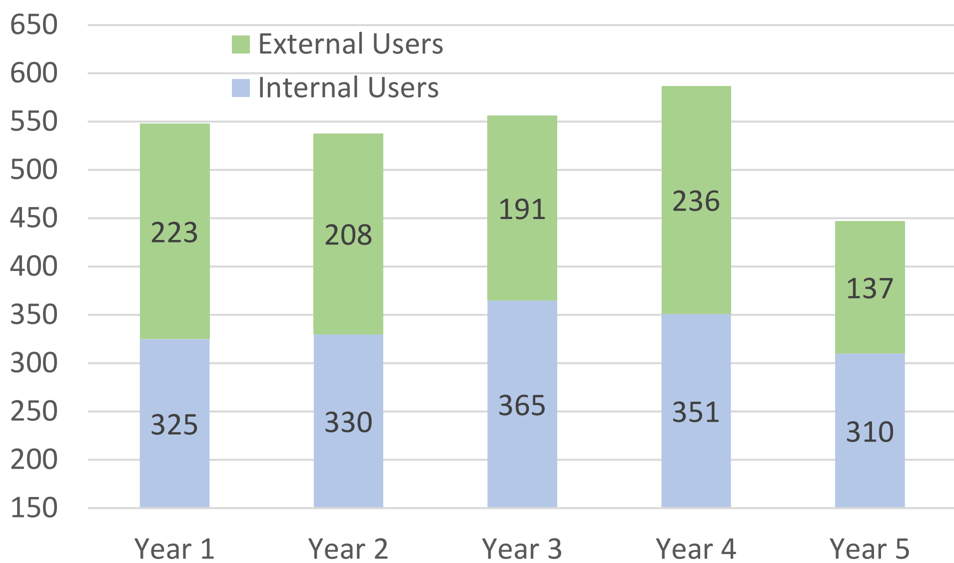
In winter 2019/20, CNF started a 4-H science club for elementary students, the S-TEAM, run by CNF staff member Beth Rhoades. Activity was cut short after only a few months due to COVID-19. We will resume after the current crisis passes.

Over the years, CNF has developed or acquired many resources and activities to support outreach to youth and the community. During this award, we were able to consolidate these resources into a small dedicated "demonstration room". Activities can be left set up and used to host student groups on short notice.

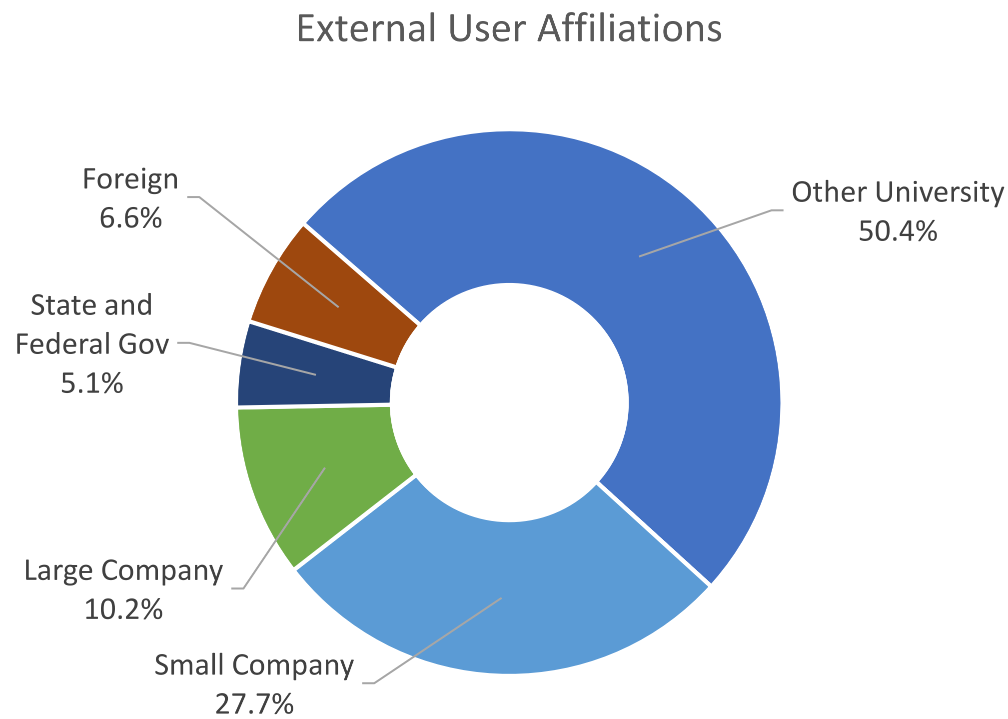
Students gathered for an optics demonstration in the CNF Demonstration Room in Duffield Hall.

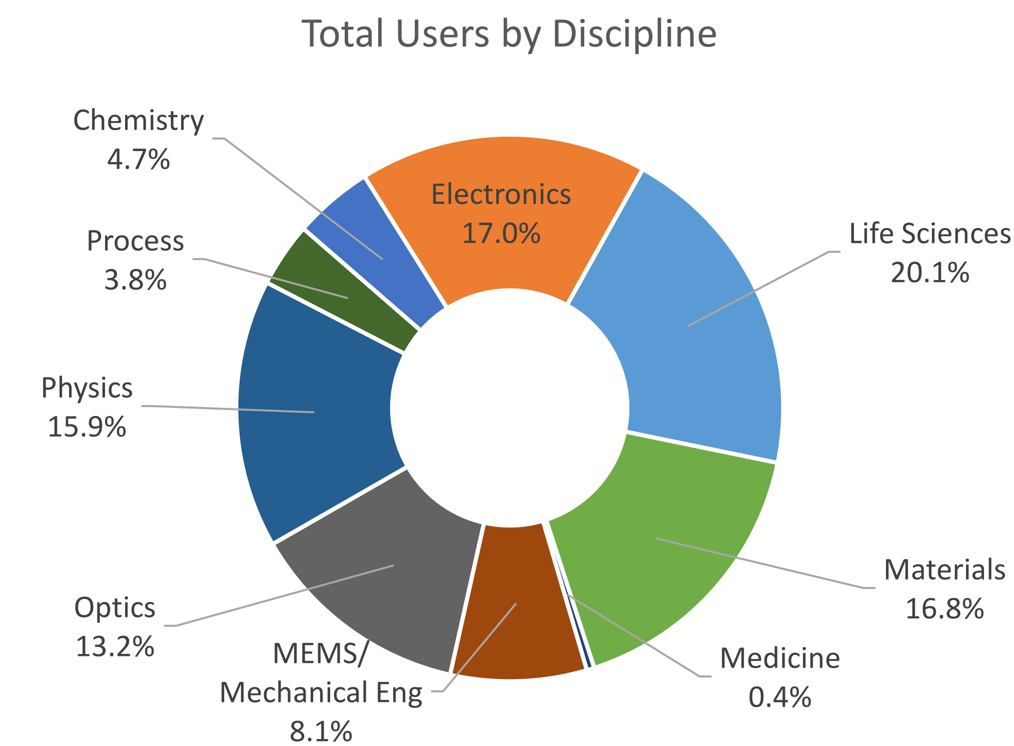
CNF Site Statistics

Yearly User Data Comparison					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total Cumulative Users	548	538	556	587	447
Internal Cumulative Users	325	330	365	351	310
External Cumulative Users	223 (41%)	208 (39%)	191 (34%)	236 (40%)	137 (31%)
Total Hours	40,544	45,340	53,680	56,668	31,415
Internal Hours	22,965	25,201	31,143	34,627	20,446
External Hours	17,579 (43%)	20,139 (44%)	22,537 (42%)	22,041 (39%)	10,968 (35%)
Average Monthly Users	210	204	225	235	149
Average External Monthly Users	67 (32%)	66 (32%)	68 (30%)	71 (30%)	39 (26%)
New Users Trained	131	161	174	208	77
New External Users Trained	46 (35%)	51 (32%)	42 (24%)	91 (44%)	12 (16%)
Hours/User (Internal)	71	76	85	99	66
Hours/User (External)	79	97	118	93	80



CNF Year 5 User Distribution





11.3. Kentucky Multi-Scale Manufacturing and Nano Integration Node (KY MMNIN)

Facility, Tools, and Staff Updates

The first half of year 5 was extremely productive, as our KY Multiscale NNCI site continued to experience increasing trends in core usage, number of users, and revenues. However, like most all the other NNCI sites, we were abruptly affected in March by the COVID-19 pandemic, which caused most of our core facilities to suspend operation and then slowly resume on a limited basis over the remaining months in year 5. In spite of the pandemic, our advanced multiscale manufacturing infrastructure continued to expand in year 5 with new equipment acquisitions, including a Xenocs Xeuss 2.0 SAXS/WAXS system for x-ray scattering materials analysis (EMC Facility), a Fischer Scientific Apreo C Low Vac SEM (HICL Facility), and an MOCVD reactor newly reconfigured for the deposition of gallium nitride-based semiconductors (Conn Center). In year 5 we were excited to welcome a few new faculty, staff, postdocs and student participants (interns/coops/assistantships/work studies) to our KY Multiscale core facility family. These new hires brought in fresh ideas and valuable expertise consistent with our site's advanced multiscale manufacturing theme. We also welcome some new faculty positions at UofL and UK in year 5 who will use our KY Multiscale core facilities. UK brought in a faculty member in Advanced Materials, Prof. Alexandra Paterson, with extensive expertise in printed and flexible electronics. UofL hired two new faculty: Prof. Joseph Chen in Bioengineering who is an expert in mechanobiological drivers of disease progression and Prof. Bikram Bikram Bhatia in Mechanical Engineering who performs research on heat transfer, nanotechnology, advanced materials, and energy systems. Two new facility managers were also welcomed in year 5: Amrit Kaphle for the UK CAM facility and David Eaton for the UK CAER facility.

In Year 5, our NNCI site was fortunate to receive a very large $1.5M NSF MRI award for the development of a custom state-of-the-art multiscale manufacturing tool. Lead by UofL Endowed Prof. Dan Popa, this next-generation advanced manufacturing system (called NeXus) strategically combines fused deposition modeling (FDM), aerosol jet printing, ultrasonic metal additive manufacturing, fiber weaving, pick and place, intense pulse light annealing, optical inspection, and electrical characterization in a single autonomous robotic system. The NeXus system will be housed in the KY Multiscale NNCI site and will be used for the automated fabrication of smart AM components, microsystems, microrobots, distributed sensors/actuators, soft robots, and wearables.

User Base

Marketing, Outreach, and Support Activities

KY Multiscale's signature outreach event is our annual *KY Nano + AM Symposium*, which focuses on the intersection of nanotechnology and additive/advanced manufacturing (AM). The two-day event consists of parallel technical and business sessions, several joint keynote presentations by national renowned speakers, poster presentations, sponsorship opportunities, food and refreshments, core facility tours, and a valuable evening networking reception (see figure below). Local dignitaries included the mayor of Louisville and the president of UofL. The annual conference includes an Industry Outreach Day where potential industrial users are invited to tour our core facilities. The goal of our annual Nano+AM Symposium is to bring together researchers in the Nano+AM space to discuss new findings, share results, discuss applications, debate the future, and network with one another. The 2019 KY Nano+AM Symposium venue was held on

July 31–August 1, 2019 at the UofL campus. The symposium brought together over 150 participants from industry and academia. The 2020 KY Nano + AM Symposium would have been the third year for this regional conference. However, due to the state's and university's in-person event restrictions of the pandemic, the symposium was postponed. It is planned for July 2021 on the UofL campus.

In light of the COVID pandemic which affected a good part of year 5, we diverted much of our efforts to planning virtual events, conducting more email marketing campaigns, developing social media content, and participating in as many virtual events as possible. For example, KY Multiscale core personnel participated in "KY Autovision 2020", an annual conference developed by the Kentucky Association of Manufacturers (KAM) for their industry members. This conference took place virtually on August 26-27, 2020. KY Multiscale Core Facilities AMIST, MNTC, HICL, and CeNSE prepared prerecorded virtual tours/introductions of KY Multiscale facilities for their presentations at the conference and participated in open virtual breakout sessions with the conference participants. Prerecorded presentations for this conference are available at http://www.kymultiscale.net/video-gallery.



2019 KY NANO + AM Symposium

A technical workshop on Electron Microscopy Imaging was organized by KY Multiscale's Micro/Nano Technology Center this past summer and hosted by Fisher Scientific via Webex. Thirty-one attendees registered for this event. The workshop highlighted the HICL's newest equipment acquisition, a state-of-the-art Thermo Scientific APREO C Low Vac SEM. We were planning a series of in-person workshops for year 5, but COVID restrictions made it impossible to host these events. We are now working with companies like Plasma Therm to help us host more of these events virtually.

In year 5, we continued to expand the marketing and communication effort of our NNCI site. We engaged an online marketing company, Constant Contact, to assist with the development and distribution of our KY Multiscale monthly newsletter and email campaign. Included in our newsletter are important information about our site's activities, new initiatives, new capabilities, exciting research results, upcoming conference and seminar opportunities, workshop information, and undergraduate research opportunities, to name a few. In year 5 our newsletter (shown in figure at right) was distributed nationally to over 3000 industry and academia recipients, as opposed to 2000 the year before.

KY Multiscale Newsletter

In Year 5, we also developed some new surveys for our stakeholders to better understand their capabilities/needs and promote more collaboration. For instance, we designed a survey which was distributed to ALL university core facilities, including those outside our KY Multiscale site, including the cores on our Health Science Campuses. With the data collected, we were able to better understand the capabilities and needs of the different research communities across campus. As a follow-on, we plan to develop specific initiatives in the immediate future to better network and engage these facilities to create a better awareness of the many diverse resources available on our campuses. This should promote growth, facilitate collaborations, and increase usage of all our cores. Other marketing efforts included the expansion of our social media presence by adding more content for our Facebook, Instagram, YouTube and LinkedIn followers. Almost daily, we post images of exciting research happenings in our cleanroom facility. Our staff has been committed to keeping our users engaged by sharing short video clips of the many remote processes that are constantly being developed for them (i.e. https://www.facebook.com/MNTCUOFL/videos/627983264400886). These videos also serve to attract new users, especially those who are unable to perform on-site processing themselves due to the pandemic restrictions.

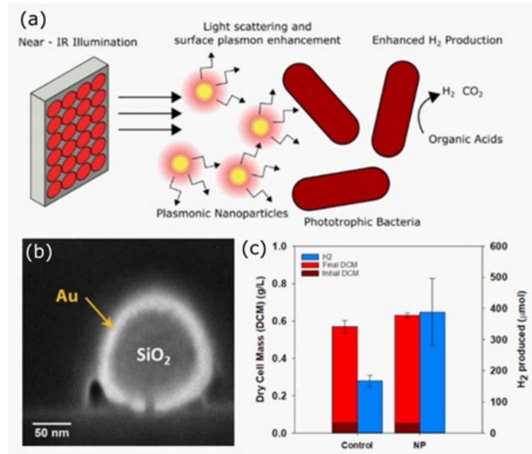
The University of Kentucky continued to offer their seed grant program in year 5. The program aims to stimulate small-scope research projects both internally and from external academic institutions. The program provides up to $2,000 over 6 months for free access to the University's NNCI-affiliated research cores.

With regard to our site's usage data, year 5 began on a very positive note with increases in both client usage and revenue. However, due to the COVID-19 pandemic, we experienced an abrupt decline in both usage and revenue starting in March 2020. Beginning in mid-April, we began reopening some of our core facilities under state and university approved COVID restrictions. These restrictions included severely limiting the number of on-site users, the density of users in the facilities, and increased safety precautions. To offset that, our staff began to perform more and more remote work for our clients. Much of that remote activity remains in effect today.

Despite the unfortunate COVID challenges, our KY Multiscale site remained busy and productive. The pandemic created some interesting opportunities for our cores and their staff to help our community as they struggled with the virus. For example, several of our core facilities donated personal protection equipment (PPE) to the COVID cause. Our AMIST additive manufacturing facility took the lead on a regional effort to 3D print protection faceshields and swabs for Coronavirus testing. At UK, Prof. Dibakar Bhattacharyya, director of the UK Center of Membrane Sciences, lead a team of scientist in the development of a membrane that will not only effectively filter out the novel coronavirus like the N95 mask does, but deactivate the virus completely. They have pending proposals into various funding agencies. At UofL, a startup company, AdhviQ, was established to mass produce both disposable and washable N95 masks using newly developed technology from the Conn Research Center.

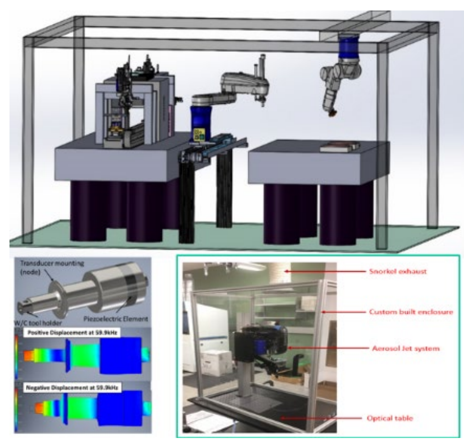
Research Highlights and Impact

Emerging hydrogen applications, such as transportation and distributed power, are not well suited to centralized gas reforming units and require innovative infrastructure solutions. To address this need, Professor Bhattacharya is leading a University of Kentucky team developing sustainable technologies for localized hydrogen production. In their recent work, purple non-sulfur bacteria were used to convert waste organic acids, such as acetic and maleic acid, to hydrogen as shown in Figure 3. The UK team improved hydrogen production efficiency with reduced greenhouse CO_2 gas content using near-infrared illumination of *Rhodopseudomonas palustris*. Silica-gold core-shell nanoparticles, with localized surface plasmon resonances tuned to the bacterial chlorophyll near-IR absorption band, further enhanced hydrogen production. The initial discovery was published in *RSC Advances,* and a more in-depth paper was recently accepted by the *International Journal of Hydrogen Energy*. Success in this effort will ultimately have a significant economic impact by enabling industrial sites to generate clean hydrogen while remediating waste. This work was supported in part by NSF award CBET-1700091 and is being conducted in collaboration with Southern Company (Birmingham, AL).



(a) R. palustris bacteria convert organic acid waste to hydrogen using near-infrared light enhanced by plasmonic nanoparticles. (b) Cross-sectional electron micrograph of a silica-gold, core-shell nanoparticle. (c) Nanoparticles enhance H2 production, but do not slow bacterial growth.

The second research highlight we present is a very interdisciplinary and highly ambitious project led by Prof. Dan Popa from the University of Louisville. Leveraging his recent $1.5M NSF MRI award, Dr. Popa has assembled a diverse team of faculty from ECE, ME and CSE to design a next generation, advanced manufacturing, autonomous, robotic assembly system called NeXus. NeXus is a new type of additive manufacturing instrument that incorporates industrial robots and custom high precision robots, along with a variety of processes such as 3D Printing, Ultrasonic Bonding, Aerosol Jetting, Microassembly, Electronic Pick and Place, Intense Pulse Light Curing and Fiber-Weaving. When completed, the NeXus system will be able to custom manufacture sensor and MEMS prototypes such as pressure-sensitive robotic skins, electronic textiles, solar cells, and microrobots. The system will be equipped with advanced human-machine interfaces to control and coordinate the additive manufacturing processes and will provide the UofL's NNCI node added prototyping research capabilities beyond the cleanroom. This research has resulted in a dozen publications to date, published in such high impact journals as *Journal of Micro Nano Manufacturing, Journal of Micro-Bio Robotics, Materials & Design, IEEE Sensors Journal, Materials Characterization, Polymers, Procedia Manufacturing, and Journal of*



SolidWorks rendering of the multi-robot NeXus instrument (top) containing a custom ultrasonic bonding tool (bottom left) and a Optomec Aerosol Jetting print engine (bottom right).

Materials Chemistry. The NeXus technology has the promise of changing the way micro-scale systems are prototyped and assembled.

Education and Outreach Activities

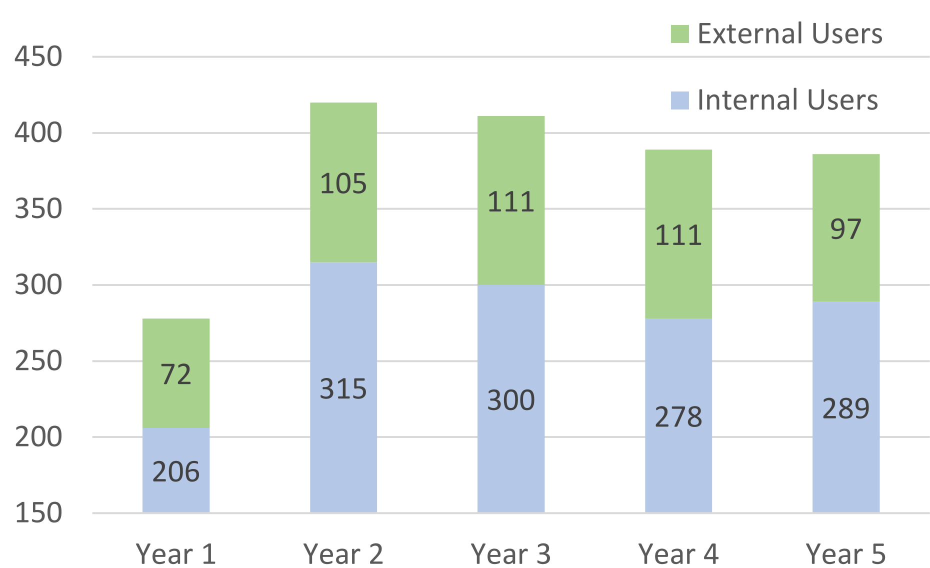
During the first half of year 5, our KY Multiscale Director (Prof. Kevin Walsh) was fortunate to receive a new 3-Year REU award from NSF. The focus of the REU program is directly related to our KY Multiscale advanced manufacturing research theme. The title of the REU award is "Interdisciplinary Micro/nano/additive-manufacturing Program Addressing Challenges Today – The Next Generation (IMPACT-NG)." Consequently, we began immediate efforts to prepare for this program. We designed and launched a new website (www.uoflnanoreu.com) that included information about our program, a user-friendly portal for applying, and a list of 13 exciting micro/nano/AM research project for the applicants to choose from. We then began the recruitment process in November, and by the end of January we had over 60 applicants, and 6 accepted participants at that time, with several other offers pending. We were in the process of finalizing or housing arrangements and our programmatic activities when COVID hit. We immediately consulted with both our NSF Program Manager and many other REU sites. After much deliberation and consternation, we decided to postpone the start of our program for a year. We considered trying to offer our program virtually, but due to the intensive hands-on nature of our IMPACT-NG program, that was not practical. Our NSF PM was supportive of our decision. The 6 accepted participants were guaranteed a spot for the following year.

Although our REU program was not suitable for a virtual format, a few of our other E&O activities were. For example, we had great participation in our 2020 Nano Image Contest called *"Plenty of Beauty at the Bottom"*. Our local winners were submitted to the NNCI coordinating office for the network-wide competition. In the summer, we offered a very well-attended virtual workshop on Electron Microscopy Imaging. Other virtual E&O activities included new instructional videos from our cleanroom staff about fabrication, as well as new videos about imaging and characterization from our other staff members.

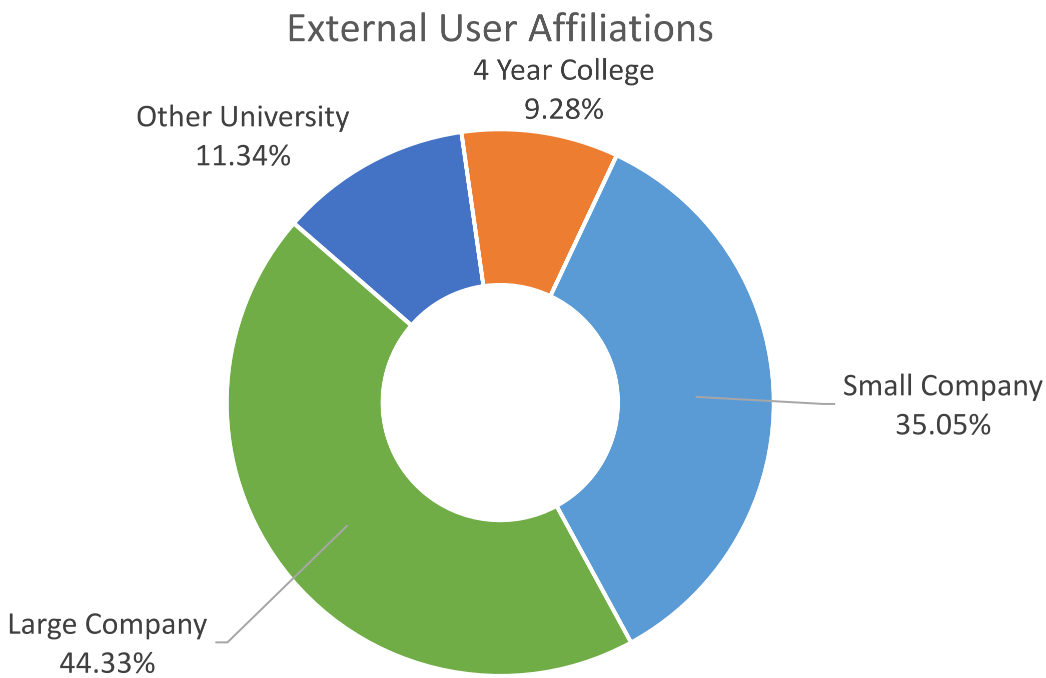
Other outreach events that had to be canceled or postponed due to the COVID-19 pandemic included the following: a) MAKER FAIRE LOUISVILLE, a gathering of engineers, scientists, artists, and crafters showcasing their hobbies, experiments, and projects, b) National Nanotechnology Day at the Kentucky Science Center. A day of hands-on showcasing nanotechnology and advanced manufacturing at the State's science museum for K-12 school groups and the general public, c) On-campus tours for school groups to our core facilities, d) Summer Science Submit, e) Engineering Day, f) GIRLS Rule STEM Summit, g) AMCC Promise Zone for Appalachia HS, h) Individual Core Facilities' Summer Camps, i) KY NANO + AM Symposium, j) Culminating UofL Summer Research Programs Poster Presentation and Reception, k) Our participation in the 2020 NNCI REU Convocation, l) Bulldogs in the Bluegrass (KY Multiscale Workforce Development Summer Internship in collaboration with Yale University), m) KY Multiscale Lunch and Learns, and n) KY Multiscale Technical All-Day In-Person Workshops.

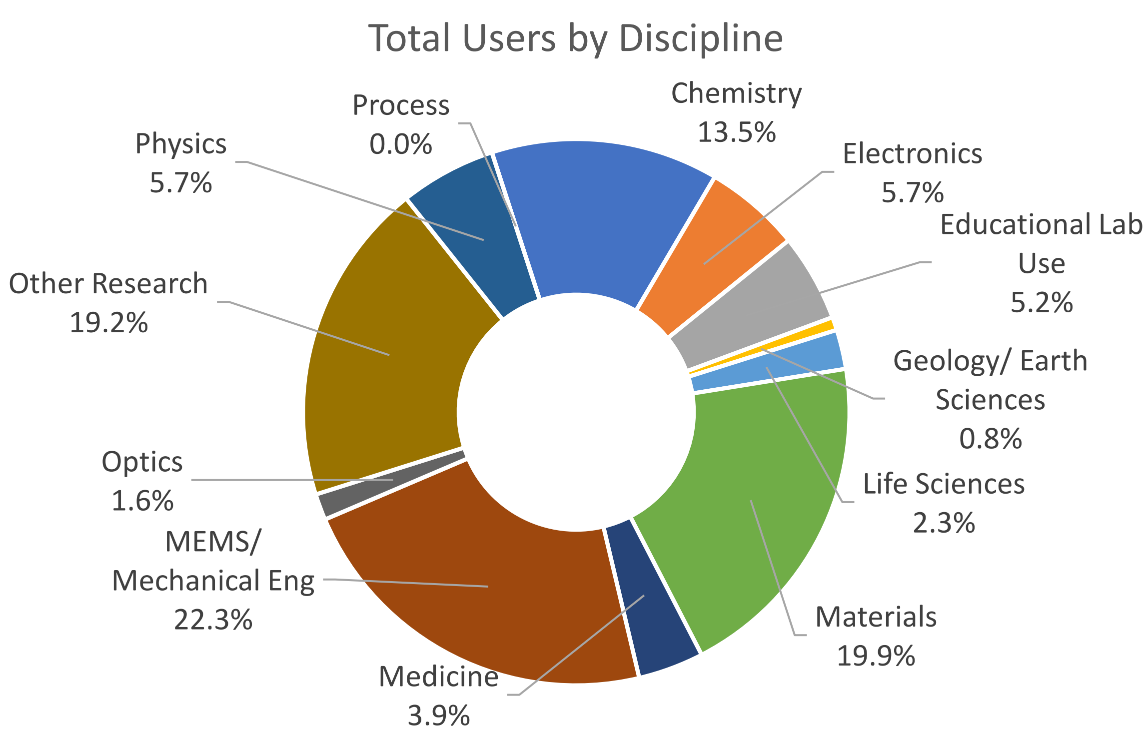
KY MMNIN Site Statistics

Yearly User Data Comparison					
	Year 1	Year 2	Year 3	Year 4	Year 5
Total Cumulative Users	278	420	411	389	386
Internal Cumulative Users	206	315	300	278	289
External Cumulative Users	72 (26%)	105 (25%)	111 (27%)	111 (29%)	97 (25%)
Total Hours	14,629	17,151	17,301	15,651	12,895
Internal Hours	9,726	12,166	10,960	11,869	9,032
External Hours	4,903 (34%)	4,986 (29%)	6,341 (37%)	3,782 (24%)	3,862 (30%)
Average Monthly Users	104	141	120	140	97
Average External Monthly Users	22 (21%)	25 (18%)	25 (21%)	25 (18%)	20 (20%)
New Users Trained	111	251	164	223	118
New External Users Trained	26 (23%)	43 (17%)	28 (17%)	22 (10%)	18 (15%)
Hours/User (Internal)	47	39	37	43	31
Hours/User (External)	68	47	57	34	40



KY MMNIN Year 5 User Distribution





11.4. Mid-Atlantic Nanotechnology Hub (MANTH)

The Mid-Atlantic Nanotechnology Hub (MANTH) is based at the Singh Center for Nanotechnology at the University of Pennsylvania and has partnered with the Community College of Philadelphia (CCP) to develop workforce opportunities and nano-related curricula for 2-year college students. MANTH provides open access to leading-edge R&D facilities and expertise for academic, government, and industry researchers who work within all disciplines of nanoscale science, engineering, and technology.

The pandemic forced a shutdown of all but essential COVID-related research at MANTH in March 2020. When we reopened in June, all researchers were welcomed back to our laboratories, including external users. In spite of this unprecedented interruption, the staff and researchers at MANTH installed new tools, facilitated educational opportunities, and conducted remarkable research, all outlined below.

Facility, Tools, and Staff Updates

MANTH's response to the COVID pandemic began in early January 2020. At that time, while we did not know how severe this crisis would be, we prepared by ensuring that we had several months of access to consumable cleanroom supplies. By March 2020, MANTH was stocked with sufficient consumable resources to run uninterrupted for 18 months. Here are the actions taken:

- With a large supply of competitively priced personal protective equipment on hand, MANTH donated nearly $39,000 in PPE to Penn Medicine.
- MANTH sold materials to the University of Minnesota NNCI site to help them maintain adequate consumables for researchers.
- MANTH worked with two vendors, five NNCI Sites, and several Mid Atlantic facilities to develop and supply a washable facemask.
- MANTH worked with Transene Inc. to produce both hand sanitizer and Hydrogen Peroxide solution for cleaning surfaces. These products are now used by dozens of research facilities and Hospitals across the US.
- MANTH found a US manufacturer and supplier for face masks. This information has been shared with over 40 organizations across the US.
- MANTH found low-cost face shields to support pandemic social distancing in labs. Cost savings of over 80% were realized.
- MANTH designed, ordered, solicited donations, and built a social distanced cleanroom gowning room. These designs have been communicated to the NNCI members and Mid-Atlantic research sites.
- MANTH is currently working on nitrile glove supplies and is developing criteria to use scarce resources most efficiently in order to limit the impact of shortages.

MANTH has invested over $18M in new equipment and in upgrades since the beginning of the NNCI program. We highlight 2 tools that we commissioned in Year 5 below.

Evatec AlScN sputterer: A new Evatech Clusterline sputtering tool was installed and commissioned in the MANTH QNF cleanroom in 2019 (figure below left). The tool is dedicated

Left: Evatec AlN sputtering tool; Right: Lattice Gear wafer cleaver

to depositing piezo-electric films of AlN and Scandium doped AlN. Applications of these materials include piezoelectric RF filters, energy harvesting devices, sensors, and ferroelectric memories. Doping AlN with Sc substantially increases the piezoelectric coefficients of the films. Results so far show that scandium concentrations > 37% can be achieved with low surface roughness and a low density of misaligned grains in the material. In addition, X-ray diffraction rocking curve peak shapes (FWHM < 2°) show that films with high degree of crystalline orientation and quality can be grown with this system.

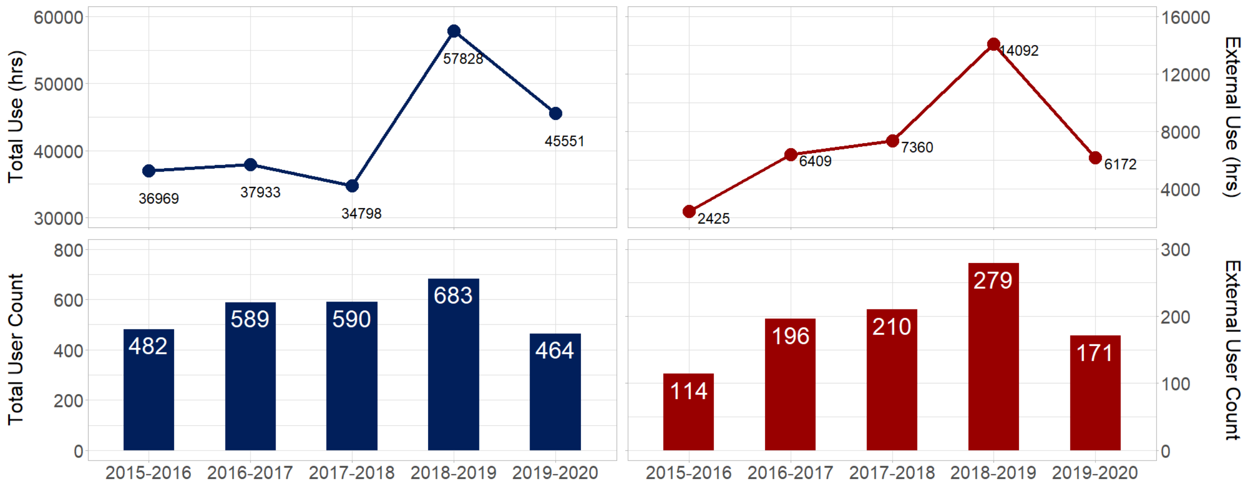
Lattice X 420: The MANTH QNF cleanroom installed the Lattice X 420 precision substrate cleaving tool from Lattice Gear in 2019 (figure above right). This instrument cleaves Si and other semiconductor substrates with a placement accuracy of 10 um, and serves as a quick, precise alternative to the more laborious wafer dicing process using a dicing saw.

<u>User Base</u>

The resources of the NNCI program have enabled MANTH to attract and accommodate users far beyond the Penn community for the past 5 years. Both total and external use has grown substantially over the lifetime of the program, exemplified by the increase from 482 in Year 1 to 683 unique users in Year 4 (see figure below). More striking is the growth in external use; for reference, approximately 50 external users conducted research in the predecessor laboratories at Penn prior to the NNCI program and by the end of NNCI Year 4, that number had grown to over 279 annual users, primarily from other nearby academic institutions and commercial entities.

The drop in all of the user metrics in Year 5 is due to the shutdown of most research activities in March 2020. The full Year 5 data disguise the role MANTH continues to play in enabling research in the Mid-Atlantic region. An examination of the first 6 months of user data for each year (from October 1 to March 31, which are regularly collected for our NSF site reports) may provide a clearer view of progress in Year 5. The table shows the 6-month user statistics forYyears 3, 4, and 5; the 30,000 user hours in Year 5 were well above even the extraordinary Year 4 numbers; and the number of external users in part-year 5 was 164 – comparable to the 160 in part-year 4.

When MANTH re-opened in June 2020, we invited all researchers back, including external users. The fraction of year 5 external users - 37% - is nearly the same as years 3 and 4 (35% and 41%), and it reflects the success we have had in providing access to our diverse user base.



The growing number of external users and their tool use from NNCI Year 1 to NNCI Year 5. Total hours (a) and user count (b); External hours (c) and external user count (d). (NNCI Year spans 10/1 to 9/30).

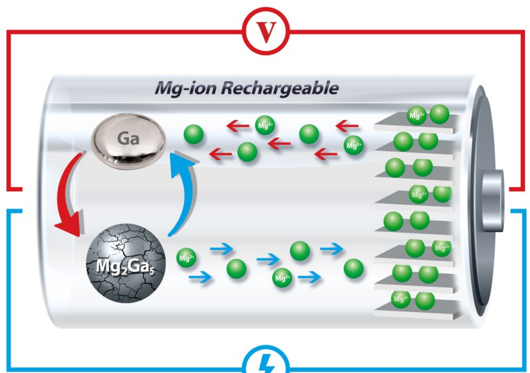
6-month user data for years 3 through 5. Part year data indicate that lab use in year 5 was on par with year 4.

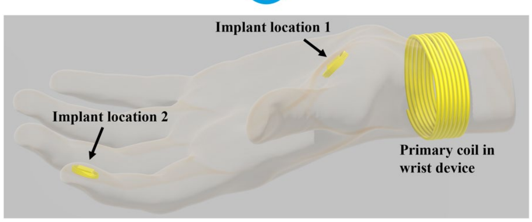
Part Year User Data Comparison			
	Year 3 (6 months)	**Year 4 Part (6 months)**	**Year 5 Part (6 months)**
Total Users	390	417	403
Internal Users	265	257	239
External Users	125	160	164
External Academic	75	96	114
External Industry	47	56	50
External Government	0	2	0
External Foreign	3	6	0
Total Hours	16208	21723	30899
Internal Hours	13126	16617	26523
External Hours	3082	5106	4366
Average Monthly Users	186	203	203
Average Monthly External Users	44	59	52
Average Monthly Remote Users	7	7	5
New Users Trained	133	181	145
New External Users Trained	53	94	92

<u>Research Highlights and Impact</u>

MANTH researchers have continued to explore and innovate in the areas of materials, nano-enabled internet-of-things devices, and life sciences. This research aligns with several of the NSF “10 Big Ideas” themes, as the 4 examples below illustrate.

Harnessing the Data Revolution: Lin Wang, Samuel S. Welborn, Vivek B. Shenoy, and Eric Detsi at Penn have discovered a self-healing liquid metal electrode that extends life of mg-ion batteries. Rechargeable magnesium-ion batteries (MIBs) are emerging as a less expensive alternative to Li-ion batteries. However the anode material in MIBs typically fails as a result of cracks and pulverization caused by significant volume variation during a solid-solid phase transformation. Ga/Mg alloys have been shown to eliminate this pulverization, significantly increase the charge/discharge cycle life of MIBs.





Above: New long-life, lower cost batteries made of Mg/Ga instead of Li. Below: Integrated artificial mechanoreceptors that offer tactile sensing in compromised limbs.

Understanding the Rules of Life and *Harnessing the Data Revolution*: Han Hao, Lin Du, Andrew G. Richardson, Timothy H. Lucas, Mark G. Allen, Jan Van der Spiegel, and Firooz Aflatouni, at Penn have created a hybrid integrated artificial mechanoreceptor in 180 nm CMOS. This device is a sensor-brain interface that performs tactile sensing using an artificial mechanoreceptor device that then encodes the detected force information to the brain using a neural stimulator.

Quantum Leap: Liang Feng and Ritesh Agarwal at Penn, Natalia M. Litchinitser, and Jingbo Sun at Duke University, Josep M. Jornet at Northeastern University, and Stefano Longhi at Politecnico di Milano have collaborated to fabricate and characterize a Tunable Topological Charge Vortex Microlaser. This device holds the promise for future development of multi-dimensional orbital angular momentum spin-wavelength division multiplexing for high-density data transmission in classical and quantum regimes.

Understanding the Rules of Life: Flavia Vitale, Brendan B. Murphy, Patrick J. Mulcahey, Nicolette Driscoll, Andrew G. Richardson, Gregory T. Robbins, Nicholas V. Apollo, Kathleen Maleski, Timothy H. Lucas, Yury Gogotsi, and Timothy Dillingham at Penn and Drexel University have created high-density, high-resolution electromyography arrays using a unique material, titanium carbide MXene, $Ti_3C_2T_x$. High-density arrays of high-resolution electrodes are a valuable tool for recording the electromyogram, a biopotential representing the activation and coordination of various muscles groups within the human body. $Ti_3C_2T_x$ is easier to microfabricate than alternatives and it possesses remarkably high volumetric capacitance and electrical conductivity, excellent mechanical properties, and a high degree of surface functionality.

A way to gauge the impact that MANTH has on nano-inspired innovation is to survey the capital that MANTH-enabled startups have raised. The table in the figure below lists some of the MANTH Innovation Seed Grant winners, small companies that competed and were awarded a few thousand dollars of MANTH cleanroom access. They have subsequently acquired nearly $13M in additional funding from venture capital firms, government, and other organizations since the inception of the program. One company leveraged the few thousand-dollar grant award to raise over $4M in start-up funds. One winner, Therapeutic Articulations, acquired a $2M Small Business Innovation Research grant in year 5. This startup used a long-working-distance microscope in the MANTH cleanroom to calibrate and verify the accuracy of their limb motion measurement tool.

Company	Money Raised
Graphwear *	$4,200,000
Iortha Mobile App	$222,000
Visiplate	$210,000
Fermento	$10,000
Group K Diagnostics	$2,000,000
InnaMed	$1,000,000
Folia Water	$1,753,750
Chromation	$1,250,000
NanoGrass Solar LLC	$300,000
Therapeutic Articulations, LLC	$2,000,000
Total as of 2020	$12,945,750

Left: List of Innovation Seed Grant companies who leveraged their use of MANTH facilities to acquire nearly $13M in startup funds. Right: Rendering of Therapeutic Articulations Mobile-Aider. This startup leveraged their MANTH Innovation Seed Grant into a $2M SBIR in year 5.

Education and Outreach Activities

The Community College of Philadelphia (CCP) and MANTH have created three new courses at CCP that are primarily nano focused or have significant nanotechnology-related content. These courses contain extracurricular programming based at the Singh Center which will expose students to content and careers in nanotechnology. CCP and MANTH also plan to offer professional development workshops to CCP instructors in order to give them the content to incorporate Nano into their existing STEM courses. These academic strategies will be combined with workforce training, which include a new paid internship program at the Singh Center for CCP students that will grow into a program in which local industry would host the interns.

During the 2019-2020 academic year, CCP offered two new courses in the Applied Science and Engineering Technology Program (ASET) that were direct consequences of the NNCI's investment into the CCP-MANTH partnership and based on information shared by industry focus groups: *3D Printing-Additive Manufacturing* and *Introduction to Nanotechnology*. These pilot courses provided CCP faculty with a base on which to develop these into robust offerings in the ASET curriculum, including ongoing discussions on how best MANTH can support these courses.

In the upcoming 2020-2021 academic year, CCP plans to offer a new Robotics course that will have a "first-year experience" designation and will expose first-year students to various careers, including those related to nanotechnology.

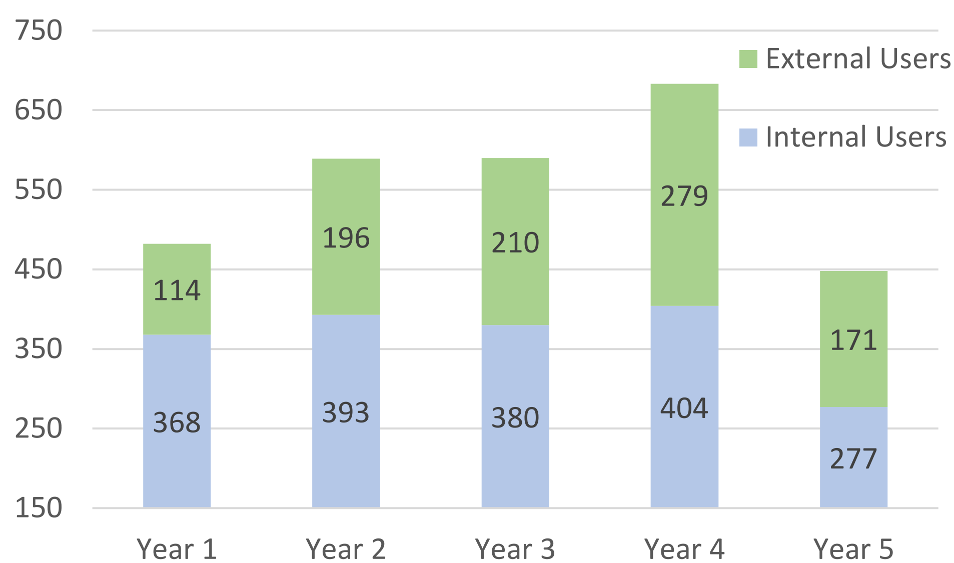
MANTH continues to offer cleanroom processing experiences to local colleges and universities. Twenty five students from CCP, Temple, Villanova, and Jefferson were given the opportunity to operate plasma deposition, photolithography and etching tools in the MANTH cleanroom in Year 5.

Date	School	Number of Participants
04/23/2018	Swarthmore	8
10/11/2018	Villanova	14
10/25/2018	Villanova	14
11/05/2018	Bryn Mawr	11
11/12/2018	Swarthmore	6
04/01/2019	Villanova	3
10/15/2019	CCP	3
11/01/2019	Jefferson	4
11/04/2019	Villanova	4
01/30/2020	Temple	6
02/11/2020	CCP	8

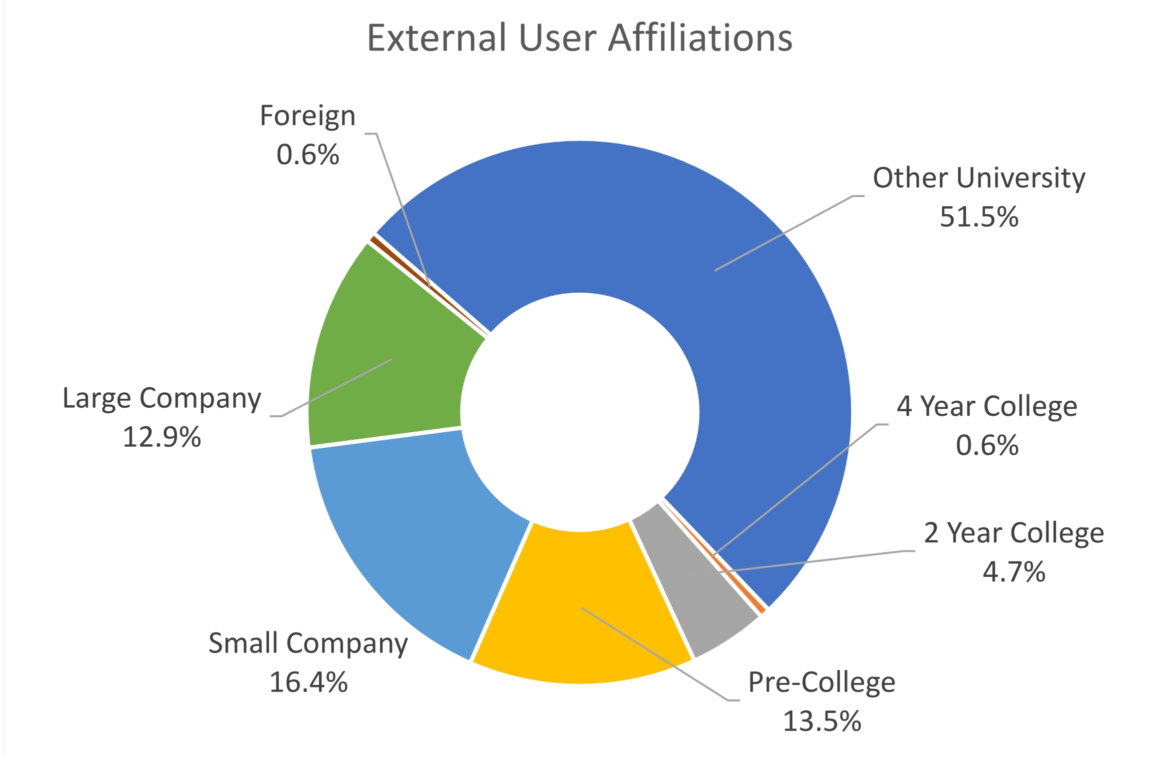
Left: List of participants in MANTH's local college cleanroom activities. Right: Students from the Community College of Philadelphia displaying wafers they have processed in the MANTH QNF fab.

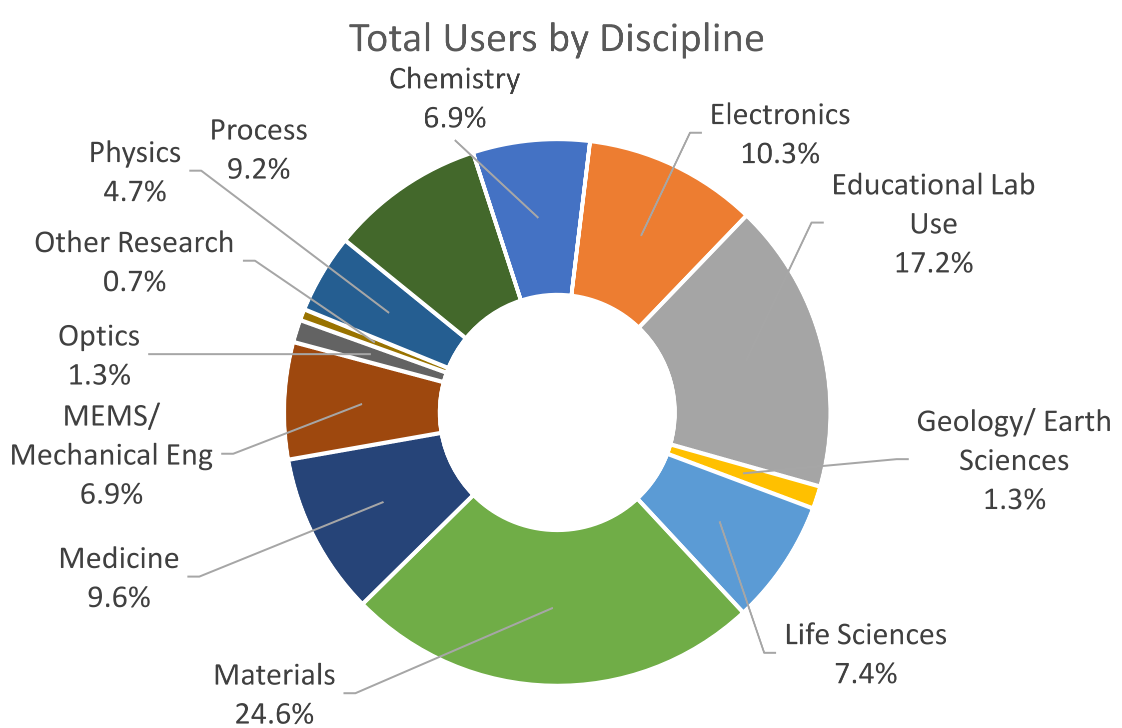
MANTH Site Statistics

Yearly User Data Comparison					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total Cumulative Users	482	589	590	683	448
Internal Cumulative Users	368	393	380	404	277
External Cumulative Users	114 (24%)	196 (33%)	210 (36%)	279 (41%)	171 (38%)
Total Hours	36,970	37,933	34,796	56,849	45,551
Internal Hours	34,545	31,542	27,436	43,673	39,379
External Hours	2,425 (7%)	6,409 (17%)	7,360 (21%)	13,176 (23%)	6,172 (14%)
Average Monthly Users	171	194	186	210	142
Average External Monthly Users	29 (17%)	44 (23%)	45 (24%)	61 (29%)	31 (21%)
New Users Trained	270	339	270	418	180
New External Users Trained	73 (27%)	138 (41%)	104 (39%)	203 (49%)	95 (53%)
Hours/User (Internal)	94	80	72	108	142
Hours/User (External)	21	33	35	47	36



MANTH Year 5 User Distribution





11.5. Midwest Nanotechnology Infrastructure Corridor (MINIC)

Facility, Tools, and Staff Updates

The MINIC node received nearly $1M in funding from university sources to improve nanoscale processing (i.e. cleanroom) capabilities through several upgrades and expanded capabilities. The first was the purchase of a new thermal ALD deposition system from Kurt J. Lesker Company. The ALD150LE (figure left) is configured for purely thermal ALD, and its unique process chamber design promotes uniform precursor dispersion and delivery. Superior heating and temperature control further enhance system performance. Has capability of up to 12 precursors to support a wide variety of films. The system was received in June 2020 and installation is complete. Training of the first users took place in late November 2020. The second was the purchase of a new deep silicon etch system from SPTS (figure right). The new Rapier etcher was received in June as a replacement for our 20 year-old etcher. The installation of this state-of-the-art etch tool in the Physics and Nanotechnology Building clean room will be completed in December 2020. It will greatly improve etch rates, uniformities and aspect ratios for MEMS users. Startup will take place in January 2021.

The Lesker ALD150LE (left) and the SPTS Rapier (right) were purchased during the fifth year. Both have been installed. The ALD system is available to users while the deep silicon etch system is in acceptance testing.

In addition to the clean room tool acquisition, new tools were also added in MINIC's Nanobio labs. The first was a new nanoparticle analyzer, the Malvern Zetasizer ZS, was added to the Nanomaterials Lab. The Zetasizer is a combination dynamic light scattering analyzer and zeta potential tool, and complements other DLS/zeta analyzers in the lab. The second was a major equipment grant was awarded from the NIH to purchase a Beckman Analytical Ultracentrifuge (AUC). The AUC (figure below) will be housed in our Bio-Nano lab and will be used to analyze nanoparticles as well as proteins and other macromolecules of biological interest. It is the first such system at the University of Minnesota and should attract new life science researchers from academic and industrial labs

Professor Theresa Reineke (Chemistry) became a co-lead for the Bionano Focus Area. A new part time lab assistant, Mr. Matthew Johnson, was hired to support work in the Nanobio Labs.

The AUC system is capable of 1000g acceleration and operates up to 60,000 rpm.

User Base

Many of our regular marketing activities, such as attending conferences, visiting potential clients, and arranging lab tours, were truncated by the COVID-related shutdown of our facility in March 2020. However, we were able to complete a more modest level of marketing outreach in the past year. This includes a quarterly newsletter on activities at the Nano Center and related facilities, distributed to all current users. MINIC also sent an annual "What's New at the Nano Center" New Year's email update to everyone in our contact list (about 1200 unique names). Finally, the annual Nanomedicine Workshop, originally scheduled for June 2020, was successfully reworked into a remote webinar held in November.

Since its inception, MINIC has emphasized growing its user base by cultivating three research focus areas. The first area is in 2-D materials: synthesizing and processing graphene, MoS_2, WSe_2, and other such materials and exploring their applications. This includes the availability of deposition systems for graphene and the transition metal dichalcogenides such as MoS_2 and WSe_2. In year five we developed a method for controllably doping the TMD films over a few orders of magnitude. The latter capability includes an aligned transfer system in a controlled-ambient atmosphere to permit the transfer of 2D material flakes onto previously patterned devices. During year five, Steven Koester developed a successful proposal to the AccelNet Program, entitled: "Global Quantum Leap" (figure at right).

Structure of the Global Quantum Leap proposal which will put NNCI into a leadership role in quantum information science.

The second area is in specialty microelectronic device packaging, for which we partnered with North Dakota State University. NDSU offers equipment and expertise well beyond the usual dicing and wire bonding that most fabs can carry out. This includes techniques for packaging other devices – including high frequency (RF) devices and circuits, MEMS devices, high power devices and circuits, sensors, and multichip structures (3D packaging) – are simply unavailable outside of groups doing packaging research. The NDSU lab has particular expertise in packaging and backend processes needed to repackage devices or assemble multichip modules including 3D packaging and integrating sensors with electronics.

The third focus area addresses the biological applications of nanotechnology, specifically making and analyzing nanoparticles and applying these materials to drug delivery and cell analysis. This focus area is concentrated in two labs. The bionano laboratory offers facilities and equipment for safely carrying out research on biosafety level 2 materials. Researchers can culture a variety of live cell types under a range of growth conditions, image cells and tissues using fluorescence and confocal microscopy, store biosamples in secure facilities, and safely manage biologic and hazardous lab waste. The lab is set up to accommodate multiple researchers while minimizing risk of sample cross-contamination. The adjacent nanomaterials lab gives users the ability to synthesize nanoparticles of almost any composition and apply surface modifications, put them into a suspension, and then characterize their size, chemical, and electrical properties such as zeta potential. Particles from nanometers to micrometers can be created and studied.

Research Highlights and Impact

The node is pleased to mention briefly a wide variety of impacts and accomplishments during the fifth year. We can summarize some of these here. A few are covered in more detail in the Research Highlights slides. Here we will focus almost exclusively on impacts for our external users.

MicoOptx Beacon™ devices were developed in MINIC to treat glaucoma.

We begin with discussing the node's impact on some small startup companies. MicroOptx used MiNIC to develop an aqueous microshunt (figure) to release excess intraocular pressure, thereby halting glaucoma. Clinical trials are now underway in three states in the US and also in Germany. Dynation LLC was awarded US Patent 10,561,627 ("Ibuprofen nanoparticle carriers encapsulated with hermetic surfactant films") based on work done in MINIC. Zeptolife used MINIC to fabricate a microfluidic environment with high magnetic moment magnetic particles and GMR sensors to form a fully-automated assay system. Two spin-out companies were created this last year: Grip Molecular Technologies, which developed a graphene-based sensor that enables lower cost, higher performance testing for infectious disease diagnostics, and Carpe Diem, a company that is developing self-aligning roll-to-roll nano imprint lithography and atomic layer deposition systems and other technologies for flexible hybrid electronics, optics and functional surfaces. Agitated Solutions is using MINIC labs to develop a new way to generate air bubbles to use as ephemeral contrast agents for ultrasound diagnostics. The technology will soon be going into animal model testing.

Next, we discuss impacts on a few of our medium to large-size company users in the fifth year. Uniqarta, a company specializing in high rate assembly of components obtained $1.5M matching funds with a $500K NSF SBIR Phase IIB. Uniqarta was also awarded a $750K NSF SBIR Phase II for demonstrating a method of ultra-high-speed parallel transfer of micro-LEDs using a single laser pulse. Work was done at the NDSU labs in MINIC. CrossFire Technologies developed a configurable platform to combine multiple die into a single component. The company went through a large round of funding during the last year. CrossFire uses both the UMN and NDSU MINIC labs. Finally, a new graphene based breath sensor was developed in the MINIC facilities in 2018. This was done by Boston Scientific in collaboration with Professor Steve Koester. In the fifth year of the node Boston Scientific moved the device into production at a 200 mm foundry.

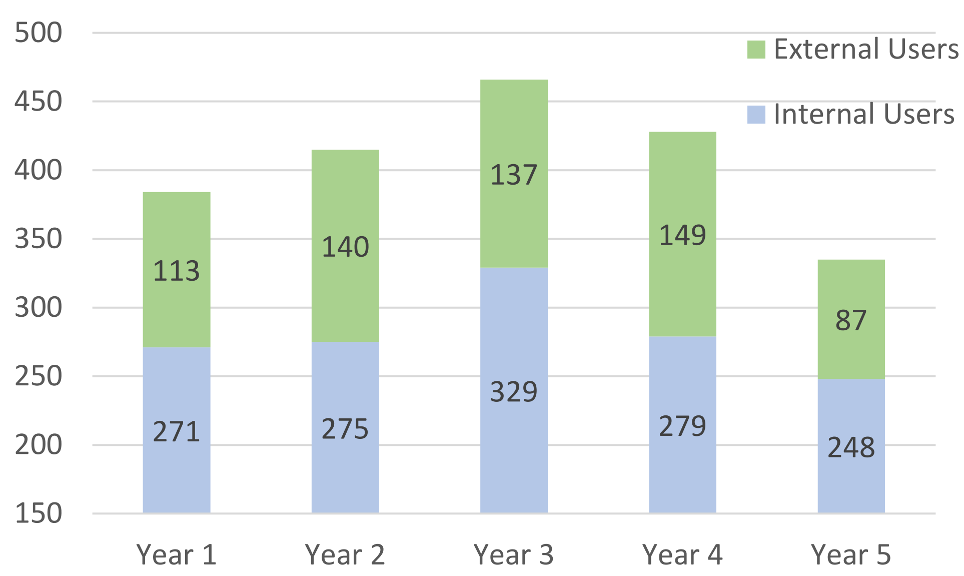
Finally, we would like to mention a few academic impacts. Professor Bharat Jalan (UMN) received the NSF PCASE award. Two groups at Michigan Technological University have used the MINIC cleanrooms for their research, publishing papers in Surface Science and Physical Review Applied. The Northern Nano Lab Alliance has been expanded to ten institutions: South Dakota State University, Mankato State University, Iowa State University, University of Iowa and Rose-Hulman Institute of Technology, Michigan Tech University, Minnesota State Mankato, Colorado University at Boulder, and the University of Wisconsin at Madison. The last three joined NNLA this year. The concept of this type of regional support has been exported to multiple NNCI nodes.

Education and Outreach Activities

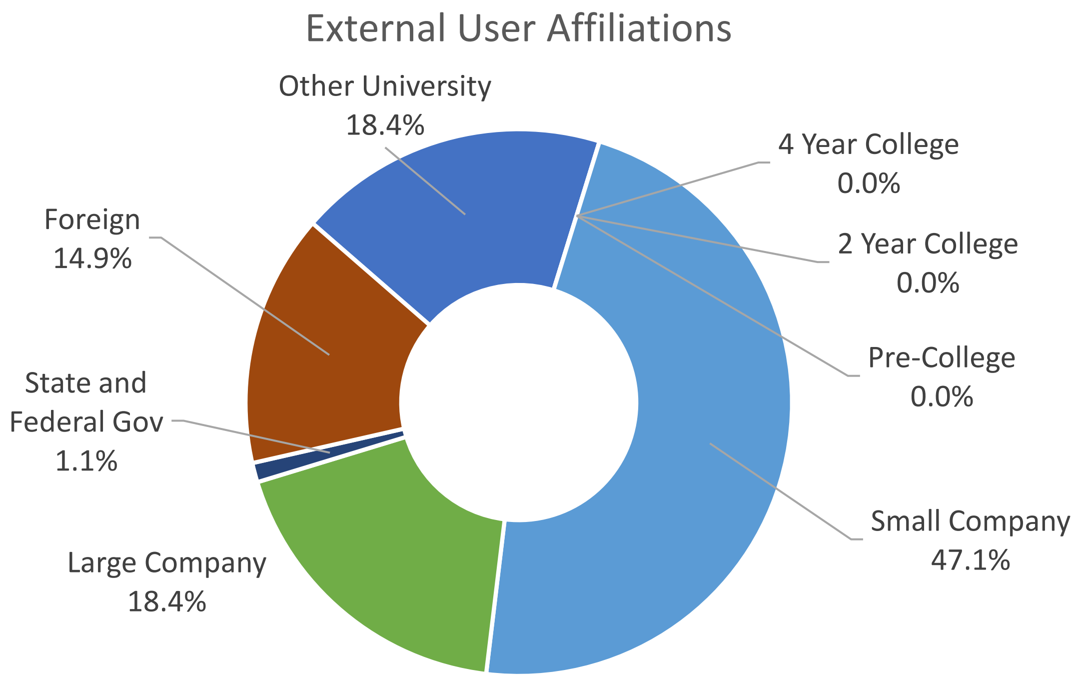
Due to widespread closures of K-12 schools in response to the COVID-19 pandemic, most of the educational outreach events regularly offered by MINIC were cancelled after March of 2020. In particular, the closures prevented us from offering our popular tours and summer camp programs during the spring and summer months. However, some programs were held prior to the shutdown. In-person classes on nanotechnology and photolithography were presented to visiting groups from two high schools, two colleges, and a conference on undergraduate women in physics. MINIC took part in the STEM Career Expo organized by the Minneapolis Public Schools. The expo attracted 2200 eighth grade students from all middle schools in the district. We recruited University of Minnesota undergrad STEM majors to talk with the students and encourage them to pursue STEM studies after high school. Finally, MINIC staffed an exhibit at the annual conventions of the Minnesota Science Teachers Association and of the Midwestern Association of Chemistry Teachers in Liberal Arts Colleges. At both events we shared information on our educational offerings with the approximately 450 science teachers. In spite of the truncated year, over 2700 students were impacted by MINC’s education and outreach efforts during year five.

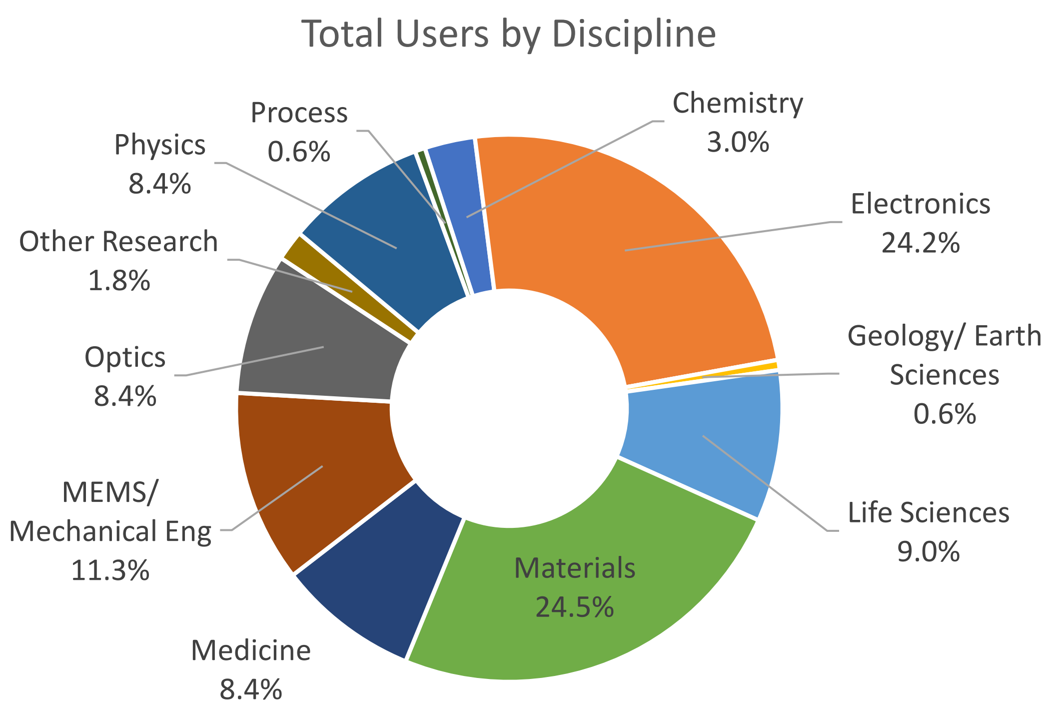
MINIC Site Statistics

Yearly User Data Comparison					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total Cumulative Users	384	415	466	428	335
Internal Cumulative Users	271	275	329	279	248
External Cumulative Users	113 (29%)	140 (34%)	137 (29%)	149 (35%)	87 (26%)
Total Hours	27,002	26,443	26,851	27,782	17,682
Internal Hours	20,495	19,733	21,324	17,780	11,491
External Hours	6,507 (24%)	6,710 (25%)	5,527 (21%)	10,002 (36%)	6,191 (35%)
Average Monthly Users	156	156	161	161	116
Average External Monthly Users	26 (17%)	33 (21%)	30 (18%)	37 (23%)	27 (23%)
New Users Trained	151	150	189	136	101
New External Users Trained	57 (38%)	59 (39%)	48 (25%)	45 (33%)	17 (17%)
Hours/User (Internal)	76	72	65	64	46
Hours/User (External)	58	48	40	67	71



MINIC Year 5 User Distribution





11.6. Montana Nanotechnology Facility (MONT)

MONT Facilities include: Montana Microfabrication Facility (MMF), Imaging and Chemical Analysis Lab (ICAL), Center for Biofilm Engineering (CBE), Mass Spectrometry, Metabolomics, Proteomics, Facility (MSMP), and transmission electron microscopy facility (TEM); Partner site with the Science Education Resource Center (SERC) at Carleton College.

Facility, Tools, and Staff Updates

The **Montana Microfabrication Facility (MMF)** completed its Cobleigh Hall cleanroom at the end of Y4 and beginning of Y5. This expansion supports microfluidics and soft lithography activities. The installation of a new e-beam evaporator with capability for ion-assisted and glancing angle deposition was completed, with funds coming from NNCI and Murdock Charitable Trust. MMF also placed a new Laurell spin coater. The facility standardized new user and safety training as well. The **Imaging and Chemical Analysis Laboratory (ICAL)** installed a new UV sensor on its Cypher AFM for higher sensitivity & resolution. They added a carbon coater for SEM sample preparation and purchased an EDX detector to replace a broken unit. The **Center for Biofilm Engineering** has a new Linkham LTS120E Temperature controlled stage for the Raman Confocal microscope and an Okolab Stage Top Incubation Chamber for the inverted confocal scanning laser microscope. These instruments were purchased with funds outside of NNCI.

Overall, we remain ahead of our target for 4x leveraging of NNCI funds (to date we've placed equipment valued at approximately $2.5M, with NNCI expenditures of $422k, with a leveraging ratio of approximately 6x).

MONT is cooperating with **Georgia Tech of SENIC** to deploy the SUMS facility management software to MONT facilities. We now have four deposition tools, one etch tool, and three furnaces hooked up to SUMS. We have not had dropouts over the last year, and we are now working to install SUMS in our second major lab. We are also developing a plan to implement SUMS for invoicing.

Staff Updates

Dr. Don Smith is the new manager of the **Mass Spectrometry, Metabolomics, Proteomics, Facility.** Dr. Smith is an expert in mass spectrometry instrumentation, complex mixture analysis, and mass spectrometry imaging. The remainder of the management staff remained stable throughout the year. However, ICAL manager Elif Roehm will be attending graduate school in the near future and may be leaving the facility.

User Base

For the first time, MONT's user base did not see a yearly increase due to closure and restrictions from late March to mid-May. However, we were pleased that the facilities added 29 new users between June and September when the facilities were re-opening; with reduced capacity in some cases.

MONT served 169 users in Y5, compared with 188 users in Y4, and 158 in Y3. MONT served 48 external users, who made up **28% of our total user base,** up slightly from 27% in Y4. This includes 10 new entities who have not uses the facilities before. This group includes: 3 large companies, 3 small companies, 1 university and 3 foreign university users. Despite the COVID-19 anomaly in Y5, **we have had a healthy number of external users, just below the 50 external users reported in Y4.**

Marketing, Outreach and Support Activities

MONT held its **Y5 Annual User's Meeting** on October 19, 2020. The meeting date was outside of the official reporting period but focused on Y5 facility updates as well as looking forward to years 6-10 renewal initiatives. The meeting included a virtual poster session with 15 poster presenters; about 35 users attended.

MONT awarded 6 **user grants to seed new projects** in Y5. The user grant program has had a significant impact for MONT researchers. Amongst former recipients: graduate student George Schaible won the NASA FINESST award of $133,000. Dr. Heveran was a winner of NSF 2026 Idea Machine award, Y3 recipient Dr. Warnat received $50,000 seed grant from NSF EPSCoR along with other internal funding. AdvR, Inc has received an SBIR award based on funded work. A Provisional Patent for Biomodum was received based upon work MONT funded in Y2.

One external grant was awarded to:

Dr. Scott Wade of Swinburne University, Melbourne, Australia. Wade is investigating microbially influenced corrosion.

Five internal grants were awarded to:

Dr. Paul Gannon is investigating Carbide-Derived Carbon (CDC), a material with tunable porosity, making it well-suited for high-capacity gas storage and many other applications.

Dr. Nick Stadie was awarded funds for PhD student Isabelle Gordon to work on fundamental materials characterization of phosphorous-doped graphitic carbon. Gordon is interested in making simple modifications to graphite by phosphorous doping to achieve a new material capable of high-density energy storage using sodium-ion based chemistries.

Dr. Yoafa Li was awarded funds for his project, Qualifying the microscale dynamics of multiphase flow in 2D porous micromodels. Use of MONT facility MMF is key to generating preliminary results as well as fostering internal and external collaborations and follow-on funding.

Dr. Roland Hatzenpichler received funding for his project, Exploring the use of nanofabrication tools to reveal the biology and in situ function of uncultured microorganisms. Two students, Kohtz and Schaible, will work in MONT facilities to design and fabricate a PDMS-based chip to study the chemotactic behavior of bacteria.

Dr. Chelsea Heveran was awarded funds to investigate her project called Biomimetic-tough cement for improved freeze-thaw resistance. The goal of this project is to improve the freeze-thaw resistance of cement through incorporating structural toughening mechanisms biomimetic of bone, a naturally tough material.

ICAL has hired a graduate student from MSU's Science & Natural History Filmmaking Program to create video tutorials on ICAL instrumentation. There will be total of 8 videos; Auger, SEM, FE-SEM, XRD, XPS, AFM, CPD and general lab tour.

The **CBE** Industrial Associates meeting was presented in a virtual format this year. MONT researchers presented in various sessions. MONT did not hold its traditional workshop due to pandemic constraints.

In March, MONT EAB member Tony Berthelot organized a MONT "show and tell" meeting with faculty and student researchers at **Salish Kootenai College** on the Flathead Indian Reservation. PI Dickensheets gave an overview of MONT capabilities and engaged in discussion about how our facilities could aid in SKC research projects. We discussed faculty/student exchanges and short courses. These activities will resume when pandemic restrictions are lifted.

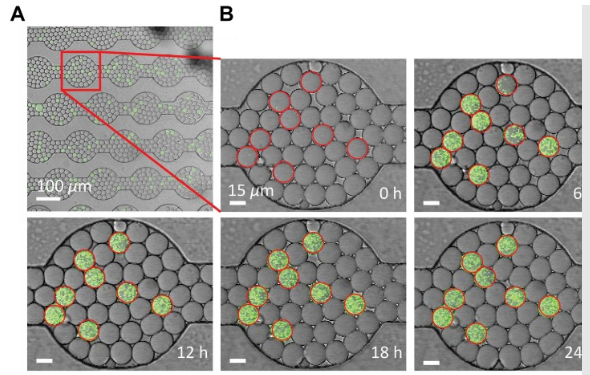
The Science Education Resource Center (SERC) at Carleton College Assessment team conducted numerous formative assessments of the Teaching Nanotechnology on-line tutorials. Feedback from these assessments has been incorporated into the website design and navigation to make the posted resources more intuitive and accessible.

Research Highlights and Impact

Scholarly impact: During 2019, MONT researchers produced 59 journal papers, 82 proceedings papers and presentations, 3 books/book chapters, and 5 patents. These 149 products represent a 57% increase compared to 2019.

Example publications include:

Pratt et al., who used MONT facilities for their ***Frontiers in Microbiology*** paper (10:2112, 2019) on "Stabilizing Microfluidic Drops for Time-Lapse Quantification of Single-Cell Bacterial Physiology." (Figure)

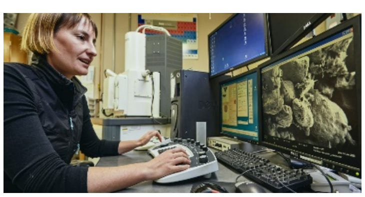


Growth of P. aeruginosa PAO1 starved for 0 days in drops over time via CLSM. (A) Using a 20X objective lens, each field of view captures approximately 1150 drops. Scale bar is 100 µm. (B) P. aeruginosa labeled with green fluorescent protein grow from single cells in the drops over 24 h. Growth was quantified from the increase in fluorescent output from each drop. Drops circled in red contain cells. Drop position remains constant over time. Scale bar is 15 µm.

Graduate student Tinabo Liu's first author paper, "MEMS-in-the-lens architecture for a miniature high-NAlaser scanning microscope" ***Light: Science & Applications*** (8:59, 2019) has five citations already.

MONT user Nick Stadie's paper, "Zeolite-Templated Carbon as theCathode for a High Energy Density Dual-Ion Battery" with Dubey et al., ***ACS Applied Materials & Interfaces*** (11:17686-17696, 2019) has had eight citations.

MONT users had several outstanding accomplishments during the reporting period, two of those include research that was funded by MONT user grants to seed novel research. **Dr. Chelsea Heveran, Department of Mechanical and Industrial Engineering**, was one of only seven recipients of NSF's 2026 Idea Machine Competition. Heveran's work centers on materials science; this award looks at how researchers could create a new generation of building materials capable of tackling some of the 21st century's biggest challenges, including human habitation on Mars.



NSF 2026 Idea Machine award recipient Chelsea Heveran, working in MONT facility ICAL.

George Schaible, a doctoral student in the Department of Chemistry and Biochemistry, was one of only 34 graduate students in the U.S. to receive the Future Investigators in NASA Earth and Space Science and Technology award. Schaible studies

George Schaible, winner of NASA FINESST award.

multicellular magnetotactic bacteria and is looking at how to culture these unique bacteria. These bacteria are a potential model for understanding the evolution of multicellular life on early Earth. Schaible was also a rotating student in MONT's ICAL lab.

Economic impact: During Y5, MONT served the needs of 23 industrial partners, 18 of which are small businesses.

Notable successes for our Industrial users included active SBIR Awards for both Phase I:

- Resodyn Corp. DOD A27136
- Resodyn Corp. NIH R43GM133253
- ZAF Energy Systems NSF 1913594
- Bridger Photonics DOE 242759
- AdvR, Inc. DOE 242697
- AvrR, Inc. NASA 193481

and Phase II:

- Sustainable Bioproducts, SBIR Phase II NASA 181083
- Agile Focus, LLC received SBIR Phase II NSF 1951117
- Resodyn Corp NIH R44H6136046
- Nanovalent Pharmaceuticals NIH R44CA233128.

Large companies such as UTRS, American Chemet and others successfully parlay MONT usage to attract additional significant government and private investment to develop processes and patented products.

Education and Outreach Activities

We were able to travel to the Flathead Indian Reservation to participate in Salish Kootenai College's Family Science Night. MONT took NanoLand on a road trip to introduce about 200 students and their families to small-scale science. MONT was fortunate that the event was held on March 5, 2020 before Montana schools were closed.

Elementary school students with graduate student at SKC Family Science Night, Flathead Indian Reservation.

On February 27, 2020 members of MONT engaged with 300+ youth and adults during **MSU Family Science Day**, a Montana State University outreach event hosted by MONT and MSU Academic Technology and Outreach.

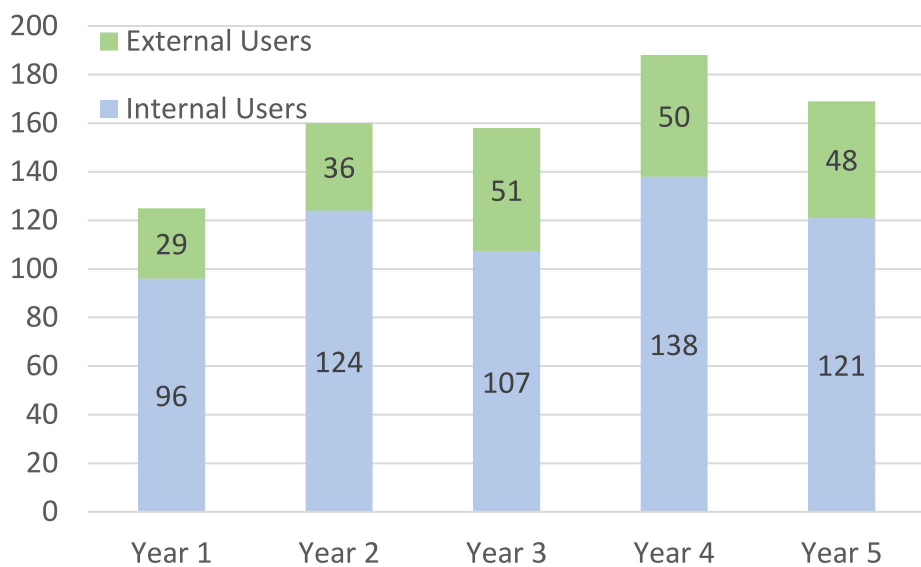
ICAL, MMF and CBE hosted several **lab tours and demonstrations** for k-12 school and academic groups in the months prior to the pandemic shut-down.

Societal and Ethical Implications Activities

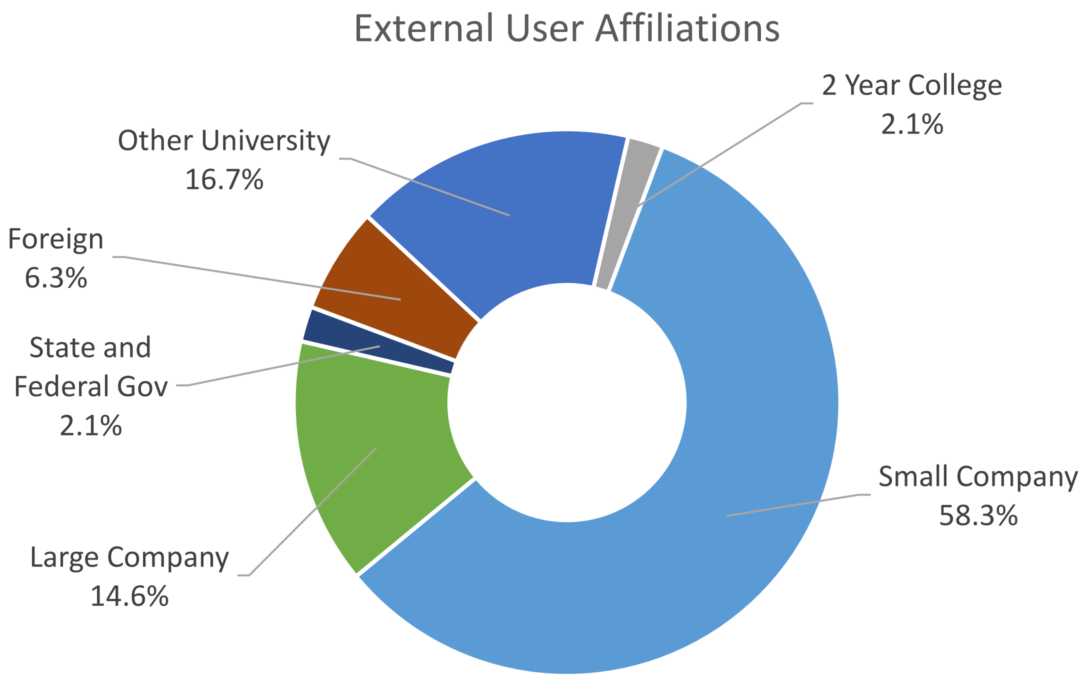
Co-PI Mogk continues to regularly participate with the NNCI/SEI committee chaired by Jamey Wetmore (2019 Annual NNCI meeting, periodic committee calls). Continued website development includes an online resource collection of journal articles and books related to ethics and nanotechnology/science, and societal issues related to nanoscience. These references can be accessed at: https://serc.carleton.edu/msu_nanotech/ethics.html.

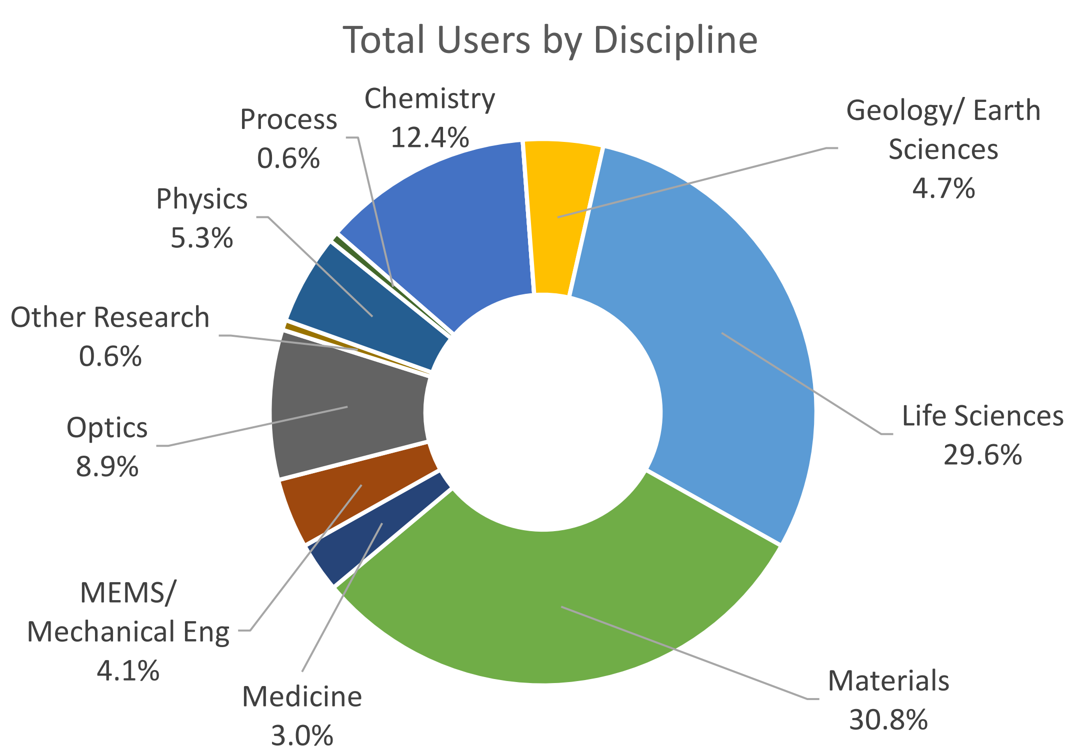
MONT Site Statistics

Yearly User Data Comparison					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total Cumulative Users	125	160	158	188	169
Internal Cumulative Users	96	124	107	138	121
External Cumulative Users	29 (23%)	36 (23%)	51 (32%)	50 (27%)	48 (28%)
Total Hours	3,599	4,713	5,420	6,398	4,858
Internal Hours	2,842	3,901	4,541	5,332	3,395
External Hours	747 (21%)	812 (17%)	879 (16%)	1,066 (17%)	1,463 (30%)
Average Monthly Users	46	51	43	62	48
Average External Monthly Users	8 (17%)	10 (20%)	7 (17%)	10 (16%)	9 (19%)
New Users Trained	36	58	58	76	70
New External Users Trained	1 (3%)	9 (16%)	8 (14%)	6 (8%)	7 (10%)
Hours/User (Internal)	30	31	42	39	28
Hours/User (External)	26	23	17	21	30



MONT Year 5 User Distribution





11.7. Nanotechnology Collaborative Infrastructure Southwest (NCI-SW)

Facility, Tools, and Staff Updates

In total, during the first five years of the NNCI ASU has invested more than $3.5M for the following tools installed in NCI-SW core facilities:

- FEI Titan Krios Cryo-TEM to image rapidly frozen molecules with 2-3Å resolution (Year 2).
- A 3-gun SC450LL sputter tool from Semicore. It includes a load-lock that decreases tool cycle time and improves efficiency by reducing the number of target changes (Year 3).
- A Woollam M-2000 ellipsometer to enhance our thin film measurement capabilities (Year 3).
- Hardware upgrades to the Tystar diffusion furnaces that allow a PC-based user interface and control system for programing furnace tube recipes (Year 3).
- Helios G4 UX DualBeam FIB with a cryogenic stage that enables the creation of ultra-thin TEM lamella with sub-nm damage layers (Year 4).

In addition to these ASU funded instruments, a new AnnealSys rapid thermal processor was acquired in Year 2 using funds from the Defense University Research Instrumentation Program.

As well as investing in new tools, ASU has also invested in a new staff member for industry liaison, technical marketing, and sales coordination. Dan Thompson was appointed to this position in October 2017 and played an instrumental role in negotiating membership contracts for access to the Eyring Materials Center by three large multinational companies. Dan recently left ASU and a search committee chaired by Thornton identified two potential replacements in January 2020. Shortly before an offer was made to one of the candidates the pandemic forced a hold on all new hires, but we are optimistic that the position will be filled in early 2021.

User Base

Each year the NCI-SW hosts the annual High Resolution Electron Microscopy (HREM) winter school. The winter school combines lectures with hands on sessions for scientists and engineers familiar with transmission electron microscopy but who need more advanced training. During Year 5 it ran from 6-10 January 2020. Of the 43 participants in Year 5, 36 were external to ASU representing 18 different universities, three national labs, and four industrial companies.

The Materials Research Society Spring Meeting has been held in Phoenix each year for 2016–2019. During these week-long meetings ASU hosted a significant sponsor presence in the conference exhibition hall. Regularly scheduled presentations were hosted by ASU faculty discussing research developments, and Thornton has presented about the NNCI support for external users. Educational and Outreach literature from NCI-SW and other NNCI sites was made available for visitors to the ASU MRS booths. The MRS Spring Meeting was scheduled to be held in Phoenix in 2020 but was postponed until the meeting in the fall due to the pandemic.

In Year 4 we started a seed funding program to recruit new users for the NanoFab and EMC core facilities. Academic users not affiliated with ASU can apply for up to $5,000 in laboratory fees to offset the costs of using the ASU Nanofab and/or Eyring Materials Center. Interested users submit a short proposal that is reviewed by the Governance Boards of the NanoFab or EMC. The program has continued for Year 5 with two new awards made to faculty at Northern Arizona University and the University of Texas at El Paso. The table below summarizes the seed funding projects awarded to date.

Faculty		Institution	Project Title
Year 4	Linran Fan	College of Optical Sciences, University of Arizona	Nanophotonic Quantum Systems
	Michael Pravica	Physics Department, University of Nevada, Las Vegas	Characterization and Synthesis of Novel Materials made via Hard X-rays, High Temperature and High Pressure
Year 5	Sreeprasad Sreenivasan	Department of Chemistry and Biochemistry, The University of Texas at El Paso	Exploring the Impact of Defects on Carrier Dynamics of 2D Quantum Structures and Heterostructures
	Miguel Jose Yacaman	Applied Physics and Materials Science Department, Northern Arizona University	Corona Virus Detection using Surface Enhanced Raman Spectroscopy

Research Highlights and Impact

The research focus of the NCI-SW is to provide general R&D micro- and nano-fabrication support across a broad range of disciplines including the life and health sciences; environmental nanotechnology; geological nanoscience; and renewable energy. The NCI-SW also established a user facility for the Societal and Ethical Implications (SEI) of nanotechnology that develops tools for the broader social science community to explore the social aspects and implications of nanotechnology.

We impact regional economic development by supporting the needs of the small business community. Our longtime external user, Laser Components DG, Inc., has continued to expand with a new building to be used primarily for product test and packaging. LC-DG will continue locating two full-time staff members in the ASU NanoFab for R&D purposes. In the 16 years that LC-DG has been a small business user of the ASU NanoFab and EMC they *have grown from a single employee to 30 full-time staff*.

New facility for LC-DG Inc.

The NCI-SW core facilities and LCnano center supported a number of Covid-19 related projects during 2020. Three ASU faculty received grants for the following projects:

- NSF RAPID: Disinfection and Reuse of Health-Care Worker Facial Masks to Prevent Infection coronavirus disease
- Nanofluidic chips for SARS-COV-2 viral particle sorting and sensing
- Single Molecule COVID detector

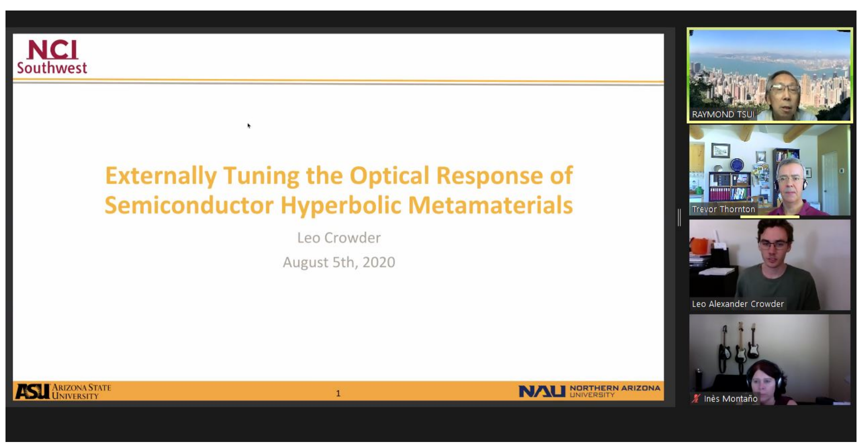
One of our external users, iNanoBio, received support from the DARPA ECHO program, for a nanopore transistor for epigenetic sequencing and diagnosing infections.

During Year 5 the NCI-SW supported the research of 507 faculty, staff, and students from ASU, as well as 159 external users. In calendar year 2019 our external users published 26 journal papers, a record for the NCI-SW. Examples of the external user research during Year 5 are presented in the Research Highlights.

Education and Outreach Activities

During the first five years of the NNCI the NCI-SW education and outreach (E&O) program, led by Dr. Ray Tsui, have focused on providing advanced lab classes for Rio Salado College; hosting research experiences for undergraduates and teachers; providing remote access to a scanning electron microscope; arranging lab tours and hands-on public activities; and, hosting nanotechnology workshops for teachers. We also maintain an on-line presence via newsletters, webinars and social media. The face-to-face activities were largely dispensed with during 2020 due to the pandemic, but the activities we were able to manage are described below.

- *Advanced Labs for Rio Salado Students*. NCI-SW is collaborating with Rio Salado College (part of the Maricopa County Community College District) to host advanced laboratory curriculum for students enrolled in their two-year, 62 credit AAS degree in Nanotechnology which contains an 18 credit Certificate of Completion. The stackable credentials offer options to students at different preparation levels. Since its launch in Spring 2017, 12 students have graduated from the program and been hired as manufacturing technicians in a variety of industries including semiconductor manufacturing and medical devices.
- *Research Experiences for Undergraduates and Teachers*. The NCI-SW has hosted a research experience for undergraduates (REU) summer program for the first five years of the NNCI. It is our experience that the program has the greatest impact on community college students who have not yet benefited from the substantially larger resources available to students at 4-year research universities. For summer 2020 we decided to forego the usual on-campus REU program due to the covid-19 pandemic. But we were able to recruit an on-line student to work remotely with Dr Ines Montano, one of our new partners for the NNCI renewal. Dr. Montano is a faculty member at Northern Arizona University in the Dept. of Applied Physics and Materials Science. She worked with an NAU undergraduate student, Leo Crowder, on a project entitled "Externally tuning the optical response of semiconductor hyperbolic metamaterials". The project is computational based and lends itself to a meaningful on-line activity. Leo presented the results of his summer research via Zoom on August 5th (see screenshot at right).



- *Newsletters, Webinars and Social Media*. A series of webinars have been hosted and archived by the NCI-SW and can be found at the webinar page on the web site. Four webinars were produced in Year 5. The webinars last approximately one hour and recent topics have included integrated nanophotonics, nanoengineered cellulose, metal oxide nanoparticles, and nanogels for biosensing. Participants sign up for the webinars in advance and can watch a live stream or review it at a later date.

The NCI-SW e-newsletters serve a number of functions. They profile center news and highlight activities at the research partner centers. They also include a section in which one of our graduate student researchers explains their research project and why it is important, using language that is accessible to our target audience. The newsletter also promotes upcoming outreach events, webinars and networking opportunities. They are sent to ~1,500 email addresses, are opened by more than 500 recipients on average, and have a 'click-through' rate as high as 7%.

We believe that social media is a useful tool for promoting the activities that the NCI-SW engages in. Since July 2017 we have been working with the Seidman Institute (part of the ASU WP Carey Business School) to actively manage our Twitter feed. The results have been impressive, with a >10X increase in the number of followers. During Year 5, 674 people were prompted to look at NCI Southwest's profile page by the tweets.

Societal and Ethical Implications Activities

Dr. Jameson Wetmore and his colleagues Ira Bennett, Erik Fisher, David Guston, and Cynthia Selin, run the NCI-SW SEI User facility, which works one-on-one with visiting scholars and also facilitates a number of workshops to do in depth training with groups of people. The SEI user facility sponsored a fourth version of Science Outside the Lab (SOtL) focused on nanotechnology in June 2019. We took 15 graduate student scientists and engineers from 8 different NNCI universities from disciplines as varied as Materials Science, Biology, and Ocean Science. In the early spring of 2020 we recruited and accepted 15 eager students ready to participate in the 5th version of the program. Unfortunately, due to the COVID-19 pandemic we had to postpone the program. Our hope is to run two programs in 2021, one with the current group of accepted students and a second one that will be filled through an open call for applicants across the NNCI.

Our efforts to support SEI work and discussion has continued in other venues as well. Over the past year Wetmore has engaged a number of organizations to promote SEI in their work. For instance, in June 2020 he hosted an online seminar for the TEDI London Summer School on "Users of Technology in the Developing World." And in August he discussed the societal and ethical implications of nanotechnology with Lisa Friedersdorf, Director of the National Nanotechnology Coordination Office, on two podcasts: "Stories from the NNI," which is designed for nanotechnology professionals, and "Nano Matters," which is aimed at a more public audience" (see: https://www.nano.gov/podcast).

Computation Activities

Dr. Dragica Vasileska, Professor of Electrical, Computer and Energy Engineering at ASU, is coordinating the computational activity for the NCI-SW, including educational activities that involve the nanoHUB. Dr. Vasileska has been a long-time contributor and user of the NCN's nanoHUB (3rd largest contributor out of 2336 contributors), although she is not funded by the nanoHUB contract. She has tallied 4936 new simulation users on nanoHUB for calendar year 2019 and her content material (e.g. lecture materials for 3 courses: Quantum Mechanics, Semiconductor transport and Computational electronics) have been accessed by 112,751 users in the last 12 months. Within ASU, Prof. Vasileska has been involved in the development of several computational modules, including:

- Full-Band Monte Carlo Device Simulator with Real Space treatment of the Coulomb interactions for modeling of 4H SiC power VDMOS devices [1],
- Bound-States Calculation Lab that is ported on nanoHUB.org [2], and
- A 2D diffusion-reaction simulator (PVRD-FASP: http://www.pvrdfasp.com), that can be used for:
    - Cu diffusion in CdTe solar cells for different temperatures and times.
    - Modeling reliability of CdTe solar cells due to various stressors (light, temperature, bias).

Outside of ASU, Prof. Vasileska is collaborating with:

- Research Assoc. Prof. Michael Povolotskyi from Purdue University on using PETSc and SLEPc numerical libraries for solving 1D Schrödinger-Poisson problem (Bound-States Calculation Lab)
- Ass. Prof. Amir Goldan Hossain from Stony Brook to understand the impact ionization process in amorphous Se photodetectors.
- Prof. Gilson Wirth from UFRGS in Porto Alegre, Brazil on the topics of NBTI in p-channel devices due to charging and discharging of traps at the heterointerface, random dopant fluctuations in the on-current in both n- and p-channel devices [3].

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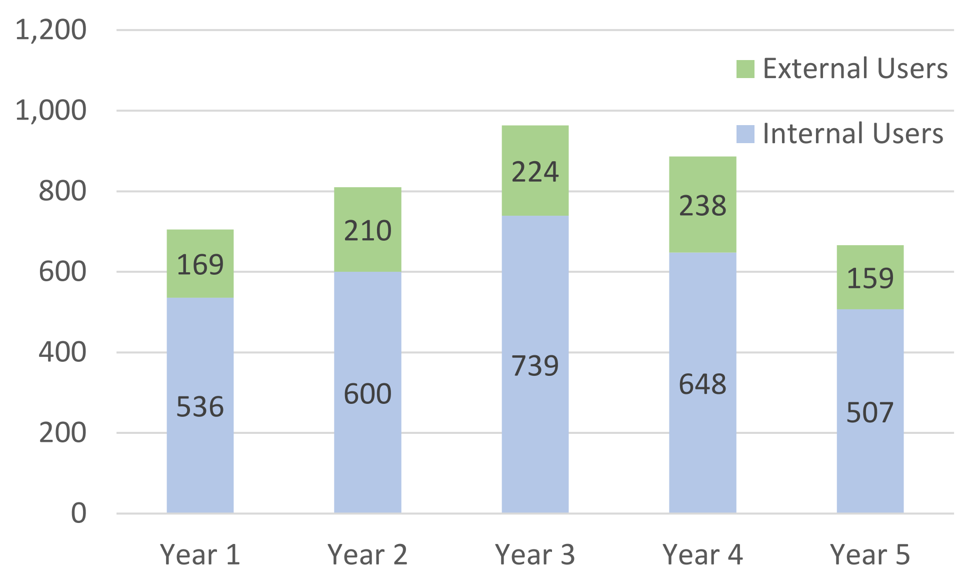
[1] Chi-Yin Cheng and Dragica Vasileska, "Static and Transient Simulation of 4H-SiC VDMOS Using Full-Band Monte Carlo Simulation That Includes Real-Space Treatment of the Coulomb Interactions", *IEEE Tran. El. Devs.*, online. Digital Object Identifier https://doi.org/10.1109/TED.2020.3007368

[2] https://nanohub.org/resources/4875

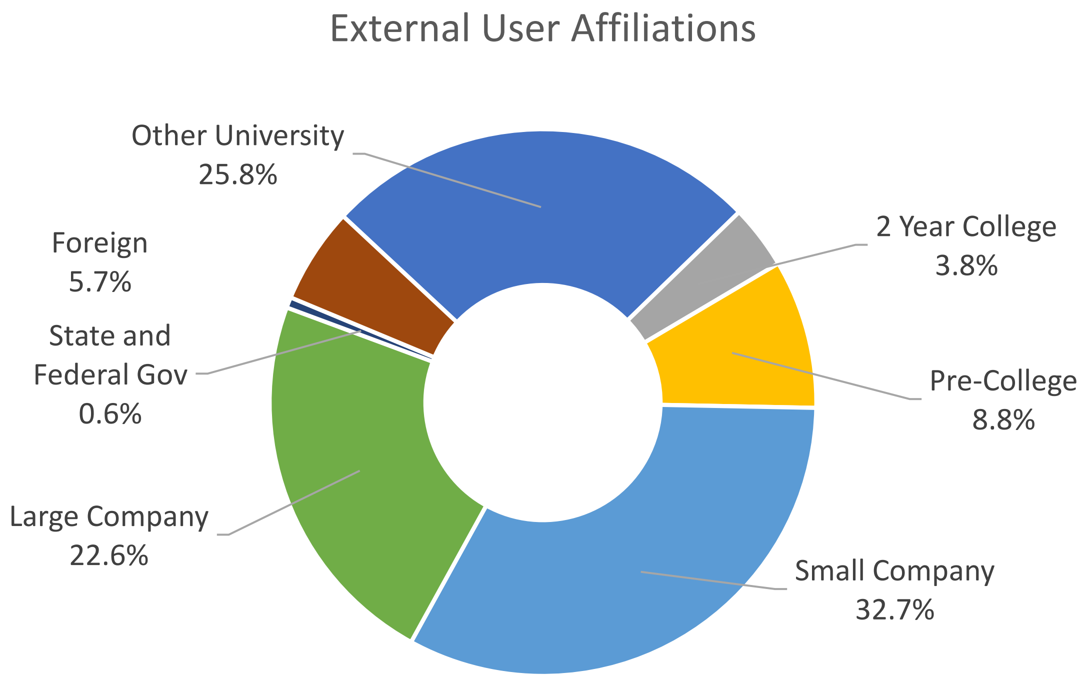
[3] A. C. J. Rossetto, V. V. A. Camargo, T. H. Both, D. Vasileska, and G. I. Wirth, "Statistical Analysis of the Impact of Charge Traps in p-type MOSFETs via Particle-Based Device Simulations", *J. Computational Electronics* 19, pp. 648–657(2020). Digital Object Identifier https://doi.org/10.1007/s10825-020-01478-6

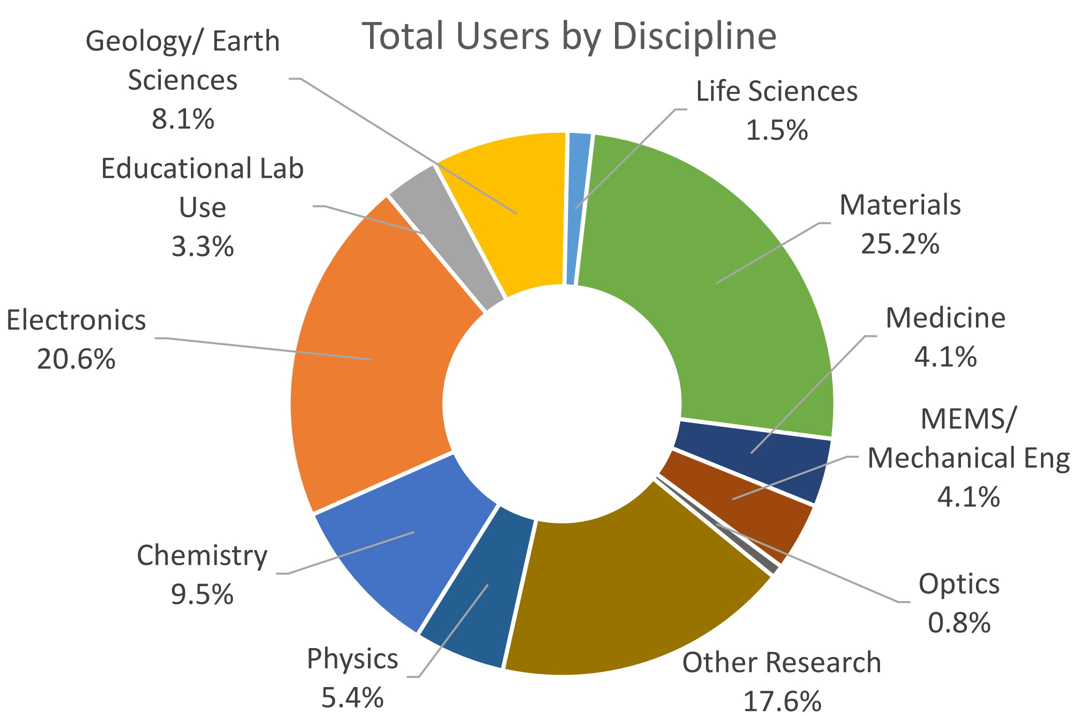
NCI-SW Site Statistics

Yearly User Data Comparison					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total Cumulative Users	705	810	963	886	666
Internal Cumulative Users	536	600	739	648	507
External Cumulative Users	169 (24%)	210 (26%)	224 (23%)	238 (27%)	159 (24%)
Total Hours	43,098	49,370	46,647	50,630	30,206
Internal Hours	32,883	38,270	37,954	37,996	23,997
External Hours	10,215 (24%)	11,100 (22%)	8,693 (19%)	12,834 (25%)	6,209 (21%)
Average Monthly Users	271	313	284	312	272
Average External Monthly Users	43 (16%)	49 (16%)	47 (17%)	56 (18%)	45 (17%)
New Users Trained	275	333	675	700	375
New External Users Trained	47 (17%)	53 (16%)	102 (15%)	143 (20%)	35 (9%)
Hours/User (Internal)	61	64	51	58	47
Hours/User (External)	60	53	39	54	39



NCI-SW Year 5 User Distribution





11.8. Nebraska Nanoscale Facility (NNF)

The *aim* of the Nebraska Nanoscale Facility (NNF) is to be an internationally recognized center of excellence for nanoscience, and a NNCI research hub for integrated fabrication, characterization and education in nanotechnology for the western region of the US Midwest.

<u>Facility, Tools and Staff Updates</u>

The enhancement of NNF facilities has proceeded in the last 5 years through funds received from the University of Nebraska, U.S. Army Research Office, NSF NNCI and NSF MRI. The Surface and Materials Characterization Facility (SMCF) added an advanced attocube system for enabling low temperature and high magnetic field SPM. The Nanoengineering Facility recently added a new ZEISS Laser Confocal Scanning Microscope, and an EnvisionTEC 3D-Bioplotter 3D printer for tissue engineering research and a cell-culture laboratory. An AR200 Laser measurement sensor from Acuity, with computer and software for TEM sample thickness measurements, was purchased by the ENIF Facility. Staff members supported wholly or in part by NNCI NNF include NNF Coordinator and User Contact Dr. Jacob John, NNF Research Technologists Dr. Anand Sarella and Dr. Andrei Sokolov, and NNF Education-Outreach Coordinator Terese Janovec.

<u>User Base</u>

A major focus of the NNF during the five years was to significantly expand the external user base. The NNF Site Coordinator initiated a highly effective industry-university outreach program throughout the Midwest region, growing external users and external usage hours during the first four years, thanks to the proactive efforts of the NNCI-supported technical staff: Drs. Jacob John, Anand Sarella, and Andrei Sokolov. Over 95% of our external users are remote users. Supporting this volume of external services would not have been possible without the NNCI grant. **NNF Seed Grant/Free Usage Program for External Universities/Companies During Campus Visits:** During the fifth year, the NNF Coordinator visited several universities and companies in the neighboring states of WY and CO, offering free usage/seed grant packages worth $2500 to universities and companies. At each university, department chairs circulated information among faculty/students, and those lacking funding or access to advanced facilities had the opportunity to hand over samples to the NNF Coordinator for analyses. Several dozen external users benefited from this external outreach. **NNF Symposium:** The Nebraska Nanoscale Facility (NNF) & the Nebraska Center for Materials and Nanoscience (NCMN) Symposium was held on December 11th and 12th, 2019 at the University of Nebraska-Lincoln. The symposium "Nanomagnetism: Finding tools for a problem and problems for a tool" brought NNCI researchers, users, specialists, and invited speakers together to contrast problem-driven and tool-driven research approaches in Nanomagnetism. Modern questions in nanomagnetism were addressed and solutions discussed using appropriate NNCI fabrication and characterization tools including those at NNF. Five external invited speakers were from the Univ. of Kentucky, Univ of Minnesota, and University of California-San Diego. **Nanotech Lab Course for Users**: This one-credit hour per semester course provided graduate students with an introductory, but yet comprehensive view into the large variety of the instruments available at the NNF. The course spanned two semesters and covered theoretical introduction and demonstration of technical capabilities in materials and nanoscience areas.

<u>Research Highlights and Impacts</u>

Research Focus Areas in NNF: The UNL hired four faculty in QMT in the Departments of Physics, Chemistry, Electrical and Computer Engineering, and Mechanical and Materials

Engineering. These new faculty, along with several present faculty, will form a strong research group in the NSF Big Idea: Quantum Leap. Because of UNL's commitment to a quantum materials cluster hire, expertise in this forward-looking field is on an upward trajectory in NE. It is also noteworthy that the NNF Director leads an EPSCoR proposal on "Emergent quantum materials and quantum technologies." In the event it manifests as a grant, interdisciplinary research by a team of 21 PIs and 4 universities in the state of Nebraska will add to the pool of NNF users and transform NE into an internationally recognized hub in the field of quantum materials. The NNF also supports major sponsored research programs at the NCMN, an institutional Nanoscale Science and Technology Program of Excellence, the Nebraska Innovation Campus, UNL's new Voelte-Keegan Nanoscience Research Center, the NSF-MRSEC, the SRC-NIST Center for Nanoferroic Devices, the DOE-EERE Collaboration on Magnetic Materials, and several other research centers and programs in other universities and colleges in the western region of the US Midwest.

Projects of External Users:

- *Monolith Materials, CA and NE*: Monolith, a California-based company, has invented and developed carbon nanoparticle production by burning natural gas. A new plant, under construction in Nebraska, will replace a coal-fired power plant with a hydrogen-burning one and employ 300 people when fully developed. The company is using NNF for characterizing the NPs using high-resolution S/TEM. NNF technologists provide their expertise to obtain HRTEM images for particle quantification and process control.
- *Vishay Dale Electronics, NE*: Vishay Dale Electronics's Nebraska plant located in Columbus is extensively using the X-Ray Photoelectron Spectrometer and X-Ray Fluorescence Spectrometer in the NNF for the elemental detection and composition analyses of thin films, plated sheets and other electronic parts. The company uses NNF equipment for the advanced investigations of the thin-film devices and fabrication-process failure mechanisms.

Economic Impacts: The NNF critically supports all research in materials and nanoscience at the Univ. of Nebraska. The related annual research expenditures were $24.4 M in FY 2019, leading to an estimated $137 M in economic activity. NNF also supports the Manufacturing economic sector of Nebraska's economy which, at $12.9 B, is third in the state's gross domestic product after Government ($14.8 B) and Finance/Insurance ($13.3 B). The NNCI grant enables NNF to provide critical resources necessary for many companies, smaller universities and colleges in the Midwest region. The NNF supported more than 60 regional institutions in 7 states in the Midwest region during the 4th NNCI year in terms of R&D, innovation, product development and testing, quality control, solving and identifying problems in product lines and identifying reasons of product failures in the field, etc. For *e.g.*, a small company that makes agricultural equipment located in Nebraska was having problems due to failure of one of their products in the field. They approached the NNF and we ran a few tests on the failing product and identified the cause of failures. The test saved that product and the company rectified the problem.

<u>NNF Education and Outreach Activities</u>

NNF-Sponsored Events: *<u>National Nanotechnology Day Celebrations</u>* on Oct. 9, 2019 included a variety of different events by the Nebraska Nanoscale Facility (NNF) 1) images contributed to the national NNCI 2019 Plenty of Beauty at the Bottom image contest, 2) hosting of an outreach booth to communicate about Nanotechnology in the Physics building with tours of the Nanoscience Center and 3) participation in the RAIN network Open House event by making the XRF equipment available to users on a national level. In addition to graduate student users we also had twenty K-6 grade students meet online with one of our scientists and introduced them to our XRF equipment.

Student Conferences sponsored annually were the *Conference for Undergraduate Women in Physical Sciences, WoPhyS* where NNF partnered with MRSEC, along with other sponsors, to bring together outstanding undergraduate researchers in science. Students from across the US attended the national conference to build on their current research experiences.

We continued hosting ***Junior/Senior High Tours*** to interested junior and senior high students, parents and teachers visiting the UNL campus until Covid-19 limited this activity. We are now using virtual tours for those interested in learning more about what UNL has to offer in nanoscience research. NNF helped coordinate tours and hands-on experiences with a variety of departments.

Partnerships: *Nebraska Math Day*: We had the opportunity to talk with hundreds of the best and brightest high school students from across Nebraska in the span of a few hours at the annual Nebraska Math Day. Our booth featured many activities about STEM/Nano so high school students could get an idea of what UNL has to offer in the area of carbon nanotubes, and graphene research.

Nano and the Nebraska Robotics Expo: The annual Nebraska Robotics Expo at the Air & Space Museum provided a unique venue for NNF to share what's happening in the Nano/STEM areas to Expo participants, spectators, and parents. Nebraska youth were given demonstrations and interactive activities about opportunities and careers in chemistry, physics, and engineering.

***Nano and Discover Engineering Days*:** NNF partnered with the College of Engineering to introduce hundreds of rural and urban middle school students and their teachers in-person and virtually to the various fields in engineering and nanoscience at the University of Nebraska–Lincoln throughout the year. Events were filled with hands-on activities that apply math, science and creative thinking skills. In September of 2020, 160 junior high students from 6 rural schools throughout Nebraska received synchronous Zoom nano lessons using hands-on materials mailed in advance.

Workforce Development: *Lincoln STEM Ecosystem - Reverse Pitch Event*: NNF gave a presentation to other Lincoln STEM-rich organizations, nonprofits, and programs about the type of work done at NNF and how to partner with us. The goal of the event was to better connect the STEM organizations serving youth K-12 and post-secondary to the businesses that are hiring in our community to ensure equity in awareness of and connection to STEM skills and careers. (150 participants)

Research Experience for Undergraduates (REU): Usually individual students and Prof./Student pairs work in research labs 8-10 weeks during the summer focused on nanoscience areas. We were not able to have the program this summer but chose students for our 2021 in-person summer REU and have committed to host the NNCI REU Convocation in August 2024.

High School Intern Program: Due to Covid-19 the Internship program pivoted to virtual format and continued remotely with limited on-site participation. Students were still able to present their research results at UNL's Summer Research Program Symposium at the end of the program remotely, to which faculty, parents and others were invited.

Rural Workforce Development: 1) We hosted tours for 10 undergraduate student cohorts from Central Community College (CCC), Columbus, NE. Students were able to experience firsthand our NNF Facilities. They are now performing research in NNF labs along with CCC faculty on a regular basis. 2) Information and hands-on activities were presented in December 2019 to 65 junior high girls from three rural schools about nanolight technology, graphene, and other topics at this Community College also. 3) NNF trained 15 undergraduates as tour guides for our Traveling Nano Exhibit hosted by CCC.

Teachers: ***Teacher Conferences/Workshops:*** NNF trained and resourced K-12 teachers with STEM/Nano-related information at the Nebraska section of the American Association of Physics Teachers Conference, the South Dakota STEM Education Conference via Zoom and through online educational videos, lesson plans, and other materials. These activities contributed to their overall nanoscience literacy. ***Teacher Education Classes:*** NNF complimented efforts by UNL's College of Education and Human Sciences by providing nanoscience-related lessons and resources to 18 undergraduate students in one of their core education classes. Students received training on nanoscience lesson preparation with activities as part of their science education program using COVID safety procedures. ***Community College Events for Teachers***: NNF made presentations about Nanoscience with hands-on activities at Central Community College to 60 middle/high school teachers from 30 rural schools at the Central Community College (CCC) Teacher Workshop.

Tribal Community College Event (Nebraska Indian Community College - Santee): We also provided on-site training to college administrators, the college Science Director and Lead Science Teacher on how to understand and use our Traveling Nano Exhibit. One teacher joined us from another college location remotely. ***Research Experience for Teachers:*** Attended Georgia Tech's remote RET and NanoSIMST- RET virtually at Stanford in preparation for NNF's 2021 RET.

Diversity: ***K-12 Diversity Programs***: 1) NNF partnered with Title 1 After-School programs in person, and the local Girls, Inc. and Nebraska College Prep Academy summer Nano camps remotely to underrepresented and first generation 10-12th grade students from regional high schools. The camps included virtual tours of nano-related research in NNF facilities and hands-on activities. 2) New nano lessons were provided for 4H/Nebraska Extension Boredom Busters virtual series for rural 6-8th graders during the 2020 summer. 3) A new partnership beginning in September 2020 with Educational Talent Search (ETS) created virtual lessons for 50 junior high/25 high school underrepresented M/H school students and ETS staff training for After-School programs to continue.

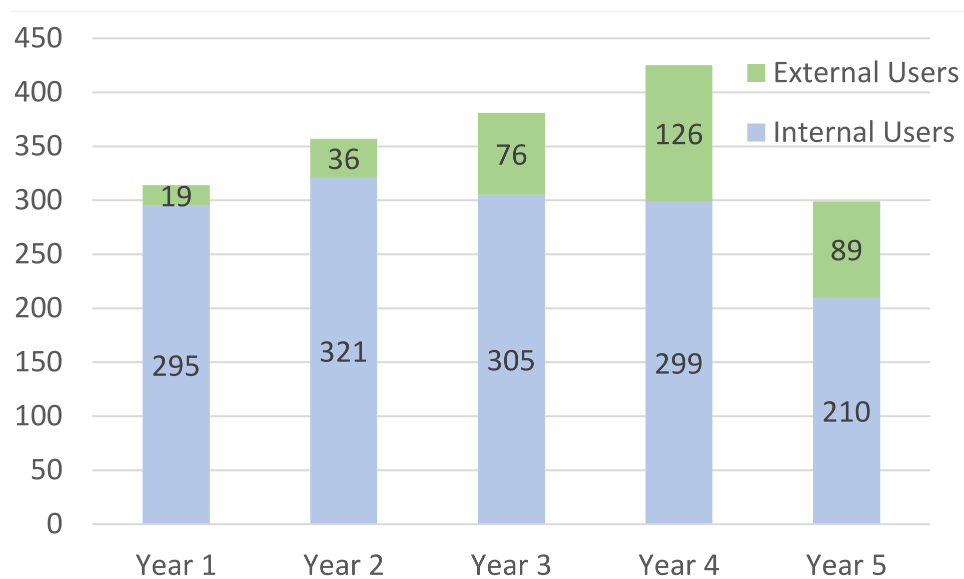
Traveling Nanoscience Exhibit: Our 400-sq.-ft.hands-on exhibit was hosted by the 1) Nebraska Indian Community College – Santee, Nebraska, 2) Central Community College in Columbus, NE, 3) Launchpad Children's Museum, Sioux City, Iowa and 4) the W.H. Over Museum in Vermillion, South Dakota. About 2,000 people were able to experience the Exhibit before moving it into storage until the Covid-19 situation changes.

Resources: ***Nano/STEM Kits*****:** We provided Nano/STEM activity kits (developed by NISE Net, a NSF-funded organization) to many teachers in the area. Multiple locations throughout the state and into South Dakota used Nano/STEM kits for the first time in classrooms, museums, and other venues to provide hands-on activities about nanoscience topics.

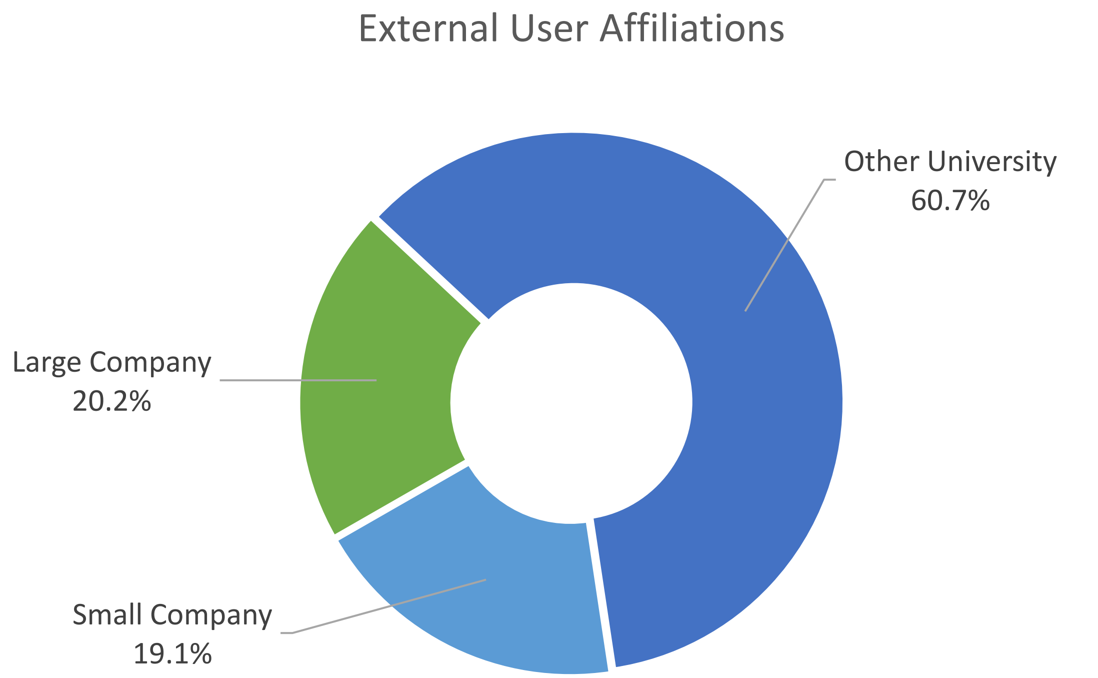
Assessment Activities: The Nebraska Nanoscale Facility (NNF) evaluated efforts to promote nanoscience among diverse, underrepresented groups, by surveying participants at the completion of After-School programs, the Summer Nano Camp, the WoPhyS Conference and workforce and development efforts to middle school girls in northeast Nebraska. Participants in the remote high school program completed pre/post surveys about their remote work in nanoscience labs during the summer. The Rural Teacher Workshop surveys provided information to us about teacher's nanoscience knowledge and what tools and activities were needed to influence their students in the nanoscience area. Students in the fall 2020 Discover Engineering virtual outreach were surveyed and 42 percent responding indicated that the lesson and activities had increased their interest in studying science and engineering.

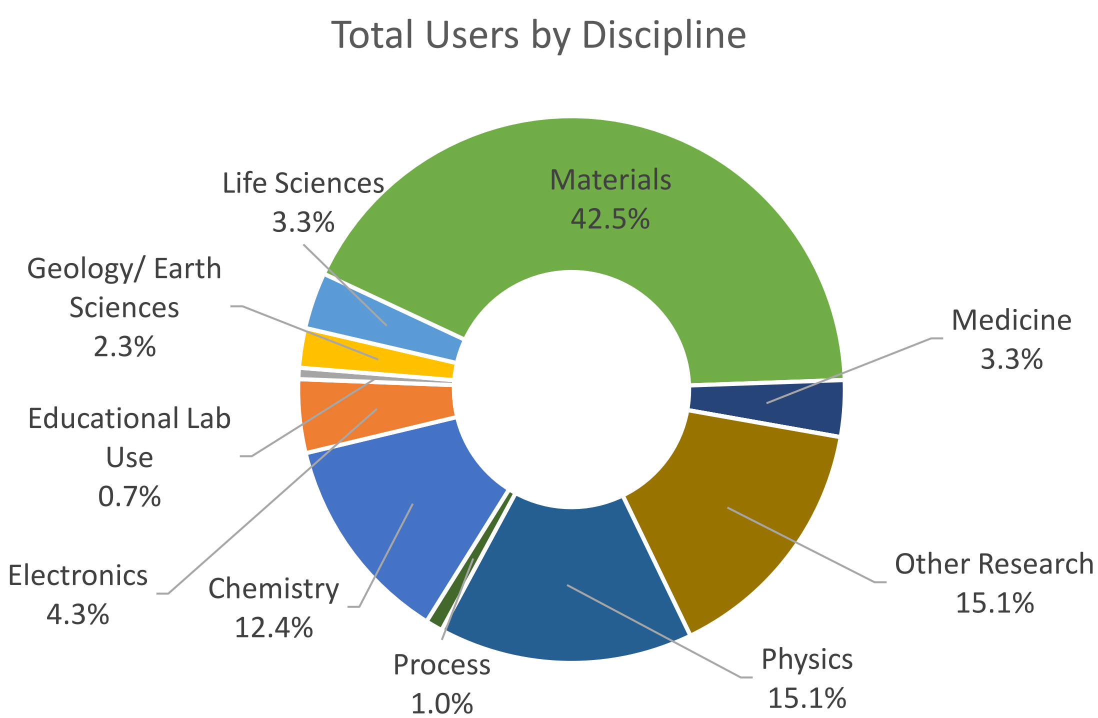
NNF Site Statistics

Yearly User Data Comparison					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total Cumulative Users	314	357	381	425	299
Internal Cumulative Users	295	321	305	299	210
External Cumulative Users	19 (6%)	36 (10%)	76 (20%)	126 (30%)	89 (30%)
Total Hours	23,445	20,102	24,008	31,037	24,002
Internal Hours	23,123	19,278	22,260	27,468	20,809
External Hours	322 (1%)	824 (4%)	1,748 (7%)	3,569 (11%)	3,192 (13%)
Average Monthly Users	40	120	132	137	90
Average External Monthly Users	3 (8%)	7 (6%)	19 (15%)	18 (13%)	14 (15%)
New Users Trained	47	54	124	98	150
New External Users Trained	0 (0%)	1 (2%)	6 (5%)	7 (7%)	5 (3%)
Hours/User (Internal)	78	60	73	92	99
Hours/User (External)	17	23	23	28	36



NNF Year 5 User Distribution





11.9. NNCI Site @ Stanford (nano@stanford)

Facility, Tools, and Staff Updates

nano@stanford

The NNCI Site @ Stanford University provides access to world-leading facilities and expertise in nanoscale science and engineering for internal users and for external users from academic, industrial, and government labs. Furthermore, we seek to develop and propagate a national model for educational practices that will help students and visitors become knowledgeable and proficient users of the facilities.

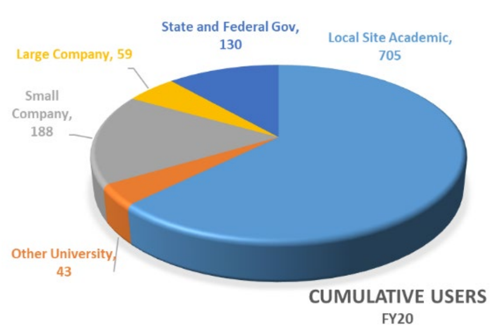
Stanford's facilities offer a comprehensive array of advanced nanofabrication and nanocharacterization tools, including resources that are not routinely available at shared nanofacilities, such as an MOCVD (Metalorganic Chemical Vapor Deposition) laboratory that can deposit films of GaAs or GaN; a JEOL electron beam (e-beam) lithography tool that can inscribe sub-10-nm features over 8-inch wafers; a Cameca NanoSIMS (Secondary Ion Mass Spectrometer) that combines the high mass resolution, isotopic identification, and sub-ppm sensitivity of conventional SIMS with 50-nm spatial resolution; and a unique scanning SQUID (Superconducting Quantum Interference Device) microscope with world-leading spin sensitivity. The facilities occupy ~30,000 sqft of space including 16,000 sqft of cleanrooms, 6,000 sqft of which meet stringent specifications on the control of vibration, acoustics, light, cleanliness, and electromagnetic interference. They offer state-of-the-art equipment as well as processes developed by scientists who work at the cutting edge of nanoscience. Close to forty expert staff members (including seventeen PhDs) maintain the instruments, teach users to operate them, and consult with users to optimize processes for their applications. The NNCI Site @ Stanford provides access to the ***Stanford Nano Shared Facilities*** **(SNSF)**, the ***Stanford Nanofabrication Facility*** **(SNF)**, the ***Stanford Microchemical Analysis Facility*** **(MAF)** and the ***Stanford Isotope and Geochemical Measurement & Analysis Facility (SIGMA).*** **New Capabilities:** During Year 5 of the NNCI award we have added a number of new instruments accessible to internal and external users, including a Lakeshore 8404 Hall Measurement System for variable temperature and mobility measurements with both DC and AC fields allowing for measurements of carriers at very low concentrations, a Raith Voyager e-beam lithography system capable of writing patterns as small as 8nm and stitching-error-free writing for centimeter(s) long features, Agilent 8900 triple quadrupole inductively coupled plasma mass spectrometer (QQQ-ICPMS) combined with an Applied Spectra Resolution SE Excimer laser sampler allowing users a unique capability of nanoscale analysis of solids in situ, Thermo Fisher Scientific Apreo S LoVac Scanning Electron Microscope (SEM) with Electron Backscatter Diffraction (EBSD) and Energy Dispersive X-ray (EDS) detectors, and mapping capabilities, PANanalytical Empyrean X-Ray Diffraction (XRD) system with multiple holders and sources to provide researchers the ability to analyze a wide variety of samples in situ including powders and thin films, LEI 1500 Eddy current system for contactless measurements of sheet resistance, Filmetrics F40 microscope-equipped spectral reflectance system for small spot film thickness measurements, and a Tosoh High Temperature Gel Permeation Chromatography (HT-GPC) which can be coupled to a Multi-Angle static Light Scattering system (MALS) to help researchers run samples at a variety of temperatures. **Personnel**: Saeed Nejad joined SNF as a Lab Operations

PANalytical Empyrean X-ray Diffractometer

Engineer, Ai Tan joined SNF as a Business Manager and also became the new Finance Manager for the nano@stanford NNCI award. Dr. Matt Mills joined SNSF as a Senior Technical Staff primarily responsible for the NanoSIMS system, Stanley Lin joined SNSF as E-Beam Lithography Manager, and Jason Tower joined SNSF as a Lab Operations Engineer.

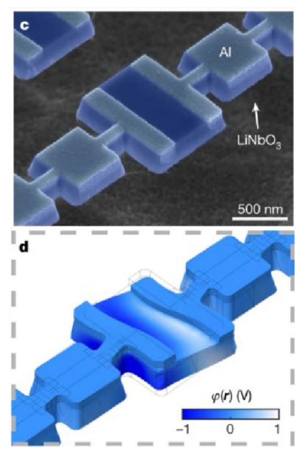
User Base

During the Fiscal Year 2020 the nano@stanford NNCI site served a total of 1125 users, despite the almost 2 month complete shutdown due to the COVID-19 pandemic. This included 705 internal users, 247 industrial users, 130 state and federal government users, and 43 users from other academic institutions. Billed user fees during that period accumulated to a total of $4.6M, of which $2.5M was collected from external users. During the 2019 calendar year we have captured 317 published journal articles from internal users, 7 articles from external users, 35 conference presentations, 10 patent applications filed, 11 patents granted, 1 textbook, and 1 book chapter. This data was captured through self-reporting and we estimate the true number to be approximately three times larger. We continue to struggle to develop an effective way of accurately capturing publications from all site users.

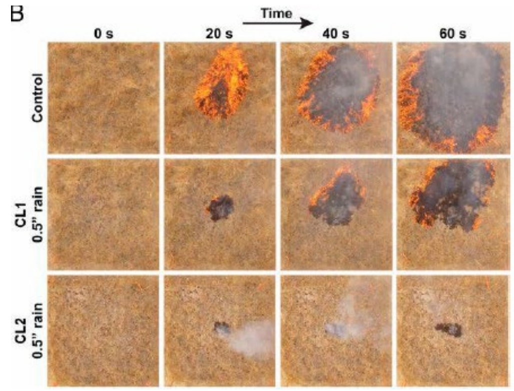


Research Highlights and Impact

Understanding the quantum nature of an oscillating mechanical object is a non-trivial task, as the coherent states that describe the classical motion of a mechanical oscillator do not have a well-defined energy, but are quantum superpositions of equally spaced energy eigenstates. To address this challenge, **Prof. Safavi-Naeini's** group devised an apparatus that measures nonresonant interaction between the oscillator and an atom with a precision greater than the energy of a single phonon. Using E-beam lithography at nano@stanford site they built a hybrid platform that integrates nanomechanical piezoelectric resonators with a microwave superconducting qubit on the same chip. They excite phonons with resonant pulses and probe the resulting excitation spectrum of the qubit to observe phonon-number-dependent frequency shifts that are about five times larger than the qubit linewidth. The result demonstrates a fully integrated platform for quantum acoustics that combines large couplings, considerable coherence times and excellent control over the mechanical mode structure. With modest experimental improvements, they expect that the approach will enable quantum nondemolition measurements of phonons and will lead to quantum sensors and information-processing approaches that use chip-scale nanomechanical devices. Their work was published the journal *Nature* and supports the NSF Quantum Leap Big Idea.



Top: SEM image of a phononic crystal defect. Bottom: Finite-element method simulation of a mechanical defect mode, showing the localized deformation of the structure and the electrostatic potential φ(r) (color scale) generated through the piezoelectricity of LN.

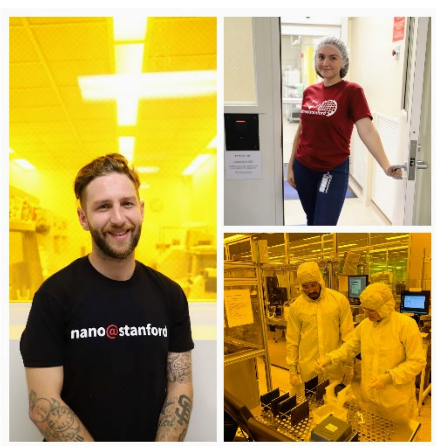


Controlled burn of unmowed grass either untreated, or treated with 2 different levels of retardant.

Wildfires continue to be a significant problem in California and other parts of the world. Polyphosphate fire retardants are a critical tactical resource for fighting fires in the wildland, but application of these retardants is limited to emergency suppression strategies because current formulations cannot retain fire retardants on target vegetation for extended periods of time. Research groups of **Profs. Apple, Criddle (Stanford University), and Acosta (CalPoly)**, working in collaboration, used nano@stanford soft materials instruments to develop a sprayable, environmentally benign viscoelastic fluid comprising biopolymers and colloidal silica to enhance adherence and retention of polyphosphate retardants on common wildfire-prone vegetation. These viscoelastic fluids exhibit appropriate wetting and rheological responses to enable robust retardant adherence to vegetation following spray application. Further, laboratory and pilot-scale burn studies establish that these materials drastically reduce ignition probability before and after simulated weathering events. The results have been published in *Proceedings of the National Academy of Sciences* journal and the technology was licensed from Stanford University to a startup company **LaderaTECH**.

<u>Education and Outreach Activities</u>

The nano@stanford NNCI site is dedicated to developing and implementing activities targeted at youth, school teachers, and the general public that will increase their interest, understanding, and involvement in STEM. These initiatives range from volunteer participation in outreach events to more in-depth workshops that span multiple days. During this reporting period, about 2,500 people were involved in these types of activities. Due to COVID-19 restrictions, many events and programs such as the Nanoscience Summer Institute for Middle School Teachers (NanoSIMST) program were held remotely. We provided kits and held Zoom calls to support teachers in the local bay area community, and recruited NanoSIMST alumni to support pedagogical efforts. We have had a significant increase in remote outreach and follow ups through our alumni network (**6/13 teachers from the 2020 cohort**). We have continued to partner with local community colleges focusing on internships for workforce development. **We hired 4 interns, all which have moved on to 4 year colleges (UC Berkeley, Cornell, SJSU, USC)**. Due to pandemic constraints, we have put this program on hold for the time being.



Tyler Fraas, Nadia Berndt, and Francisco Mires (from 4 year colleges) during their internship at nano@stanford.

To support social distancing, we published several modules on EdX for remote training, and have added over 140 videos to support various fabrication and characterization tools on YouTube. We hope to continue leveraging our online resources to adapt to the dynamic changes of these unprecedented times.

Societal and Ethical Implications Activities

We had 2 users from Stanford participating in the "Science outside the Lab" event in the summer of 2019. Senior R&D Engineer Michelle Rincon has taken the lead in nano@stanford SEI activities and we are expecting the program to grow significantly in the upcoming year.

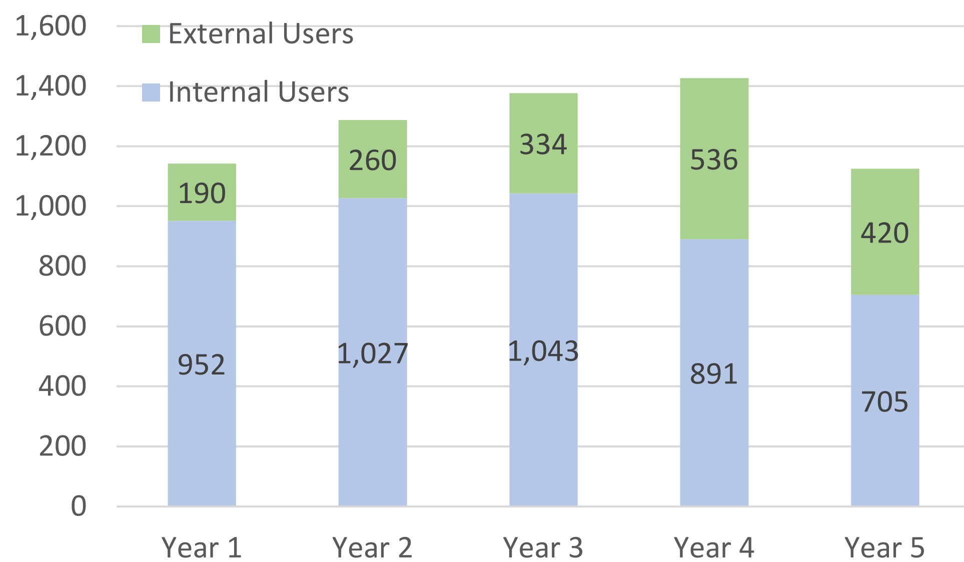
Computation Activities

Stanford researchers have continued to develop software solutions to model and simulate piezoresistive and piezoelectric sensors, heterogeneous catalytic reactions, photonic structures, metallic single-wall carbon nanotubes, carbon nanotube transistors, graphene transistors, 2D field-effect transistors, and resistive random access memories. Especially worth highlighting is the work of Prof. Jelena Vuckovic, who in 2019 released a computational library called "Spins-B" which can be applied to inverse design and optimization of nanophotonic structures, with the emphasis on flexibility and reproducible results. This resource is freely available to researchers through GitHub (Reference for Spins/Spins-B software: https://arxiv.org/abs/1910.04829).

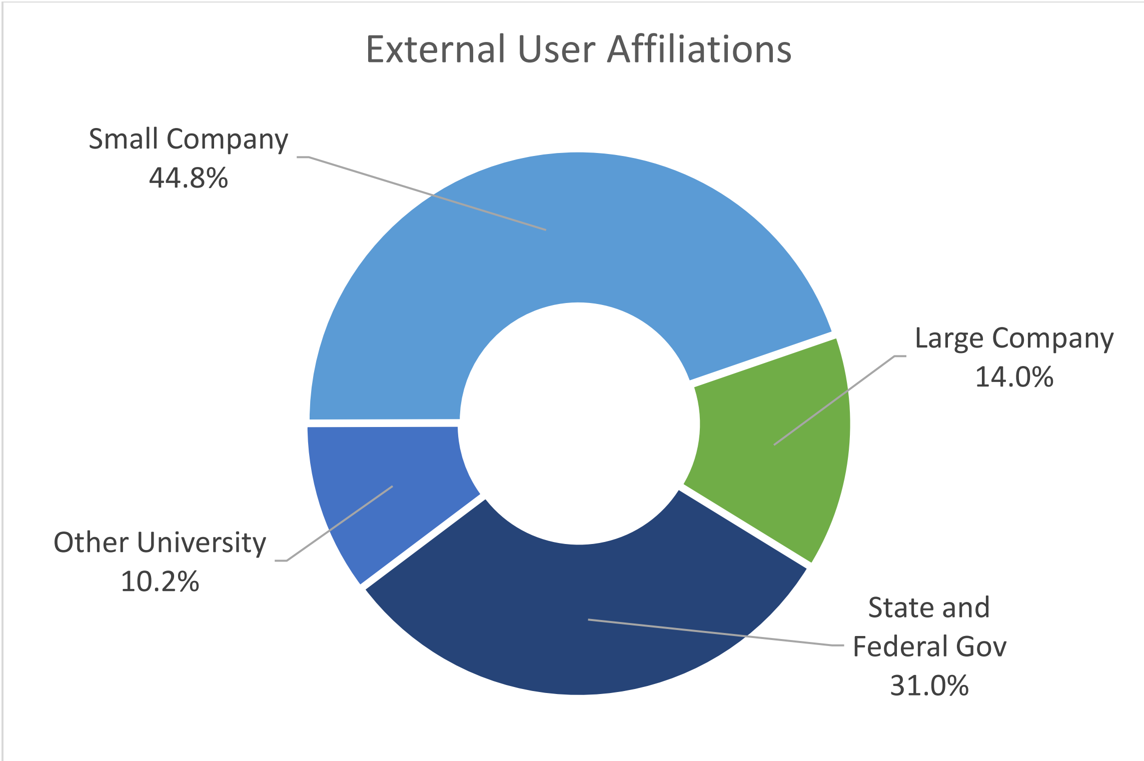
nano@stanford Site Statistics

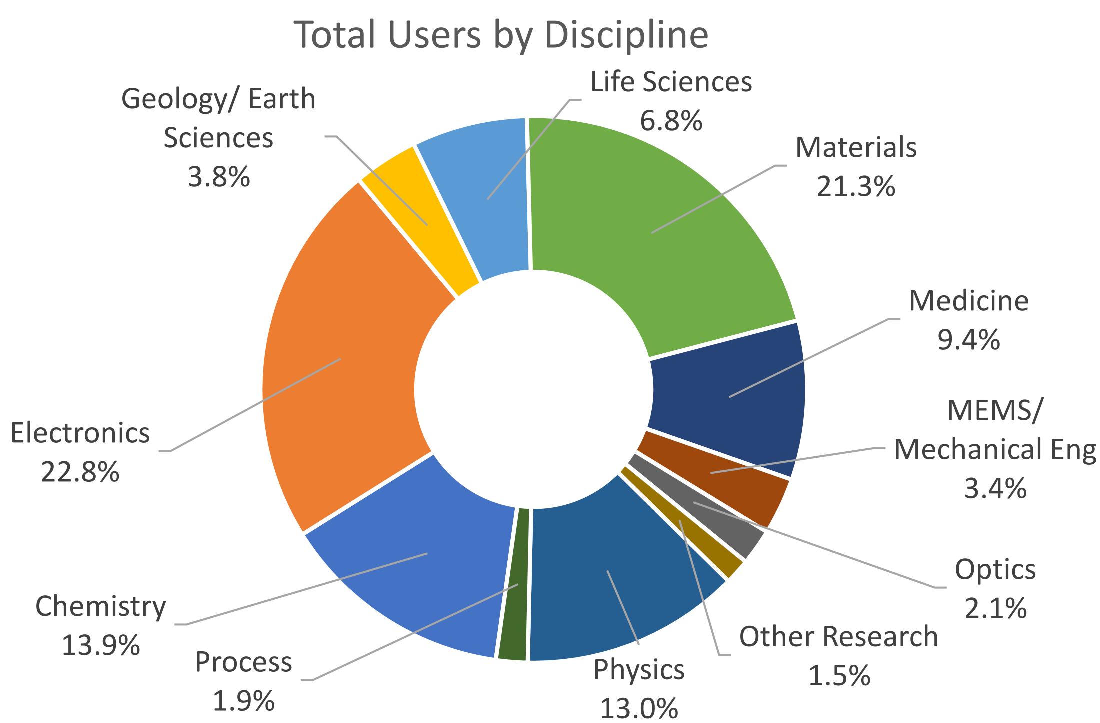
Yearly User Data Comparison					
	Year 1	**Year 2**	**Year 3**	**Year 4***	**Year 5**
Total Cumulative Users	1,142	1,287	1,377	1,427	1,125
Internal Cumulative Users	952	1,027	1,043	891	705
External Cumulative Users	190 (17%)	260 (20%)	334 (24%)	536 (38%)	420 (37%)
Total Hours	113,089	113,193	135,054	119,877	78,663
Internal Hours	94,996	91,248	105,083	72,408	47,856
External Hours	18,093 (16%)	21,944 (19%)	29,971 (22%)	47,469 (40%)	30,807 (39%)
Average Monthly Users	520	572	601	615	405
Average External Monthly Users	74 (14%)	92 (16%)	115 (19%)	213 (35%)	136 (34%)
New Users Trained	550	579	584	596	359
New External Users Trained	97 (18%)	143 (25%)	194 (33%)	262 (44%)	159 (44%)
Hours/User (Internal)	100	89	101	81	68
Hours/User (External)	95	84	90	89	73

*Starting in Year 4 the Stanford site began to categorize users from the SLAC National Lab as federal government (external) users instead of internal users.



nano@stanford Year 5 User Distribution





11.10. Northwest Nanotechnology Infrastructure (NNI)

The Northwest Nanotechnology Infrastructure (NNI) site, the Pacific Northwest node in NSF's NNCI network, includes world-class facilities at the University of Washington (UW) in Seattle, Washington and at Oregon State University (OSU) in Corvallis, Oregon. These publicly accessible facilities provide researchers and engineers in the region, across the country and around the world, with access to both workhorse and cutting-edge tools, advanced training opportunities, and other specialized resources. Moreover, NNI leverages collaborations with academic, industry, and government partners, such as the Department of Energy's Pacific Northwest National Laboratory (PNNL) in Eastern Washington State, to expand NNI capabilities. By linking together characterization and fabrication capabilities across the Pacific Northwest, NNI streamlines and expands the breadth of equipment and expertise available to scientists with diverse research interest and needs. The increasingly large and distributed user base of NNI facilities includes academic and industrial users as well as nontraditional users in materials science, clean energy, and biotechnology. NNI also plays an important role in educating and training the highly skilled workforce of engineers, researchers, and technicians needed by industry. NNI continues to be key to affirming the Pacific Northwest's leadership in research and innovation for nanotechnology and quantum information science and technology.

<u>Facility, Tool, and Staff Updates</u>

Infrastructure Investments

The new NanoES building, inaugurated in December 2017 with 45,000 assignable square feet of research space and host of the 2018 NNCI Annual Conference, is now fully occupied by an interdisciplinary assembly of researchers in nanotechnology, molecular engineering, clean energy, and protein design. The NNI Molecular Analysis Facility (MAF) has expanded into the ground floor of NanoES with upgraded TEM and cryoTEM services.

Major New Tools and Capabilities

University of Washington:

- Tousimis Autosamdri-931 Critical Point Dryer for sample treatment at WNF
- Two new Nikon optical microscopes at WNF
- Oxford Symmetry electron backscatter detection (EBSD) added to MAF's new FEI Apreo SEM with sTEM
- New Leica EM ACE600 sputter coater with C and Pt added to the MAF
- New EDAX Elite T energy dispersive x-ray spectroscopy (EDS) detector purchased and to be added to MAF TEM

Oregon State University:

- Ultra-fast laser system for characterization of thin films under development, funded by an NSF MRI
- Veeco Savannah S200 atomic layer deposition (ALD) with three-dimensional coating, low vapor pressure delivery (LVPD), and rotary particle kit
- OAI Model 206 mask aligner with backside alignment
- nScrypt 3Dn Tabletop multimaterial 3D printer with dual heads and integrated femto-second laser

- Allwin21 AW610 rapid thermal annealing system with Ar, N_2, H_2/N_2, and O_2

Staff Updates

WNF hired two engineers, Sarice Jones and Jean Nielsen, in late 2019. Also in 2019, Makeda Beck was hired as the administrative assistant of the WNF. In February 2020, our facilities engineer Sithika Ky left to pursue a career in the private sector. Since then and due to the pandemic, WNF had a hiring freeze. However, with funds from Intel Corporation, we were able to hire a recent UW B.S. graduate, Ana Constantin, as a temporary junior process engineer on a 6-month contract. Dr. John Sumida left the MAF to pursue research options. Dr. Timothy Pollock (previous MAF student staff) has been hired. Dr. Pollock is an expert in advanced laser techniques.

User Base

Academic research at NNI spans a wide range of topics including the principal research areas of integrated photonics and quantum devices, advanced energy materials and devices, and bio-nano interfaces and systems. This work is complemented by users from government laboratories and industry, with regional startups and small businesses representing the largest portion of external users.

This year has been tumultuous for the WNF. By the end of 2019, the facility had been through yet another significant operations disruption due to cleanroom flooring repair. With the onset of COVID-19, operations were suspended for one month and then only COVID-19 research was allowed. In May, select users started to be allowed back into the facility but only after strict protocols had been established. Gradually more users have been allowed and operations have been stabilizing starting in August. For now, we allow academic users working on critical and time sensitive projects, students who need to graduate or have deadlines, and companies that are deemed either critical/essential or are allowed operations under WA State mandates for Phase II operations. Current operation remains below 100% since the WNF is open 24 by 5 (Monday-Friday midnight), closed on holidays and weekends. Further, the remote workload is increasing since Jason Tauscher, WNF's manager of business outreach and customer development, is focusing on attracting new users. During the period September 2019-September 2020, approximately 1300 tool hours have been logged for remote work.

MAF staff have put a major effort into making training videos and developing remote methods to get people trained on our tools. In addition, MAF staff are, as usual, available to acquire data for users. During the initial COVID-19 shutdown MAF tools were available for critical research and staff collected data for both internal (UW) and external (industrial) research on the COVID-19 virus. MAF has recently been seeing an increase in interest from industrial users. In addition to the recent tool upgrades and updates in the MAF, we are currently working on funding to update 'workhorse' tools such as the x-ray photoelectron spectrometer, as well as upgrading it with capabilities that will better serve our users.

During the past year, the Advanced Technology and Manufacturing Institute (ATAMI), the Materials Synthesis and Characterization Facility (MASC), and the Ambient Pressure Surface Characterization Laboratory (APSCL) at OSU had limited user access to the resources. Our initial shutdown efforts were focused on improving standard operating procedures and making training videos. Resources were still available for critical research, where access requested approval by the Dean of the College of Engineering. During research resumption at OSU, ATAMI, MASC and APSCL were amongst the first facilities open for use. Priorities for access were given to graduate students, postdoctoral fellows, and assistant professors. In most cases, samples were processed and analyzed by NNI staff. Users with prior training on equipment were also given priority access. During July-September 2020, equipment use was down ~60% due to COVID-19 restrictions.

Research Highlights and Impact

Quantum information science and technology (QIST) activities have switched into high gear. The prior year saw the inauguration of QuantumX, a UW campus-wide interdisciplinary initiative of faculty performing cutting-edge research in QIST, and of the Northwest Quantum Nexus (NQN), a UW-led coalition of research institutes and industrial organizations in the Pacific Northwest and neighboring regions (including Microsoft and Pacific Northwest National Labs) with the goal of advancing QIST research and developing a QIST-trained workforce.

Numerous new QIST activities have launched this reporting period. Co-PI Mo Li leads an NSF Convergence Accelerator in Quantum Technology team that includes PI Böhringer as well as other colleagues from UW, UIUC, and Atom Computing, a start-up company in the Bay Area. The goal of this program is to develop a chip-scale acousto-optic beam steering system for cold-atom quantum computing. If successful, this system will enable a dramatic scale-up of the current state of the art to an intermediate system consisting of more than 1,000 qubits, capable of performing simulation tasks for quantum chemistry and optimization algorithms.

Prof. Kai-Mei Fu leads a $3M NSF Research Traineeship for graduate students in quantum information science and technology. This new traineeship — known as Accelerating Quantum-Enabled Technologies (AQET) —makes the UW one of just a handful of universities with a formal, interdisciplinary curriculum in this field. AQET students can come from doctoral programs across Arts & Sciences, Engineering, and Computer Science & Engineering. The program is intended to complement the training and education that participating students receive in their home doctoral programs, while also preparing them for future careers in quantum information science and technology.

NNI is a partner site in the recently approved NSF AccelNet program "Global Quantum Leap." This program will create network-to-network partnerships between NNCI and partner networks around the world that have long-standing collaborations with several NNCI sites. The goals of this new global network are to create key linkages between nanofabrication and quantum information communities on a global scale, develop a process and fabrication technology roadmap for emerging quantum computing systems, and to equip students and early-career researchers with skills to collaborate with international teams that will tackle challenges related to quantum computing systems.

A cluster hire of at least 5 new QIST faculty in the UW College of Engineering has commenced in autumn 2020, in addition to a quantum computing theory position supported by an NSF Quantum Computing & Information Science Faculty Fellow grant to the UW.

Co-PI Mo Li, Profs. Kai-Mei Fu, Arka Majumdar, and Xiaodong Xu, all key participants of NNI, also lead numerous projects in QIST, including two new NSF ACQUIRE projects, an NSF QII-TAQS project, as well as other NSF and DOE programs.

Other major developments: During the current reporting period there has been a significant increase in external use of APXPS/AP-STM capabilities in the APSCL, including users from Lam Research, the Illinois Institute of Technology, and Qatar University.

Inpria, which is developing resists for extreme ultraviolet photolithography, uses ATAMI, OPIC, and APSCL facilities and has been awarded $31M in its third round of funding. Inpria's backers include JSR Corp., Intel, Samsung, TSMC and Hynix.

UW spin-out Tunoptix, LLC, which develops tunable metasurface optics for machine vision and AR/VR applications, received seed funding from a leading intellectual property commercialization company and a DARPA Phase-II grant.

Education and Outreach Activities

NNI's E&O portfolio continues to emphasize workforce development, K-12 outreach, underrepresented populations in nanotechnology (including women and communities farthest from educational justice), and engagement of Regional First Nation Tribes. While NNI's traditional K-12 in-person E&O activities were significantly hampered by the global COVID-19 pandemic, we are actively engaged with partners throughout the NNCI network to pivot our E&O activities for a remote environment. Meanwhile, we continue our workforce development and training efforts under the safety protocols developed by the UW and OSU.

Workforce Development

NNI facilities support the development of highly skilled researchers, engineers and technicians to supply increasing demand from industry. In addition to helping students and young professionals gain training and experience, NNI facilities also provide students with unique opportunities to interact with users in industry.

Providing traditional 4-year undergraduates and community college students engaging research opportunities is one of several ways NNI facilities have supported workforce development in the region. Even during the COVID-19 pandemic, WNF has a number of undergraduate students hired through the Student Laboratory Assistant Program. Students from the UW and partner community colleges worked with WNF staff on research and contract projects, gaining hands-on nanofabrication experience that helped advance their academic and professional careers. Many students continued their nanotechnology training in graduate school while others were hired directly into jobs in industry (often hired by WNF industry clients). In a typical year, the WNF employs roughly 30 students through this program, many of whom remain with the WNF for several years. Prior to the COVID impacts, there were 24 student lab assistants, half of whom are women. Due to COVID-19 impacts, this number was reduced to 7 students.

In addition to WNF's Student Lab Assistant Program, this past year, the MAF also employed 3 paid UW undergrad research assistants (including 2 women). MAF student assistants learn about lab safety, and data processing, and how to use various MAF instruments.

NNI facilities at OSU had 5 undergraduate researchers working on different nanotechnology related projects under the guidance of NNCI faculty and staff. Students ranged in experience level from freshman to seniors and included participants in STEM Leaders, a mentoring and research program aimed at increasing diversity in STEM fields. Close to a third of students participating in OSU NNI related activities identify as female or other underrepresented groups in engineering.

First Nations Engagement

NNI is committed to engaging first nations to expand access to nanotechnology and to connect opportunities for nanotechnology to address needs identified by communities from diverse backgrounds. NNI has sought candidates from local tribal nations to participate in the cleanroom internship program. Our longest partnership includes a student who is now in his senior year at UW, having joined WNF as a high school intern from Chief Leschi School.

NNI typically hosts visits for middle and high school students from local Native American schools, including multi-day visits by the Paschal Sherman Indian School in Omak, Washington. These have been an overwhelmingly positive experiences but could not happen this year due to the COVID-19 pandemic. While in-person visits were not possible, PI Ratner has engaged with the Western Washington Native Education Consortium to train district staff in over 20 regional school districts on 4-year pathways and access programs at the University of Washington. This engagement is being expanded into relationships to support remote student engagement in the coming academic quarters subject to COVID-19 restrictions.

Educators-in-residence

Co-PI Baio has designed a program to bring science teachers from Chemawa Indian school to OSU to participate in a NNCI supported research project. Chemawa is a Native American boarding school 30 miles north of OSU and serves students of tribes from throughout the US. Each teacher will work for 5 weeks and participate in data collection and analysis, literature discussions and weekly lab meetings with the project team, thereby exposing the Chemawa instructor to state-of-the-art experimental protocols, numerical methods and advanced spectroscopic techniques. During future summer programs each teacher will be paid $1,000/week plus material expenses for the course development work. Unfortunately, these teacher training activities planned for this final award year were significantly hampered by the global COVID-19 pandemic, but we are in the process of pivoting E&O activities for a remote environment.

REU

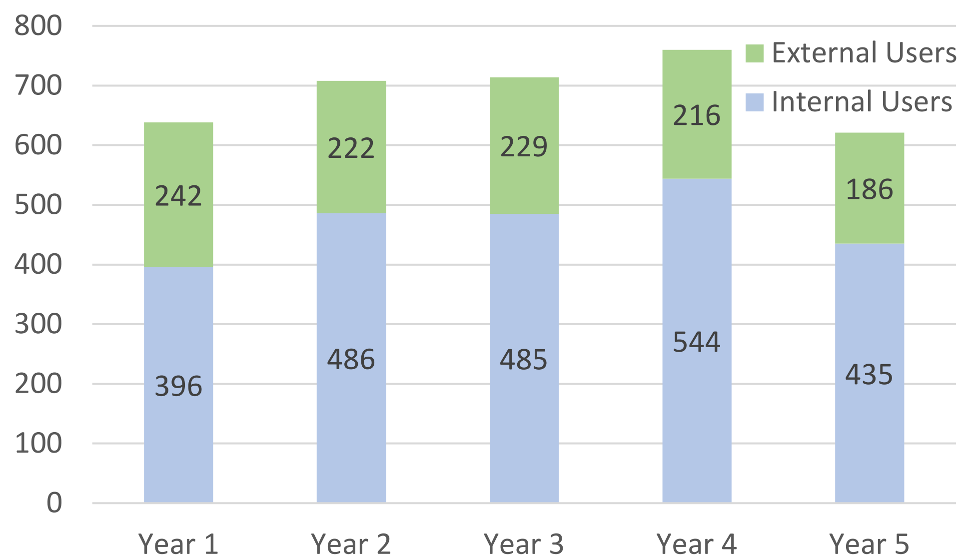
In collaboration with NNI-affiliated investigators and the UW Molecular Engineering and Sciences Institute the Clean Energy Bridge to Research REU (Christine Luscombe, PI) hosted 5 students remotely due to COVID-19.

Undergraduate and Graduate Courses

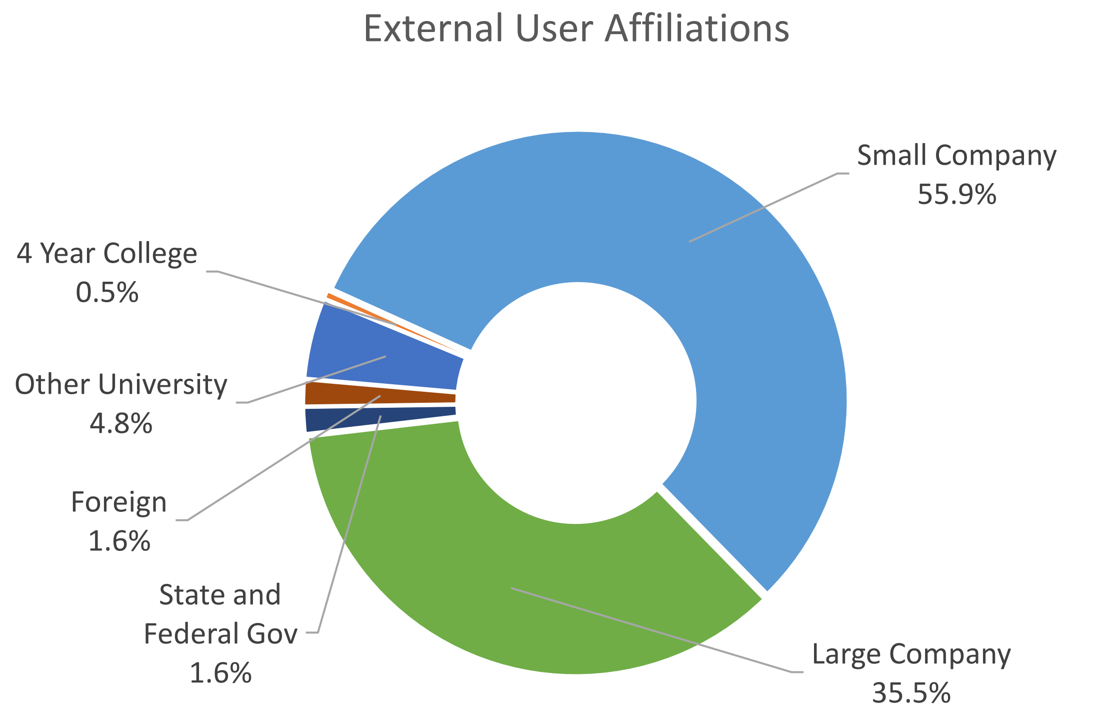
The University of Washington and Oregon State University offer comprehensive curricula with both conventional graduate courses and evening classes for professional master's program (PMP) students. Currently, several courses utilize the NNI facilities: EE 527 Nanofabrication Techniques, EE/ME/MSE 504 Introduction to Microelectromechanical Systems (MEMS), EE/MSE 486/528 Integrated Circuit Fabrication, ME 461/561 Mechanics of Thin Films, and OSU's CHE 444/544 Thin Film Processing.

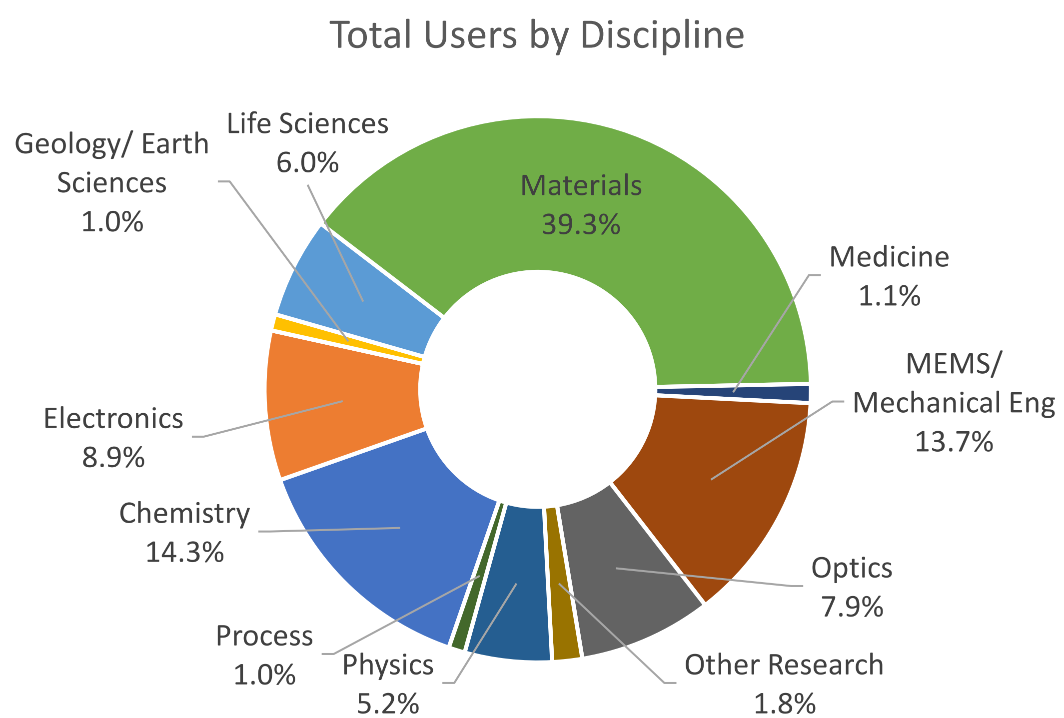
NNI Site Statistics

Yearly User Data Comparison					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total Cumulative Users	638	708	714	760	621
Internal Cumulative Users	396	486	485	544	435
External Cumulative Users	242 (38%)	222 (31%)	229 (32%)	216 (28%)	186 (30%)
Total Hours	38,350	46,562	55,925	65,032	55,939
Internal Hours	21,822	30,600	27,695	35,564	22,262
External Hours	16,528 (43%)	15,962 (34%)	28,230 (50%)	29,468 (45%)	33,677 (60%)
Average Monthly Users	267	277	266	304	226
Average External Monthly Users	103 (39%)	98 (35%)	93 (35%)	93 (31%)	77 (34%)
New Users Trained	126	159	206	134	64
New External Users Trained	41 (33%)	37 (23%)	57 (28%)	31 (23%)	18 (28%)
Hours/User (Internal)	55	63	57	65	51
Hours/User (External)	68	72	123	136	181



NNI Year 5 User Distribution

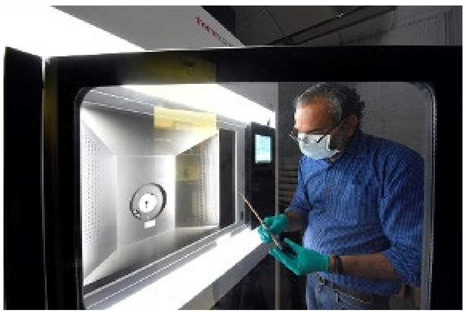




11.11. Research Triangle Nanotechnology Network (RTNN)

Facility, Tools, and Staff Updates

Staff: Nilakshee Bhattacharya joined Duke's Shared Materials Instrumentation Facility (SMIF) as the Cryo-EM Facility Team Leader and began working in SMIF on July 1, 2020. She manages SMIF's Cryo-TEM and all Cryo sample preparation capabilities. Catherine McKenas also joined SMIF as an engineer focused on characterization techniques. Catherine received her PhD at UNC-Chapel Hill. While there, she worked in another RTNN facility, the Chapel Hill Analytical and Nanofabrication Laboratory (CHANL) and supported many education and outreach programs including launching the remote access program. **Tools:** Through university support and by leveraging external funding (such as NSF's MRI program), we have acquired new equipment and upgraded existing equipment to expand RTNN capabilities including a sputter tool, e-beam evaporator, high pressure freezing system, an ion mill, a nano-infrared spectrometer, a nanoindenter, a scanning transmission electron microscope (S/TEM, see figure) a plasma FIB, and a second Hitachi Tabletop scanning electron microscope (SEM) for education and outreach. **Techniques:** A Jackfish Spectrochemical cell fixture has been acquired for one of our FTIR systems. This cell enables fundamental studies of the electrified metal-solution interface with applications in self-assembly, interfacial sensing, and next generation energy solutions. Axon software has been added to the Titan and Talos TEMs to dramatically improve sample stability during in situ experiments. Axon tracks sample location and minimizes sample motion during sample heating, cooling, or when gasses or liquids are introduced in sample chamber. An integrated RGA (residual gas analyzer) is now attached to our Protochips Atmosphere system. The RGA enables quantitative control and examination of nanoscale reactions within the gas cell holder and allows for improved control over gas chemistries introduced to the sample environment. The NC State Nanofabrication Facility (NNF) has characterized large-scale submicron lithography patterning down to 500 nm and is currently developing a process down to 400 nm.

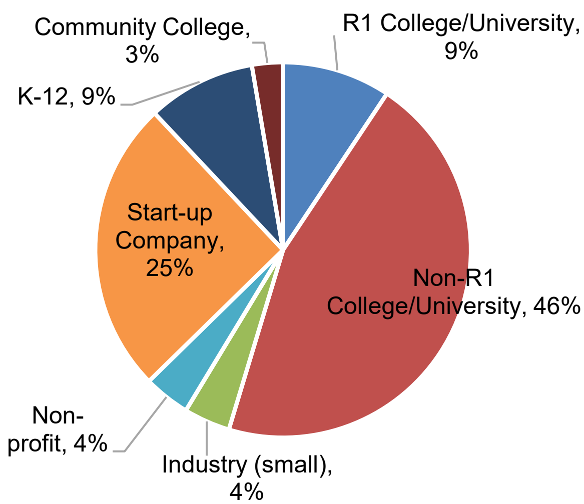


RTNN staff member Dr. Amar Kumbhar loads a sample in the Talos S/TEM

User Base

The overarching goal of the RTNN is to build the user base. We make a concerted effort to reach out to users from underrepresented demographic populations, rural areas without access to Research 1 (R1) institutions, non-R1 institutions, and industry. As identified in our proposal, three barriers to engaging new users are distance, cost, and awareness. To address these barriers, we have implemented targeted, innovative programs and activities.

Greater than 50% of current users come from non-traditional disciplines, such as textiles, biology, and agriculture. *Satisfaction*: Unique, IRB-approved surveys collect demographic and satisfaction data from all facility users. To increase the response rate in Year 5, we entered all survey respondents into a drawing to win an iPad. This incentive was added to our IRB protocol. Overall, users were very satisfied with their experiences (6.34 ± 1.05, 7=very satisfied; n=335). More than 97% of users would return to the lab if further work was necessary. These results are comparable to users' satisfaction levels in Years 1-4.



Affiliations of participants in the Kickstarter program (n=75)

RTNN Kickstarter Program: This program supports use of the facilities by new, non-traditional users by providing free initial access. To date, 75 projects have been selected for over 1,300 hours of use (Year 5: 10 projects, >115 hours use). The figure at left shows the affiliations of the program participants. The majority of participants are from non-R1 colleges/universities (46%), start-ups (25%), and K-12 students/classrooms (9%). The RTNN strives to retain the participants as long-term RTNN users and to highlight their successes via social media campaigns to recruit new users and solicit proposals. **More than 36 percent of participants who completed the program continued work in the facilities with their own financial support resulting in >$200,000 in subsequent revenue.** The program brings in new users and provides a pathway to facility sustainability. *Assessment:* Semi-structured interviews have now been conducted with 24 participants (6 in Year 5). Respondents continue to be happy with the program and have indicated they will return. Common themes from respondents were the ability of the program to push the research project forward and incredibly positive interactions with RTNN staff. Many interviewees mention staff members by name.

Online Coursera Course: "Nanotechnology, A Maker's Course," introduces nanotechnology tools and techniques and shows demonstrations within RTNN facilities. The course targets students who have a high school or higher science background and limited exposure to these facilities. **Since the course launch, over 141,000 people have visited the course website, over 22,800 have engaged with course components, and over 6,600 have completed the course.** Students hail from more than 165 countries; learners from India (35%) and the United States (11%) account for 46% of total learners. Several participants have engaged with RTNN outside the course (e.g. Kickstarter program, workshops, newsletter subscription). As a result of the course, we also received an invitation to speak to students at St. Aloysius College in Mangalore, India. We provided a virtual lecture on the basics of scanning electron microscopy and photolithography and then conducted a remote SEM session where we imaged nanofabricated particles. Over 1,500 students attended. *Assessment:* Students were highly satisfied (7=very satisfied) with the course materials on all five measures (6.46). Students were also highly satisfied with the course instruction on all five measures (6.25). Similarly, students were also highly satisfied with the multimedia content of the course (6.57). Over 90% of respondents noted they were "likely" or "very likely" to recommend the course to others. 79% of respondents noted they had a better knowledge of the capabilities of RTNN's facilities.

Workshops, short courses, symposia: In Year 5, RTNN held 11 technical workshops and short courses (>180 participants) on engaging and relevant topics. The RTNN also helped to plan and execute the Carolina Science Symposium with collaboration from the Joint School of Nanoscience and Nanoengineering (JSNN), an institution in the SENIC NNCI site. This event is student-focused, giving many early career students their first opportunity to present research in a professional setting. In 2020, this event transitioned to a two-day virtual event. The symposium attracted over 80 participants over the two-day period.

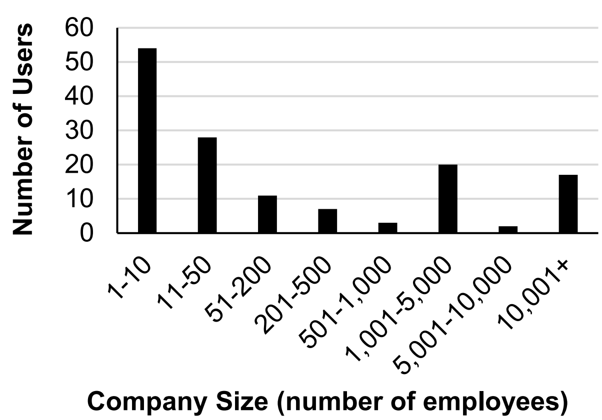
Communication: One of our main methods to disseminate information to stakeholders is via the RTNN website (www.rtnn.org). The website describes RTNN events, programs, and opportunities (e.g. nanotechnology jobs board). It also highlights recent nano-related news and provides an overview of research being pursued by principal faculty. The website has >1.300 unique visits monthly with >80% of these new visitors to the site. We also maintain two subscription lists to share information and opportunities: one to principal faculty (>100 nanotechnology faculty) and one to other stakeholders (>3,700 subscribers). We have worked diligently to broaden our reach by adding new contacts to our subscribers list and have increased the number by over 35% in the past year.

We are active on multiple social media platforms including Twitter, Facebook, and LinkedIn as a means to promote our activities, events, and opportunities. Facebook was chosen as the main social media platform for RTNN, as it reaches a broad range of the public including the professional community, students, and educators. We have seen a 110% increase in Facebook followers, 473% increase in Twitter followers, and a 73% increase in LinkedIn followers since these platforms were launched.

Research Highlights and Impact

Core technical capabilities and expertise span: interfaces, metamaterials, fluidics and heterogeneous integration; nanomaterials for biology and environmental assessment; organic/inorganic 1-D and 2-D nanomaterials; and textile nanoscience and flexible integrated systems. Much of this research is guided by the NSF Big Ideas and other national research priorities.

Scholarly and Economic Impact: Work performed in the RTNN led to >225 publications in 2019 by our users. (168 of which cited the NNCI award). 47 of these publications were authored by external users (31 cited the NNCI award). In 2019, the RTNN impacted $84.1 million in research activity, as defined by annual research expenditures, for projects that utilized the facilities. In 2019, the RTNN enabled users to achieve 22 awarded patents, 158 filed patents, and 24 invention disclosures. Our Kickstarter program has given 19 start-ups free access to the facilities, facilitating the success of these nascent business ventures. The figure at right demonstrates the tremendous impact we have on small companies; 58% of industry users are from companies with less than 50 employees.



RTNN industry users as a function of company size (Year 5)

Education and Outreach Activities

The RTNN's educational and outreach activities are a focal point of RTNN's goal to build the user base; the table below gives an overview of RTNN's educational and outreach activities. In Year 5, much of our outreach efforts shifted to virtual experiences due to the COVID-19 pandemic.

Outreach to K-Gray Participants: In Year 5, we reached over 900 people (in-person) through our outreach programs with >54% of participants from underrepresented groups in STEM. **Immersive lab experiences:** Over 170 people visited our facilities in Year 5 to engage in hands-on activities with RTNN tools. **Visits to Classrooms and Schools**: RTNN staff traveled to many classrooms and schools (K-Community College) to introduce nanotechnology, interacting with over 170 students. These visits were paired with hands-on activities to engage students. For example, in December 2019, RTNN staff provided an overview lecture on nanotechnology and electron microscopy to students enrolled in the Physics II course at Durham Technical Community College. Students then participated in a lab where they imaged samples using the SEM and designed different types of photomasks. **Take-out Science:** During the COVID-19 pandemic, we designed a program to connect our facilities to people at home and bring them "Take-out Science." Staff member Holly Leddy set up one of our portable SEMs in her guest bedroom.

RTNN Education and Outreach Events, Events that are highlighted in grey were evaluated.

Education & Outreach Events (Year 5)			
	On-Site Participants	%	Online Learners
Kickstarter Program	10	1.1 %	-
Event booths (e.g. conferences, museums, libraries)	247	26.1%	-
K-12 booths (e.g. science nights)	254	26.9%	-
Immersive lab experiences: Tours, demos, hands-on activities	176	18.6%	-
Classroom visits	176	18.6%	-
Coursera course on nanotechnology	-	-	>12,000
Take-out Science, Sciencing with Abby	-	-	>5,970
Remote events (e.g. webinar, equipment demo)	-		>1,550
Technical Events (e.g. short courses, workshops)	82	8.7%	>100
Symposia/conferences	-		>80
Total	945	100%	>19,700

During the spring of 2020, we live streamed a new show weekly focused on a different theme. Holly guided participants through observation of samples related to that theme with both a light microscope and an SEM. She also described how the two instruments worked and compared their capabilities. For two of the episodes, we worked with staff members at one of our peer NNCI sites, SDNI. All of the shows are available on YouTube, and with colleagues at Hitachi, we have begun

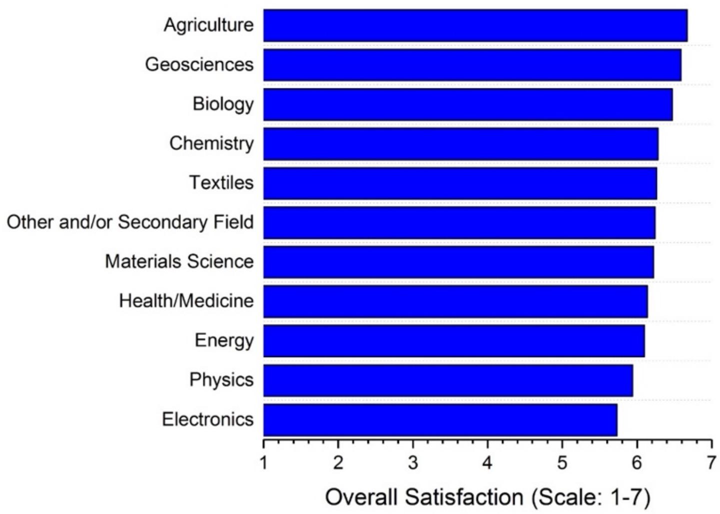
Left: RTNN staff member, Dr. Holly Leddy, is assisted by June "The Science Dog" during Take-out Science from her guest bedroom. Right: YouTube live screen showing Dr. Holly, the light microscope view, and the SEM view. Spanish subtitles help to reach a broad audience.

to add Spanish subtitles to each episode (see figure above). To date, the show has generated >4,800 views on YouTube over 15 episodes. **Sciencing with Abby:** In this video series, also launched during the pandemic, kids (and adults) are invited to conduct science experiments with us using supplies they can find at home. Each experiment has two levels: beginner videos are aimed at GK-5 audiences and advanced at G6-12. Videos are hosted by Abby Carbone, a recent NC State graduate and former Analytical Instrumentation Facility staff member. Abby's videos have received over 1,100 views on YouTube. **Community Engagement:** We organize many events at local museums and libraries. These locations provide a means to reach new populations. We bring the portable SEM and other hands-on activities to attract library/museum visitors (see image at right). Using this model, we have expanded into rural areas of North Carolina: Fayetteville (70 miles from the Triangle), Hickory (160 miles), and Asheville (230 miles). These events were organized across multiple days in an effort to reach a broad swath of the community. By partnering with volunteers from JSNN, we were able to support multiple activities and a greater number of participants. The pilot events engaged over 800 K-gray participants. **Other:** We hosted many booths at school science nights, participated in North Carolina Science Festival activities, and welcomed tour groups in facilities and remotely.

RTNN staff member Abby Carbone explains SEM operation to visitors at the Catawba Science Center in Hickory, NC.

Societal and Ethical Implications Activities

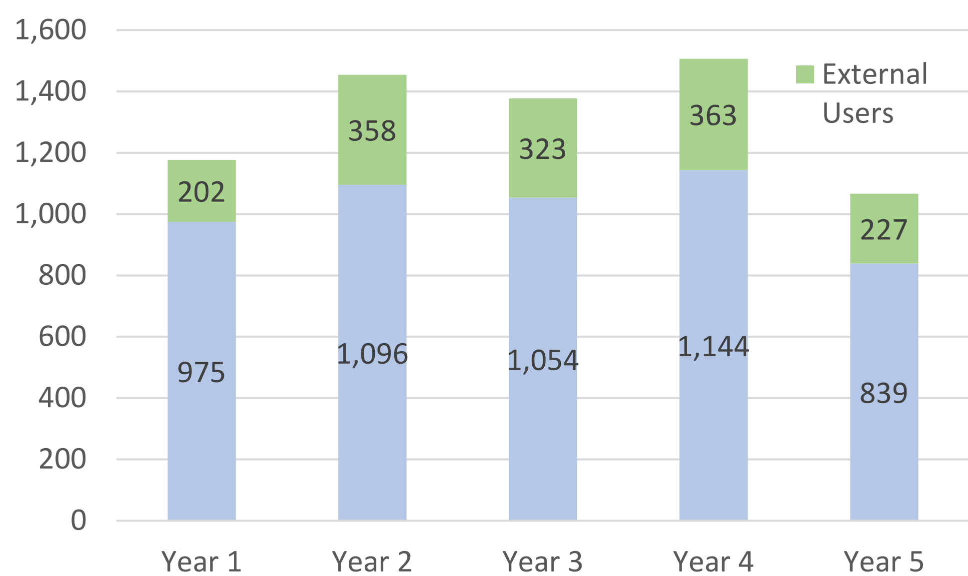
The RTNN research in the area of Societal and Ethical Implications (SEI) of nanotechnology leverages the RTNN team and user base to enhance the instruction and understanding of how humans engage with nanotechnology. IRB-approved surveys were designed for deep assessment of the user base and implemented for specific activities (e.g. Coursera course, Kickstarter program). Results from this work are highlighted above. The data is used iteratively to improve RTNN facilities and programs. After Year 4, we reached a sufficient sample size in our user satisfaction surveys to begin regression and ANOVA work and analyzed this in Year 5. This data enabled us to discern differences in satisfaction levels across different demographic groups. For example, when the data is correlated to user discipline, we begin to see significant differences. For example, users in non-traditional disciplines (e.g. agriculture, geosciences, biology) are more satisfied than users from traditional disciplines like physics and electronics (see figure). In Years 6-10, the SEI team will work to investigate the source of these differences and determine why different users experience the facilities differently. We are currently designing research questions that help to better elucidate the reasons for these differences. The SEI program further integrates with the RTNN social media presence to study how social networks influence nanotechnologists' decision making.



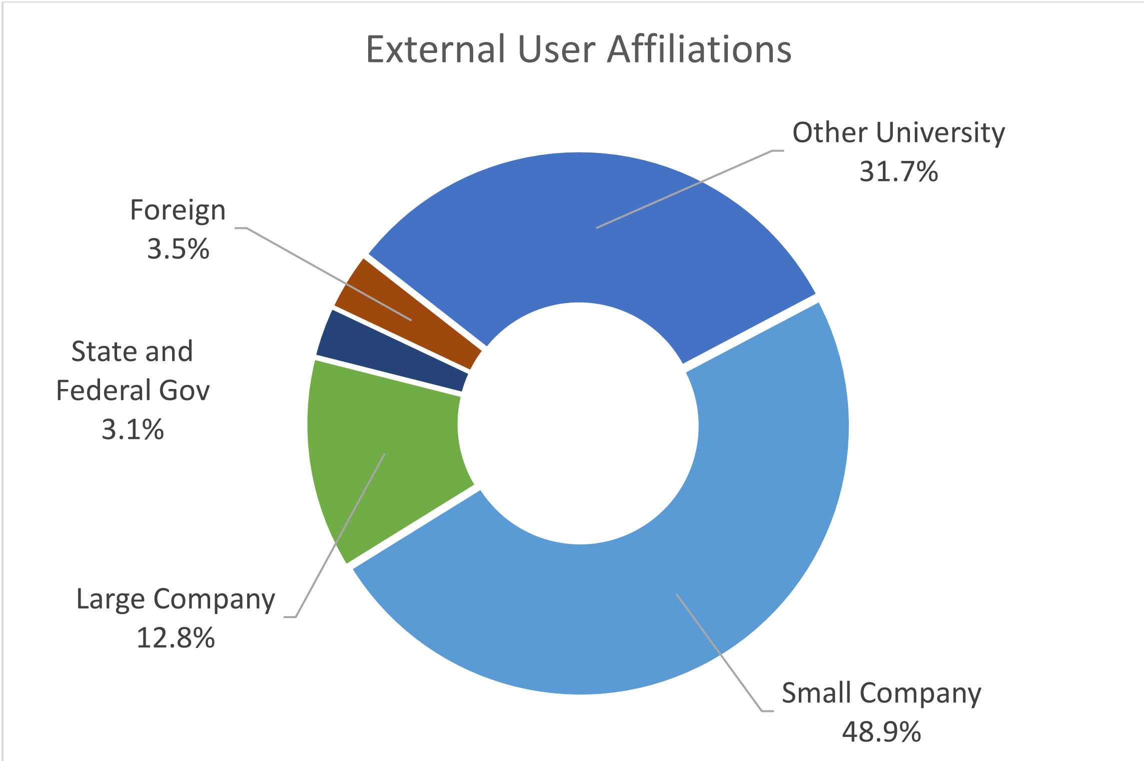
Overall satisfaction (Years 1-4) as a function of user discipline

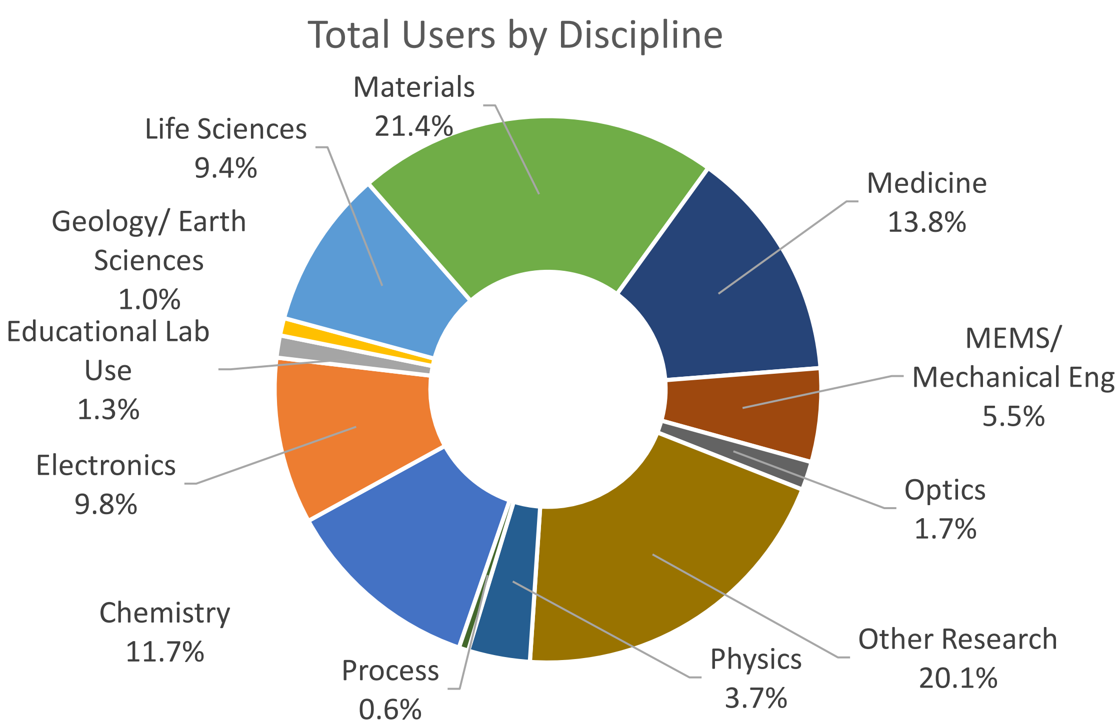
RTNN Site Statistics

Yearly User Data Comparison					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total Cumulative Users	1,177	1,454	1,377	1,507	1,066
Internal Cumulative Users	975	1,096	1,054	1,144	839
External Cumulative Users	202 (17%)	358 (25%)	323 (23%)	363 (24%)	227 (21%)
Total Hours	53,044	51,747	55,684	61,404	43,099
Internal Hours	46,908	43,053	46,422	49,685	33,636
External Hours	6,136 (12%)	9,694 (17%)	9,263 (17%)	11,719 (19%)	9,463 (22%)
Average Monthly Users	395	422	420	445	308
Average External Monthly Users	50 (13%)	63 (15%)	71 (17%)	74 (17%)	53 (17%)
New Users Trained	433	527	695	627	288
New External Users Trained	71 (16%)	69 (13%)	82 (12%)	102 (12%)	54 (19%)
Hours/User (Internal)	48	39	44	43	40
Hours/User (External)	30	24	29	32	42



RTNN Year 5 User Distribution





11.12. San Diego Nanotechnology Infrastructure (SDNI)

Facility, Tools, and Staff Updates

Facilities and tools: The capabilities of SDNI is centered on our well-established Nano3 cleanroom fabrication and characterization facility. The integration of our site into the NNCI network has resulted in rapid expansion and integration of several new facilities into our local network of user facilities, including facilities for magnetics, energy, and quantum devices materials characterization, microfluidics medical device fabrication, high-resolution imaging, and photonics testing. During Year 5, we successfully carried out major laboratory renovations and installed a 200kV Transmission Electron Microscope with advanced EDX and EELS options. All of the instruments acquired and installed in year 5 were procured from UCSD internal funding.

In year 5, we also established the Center for Memory and Recording Research (CMRR) *Materials Characterization Facility* under the SDNI umbrella. This major addition to SDNI's facility enhances the facility's ability to meet the great need for characterization capabilities to support our efforts in the magnetics, energy, and quantum devices areas. The equipment for this new lab is primarily from a large industrial donation and existing equipment of the participating PIs affiliated with CMRR. The funds to move and set up the equipment were provided by CMRR, Sustainable Power and Energy Center (SPEC), and the Office of Research Affairs at UCSD. This new facility complements the capabilities currently available in the SDNI, providing new capabilities in X-ray diffraction, magneto-transport measurements, magnetometry, UV-visible/NIR spectroscopy, photoelectron spectroscopy, and pulsed laser deposition. Like all other facilities of SDNI, the Materials Characterization Facility is operated as an open access, shared campus recharge facility, utilizing the Facility Operation Management (FOM) Software to manage the user database and equipment access.

A new building, *Franklin Antonio Hall* that is right next to the SDNI site broke ground in mid-2019 and was scheduled to complete in spring 2022. The new building will provide significant space for cross disciplinary research and shared facilities, providing *synergistic supports to SDNI's new focus on convergence research*. Franklin Antonio Hall will also be home for the newly established UCSD MRSEC center that has had close collaborations with SDNI from the very beginning (with a significant overlap in the leadership team of the two organizations). It is anticipated that SDNI will be home for several new tools acquired by the MRSEC center in the coming years.

Staff: We had departure of one cleanroom technician due to personal reasons in the past year. Otherwise we have maintained the same size of staff. Due to the pandemic, we had to reduce the number of student interns between March and September. The number of student interns (originally about 25) was significantly reduced between March and July and was partially restored recently. We have promoted two cleanroom staff to manager positions in charge of equipment/tool support and engineering projects for remote users. We also appointed one manager (with partial support from the SDNI grant) to be in charge of the newly established Materials Characterization Facility.

User Base

The SDNI offers technical strengths in the areas of Nano/Meso/Metamaterials, NanoBioMedicine, NanoPhotonics, and NanoMagnetics and supports academic and industrial research with state-of-the-art tools and technical expertise. SDNI's users have diverse disciplinary areas and education levels and are from all kinds of organizations. We support these users wholeheartedly to achieve their research, education, and business goals. At the same time, their activities synergistically support SDNI's strategic goals, which are: (1) provide infrastructure that enables transformative research and education and leverages San Diego's innovation ecosystem, which includes major research institutes and over 2,000 companies employing more than 60,000 scientists and engineers; (2) accelerate the translation of discoveries and new nanotechnologies to the marketplace; (3) support and advance the nation's nanotechnology infrastructure as a key contributing member of the NNCI Network; and (4) develop education and outreach programs to promote STEM efforts in California high school and community colleges, especially at schools with high populations of underrepresented minority (URM) students.

Site usage during Year 5 was heavily impacted by the 2020 Covid-19 pandemic that led to strongly curtailed operations beginning in March 2020. SDNI was able to maintain utilization of approximately 60% of pre-Covid-19 averages in hours and about 70% in user fees by implementing an effective and enforceable health and safety measures in compliance with the CDC, State of California, and university Covid-19 guidelines. We minimized the operational and financial impact of the pandemic by rapidly adapting to Covid-19 imposed safety measures and by expansion of our direct service provisions to users by staff. However, our approach cannot completely offset the impact because of the necessity to reduce onsite presence of personnel. Many user projects have experienced delays of different extents due to the limited on-site occupancy. Those projects that required independent user access to the facilities have suffered the most. On the other hand, projects that can have certain parts or steps delegated to SDNI staff experienced minimal delay. Many industry users have quickly transferred from on-site usage to remote direct service provisions by our staff to minimize project delay.

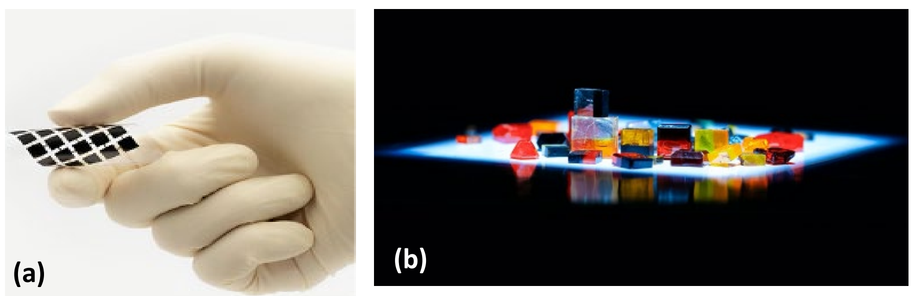
By far the strongest impact of the pandemic has been on the numbers of new users trained. Prior to the Covid-19 response measures, we trained an average of 20 new users per month. This number was reduced to essentially zero for the time period of March 2020 through June 2020. We have only been able to begin training of new users in August 2020, and our ability to train users is still reduced by the pandemic. This can have substantial ripple effects on the post-pandemic growth as we need to provide timely trainings to new users to maintain the user pipelines and the momentum of growth. We are developing innovative methods to shift many training programs online without compromising lab safety and the rigor of the training to create a technically competent user community.

Overall, during the first 9 months of Year 5, SDNI served users from 72 external institutions and 90 UCSD internal academic groups. The breakdown of external user institutions is: 8 non-UCSD US academic, 3 state/federal government, 43 small companies, 14 large companies, 1 international. The numbers for Year 5 very closely match the average numbers throughout the entire NNCI program to date for SDNI. On average SDNI annually served 71 external institutions (9 non-UCSD US academic, 3 state/federal government, 42 small companies, 16 large companies, 1 international) and 92 UCSD internal academic groups.

Research Highlights and Impact

Scientific impact: Like we did in previous years, SDNI has contributed to scientific advances in year 5. Noticeable accomplishments include discovery of a method to drastically improve durability and performance of perovskite materials, nanodiamond (NV centers) for weak magnetic field sensing and quantum computing, the topological states for quantum computing, graphene nanophotonic structures that led to the world's thinnest (3 atoms thick) optical waveguides, the world's first strain-engineered epitaxial perovskite heterostructures of superb stability, and continuing work on starshade masks with NASA/JPL for the project of discovering earthlike planets.

One example of the scientific/technological breakthrough is "*Demonstration of ultrahigh quality strain-engineered single crystalline perovskite with enhanced stability (Nature July 2020)*", a project led by Prof. Sheng Xu in collaboration with SDNI staff. Perovskites are a class of semiconductor materials that demonstrate highly promising electronic and optoelectronic properties. Currently, almost all perovskite fabrication approaches are focused on polycrystalline structures that suffer from low stability. The ability of producing high-quality single crystalline perovskite is a breakthrough because the material stability and reliability is the Achilles heel of all perovskite materials. In this new research, scientists from Prof. Xu's group and the SDNI staff developed the new process that can produce not only crystalline perovskite but also high reliable and durable films on flexible substrate to be applicable to a wide range of applications including wearable electronics and sensors (see figure).



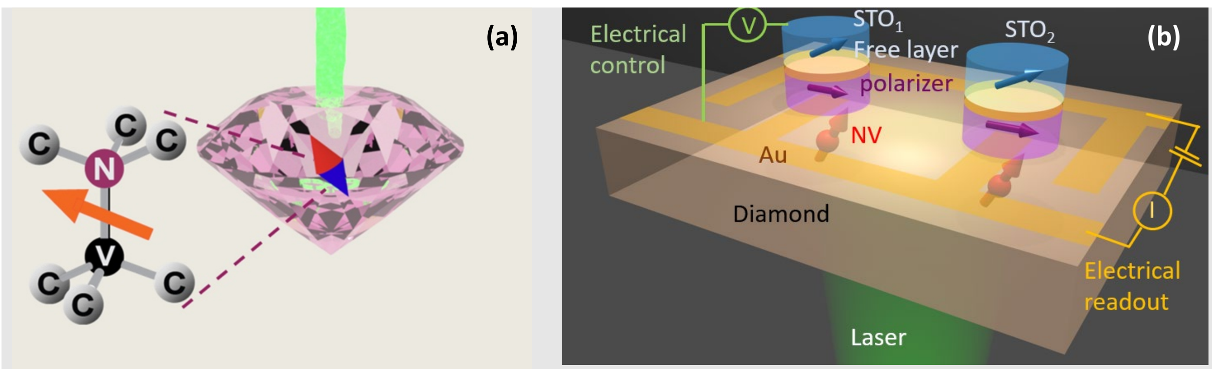
(a) Single-crystal perovskite films could enable more efficient flexible solar cells such as the one pictured here. (b) Graded single crystal perovskites.

The new technique controls the growth of the perovskites using lithographically defined patterns that control growth in both lateral and vertical dimensions. A lead-tin mixture with gradually changing composition is applied to the growth solution, creating a continuously graded electronic bandgap of the single-crystal thin film. The perovskite resides at the neutral mechanical plane sandwiched between two layers of materials, allowing the thin film to bend. This flexibility allows the single-crystal film to be incorporated into flexible thin film solar cells and into wearable devices, contributing toward the goal of battery-free wireless control.

The material synthesis and device fabrication method developed at SDNI are breakthroughs because they show the possibility for making *stable and efficient single-crystal perovskite devices* using nanofabrication procedures and materials. The above research represents a great achievement *in convergence research and human-technology frontier*.

Another example is the groundbreaking research of *nitrogen-vacancy (NV) center-based hybrid quantum device for quantum sensors and quantum computing*, led by Prof. Chunhui Du. NV centers in diamond are regarded as a major discovery and technology breakthrough for their abilities to measure extremely weak magnetic field (for brain activities), produce quantum sensors, and generate entangled states as qbits for quantum computing that are stable under room temperature.

An NV center is formed by a nitrogen atom (N) adjacent to a carbon atom vacancy (V) in one of the nearest neighboring sites of a diamond crystal lattice. The negatively charged NV state has an S = 1 electron spin with a spin triplet ground state ($m_s = 0, \pm 1$). It possesses excellent quantum coherence and notable versatility in a wide temperature range. Over the past decade, nitrogen-vacancy (NV) centers have been demonstrated to be a transformative tool in exploring the magnetic and electric features arising from various material systems with unprecedented field sensitivity and nanoscale spatial resolution. In comparison to the conventional magnetometry techniques (Hall probe, SQUID, and atomic vapor cell), the NV spin quantum sensor possesses *a combination of the high field sensitivity down to 10^{-9} Tesla regime and nanoscale spatial resolution* providing an ideal measurement platform to explore the local magnetic and electric features arising from miniaturized electronic devices. Building on this state-of-the-art quantum sensing platform, Du's group has demonstrated the high sensitivity of NV sensors to the local magnetic fluctuations generated by incoherent magnons. Magnetic resonance was employed to control the magnon density of a proximal $Y_3Fe_5O_{12}$ film and measure the fluctuating magnetic fields generated by the sample through NV relaxometry method.



(a) Schematics of the quantum sensing platform based on the S=1 electron spin of the nitrogen vacancy (NV) defect in diamond. It acts like an atomic-size compass that is extremely sensitive to the local magnetic field environment. We can optically initialize and read out the NV spin state. (b) Schematic of the NV-based hybrid quantum device to form entangled states for qbits.

The same principle can also be used to produce entangled states as qbits for quantum computing. Shallow NV centers at the diamond surface (NV depth ~ 10 nm) are created by N+ ion implantation. Spin torque oscillator (STO) devices consisting of NiFe/Cu/CoFe nano-junctions are fabricated on the diamond substrate. The CoFe thin film serves as a spin polarizer (fixed layer) and the NiFe thin film is used as a free layer. Two NV centers which are close to the STO devices (STO1) and (STO2) can produce the entangled states. When the ferromagnetic resonance frequency ω_{NiFe} matches the NV electron spin resonance frequency, the electrical induced microwave field generated by the STO device can drive the NV spin rotation between the $m_s = 0$ and the $m_s = -1$ state. *Room-temperature quantum entanglement* between NV centers can be established by the dipolar fields generated by individual NV spins with a distance less than 50 nm. The entangled NV spin states and the coupling strength can be measured by monitoring the oscillation of the photocurrent as a function of the coupling duration time. This research marks significant advances *in quantum materials and quantum systems*. SDNI's unique tools and nanofabrication capabilities have played pivotal roles in enabling this important research.

Contributions to economy: SDNI has helped many companies to develop cutting edge technologies into high value products. In Year 5, SDNI helped startup companies such as NanoCellect Biomedical to commercialize its microfluidic benchtop fluorescence-activated cell sorter (FACS) that is now sold to 16 countries as the leading product supporting research in cell line development for therapeutic drug development, gene editing, immunotherapy, and single-cell genomics. The company's microfluidic devices and disposable cartridges were developed in the SDNI Microfluidics Facility with the assistance of SDNI staff engineers. Over 70 NanoCellect systems were installed in 2020, with the essential support of SDNI facility that continued to serve its users during the COVID-19 pandemic. SDNI has supported startup companies such as Roswell to revolutionize the genomics field and Rigetti to advance quantum computing. SDNI also continued its support for large companies such as Samsung, Qualcomm, Google, etc. for 5G, advanced electronics and display projects. Examples include development of gray scale lithography nanophotonic fabrication processes by the SDNI engineering team. In Year 5, SDNI has supported dozens of companies in the areas of wearable sensors, night vision, imaging, optical communications, quantum sensing, genetic engineering, pharmaceuticals, health monitoring, artificial intelligence, robotics, semiconductors, etc. to develop prototypes for proof of concept and commercialization.

Education and Outreach Activities

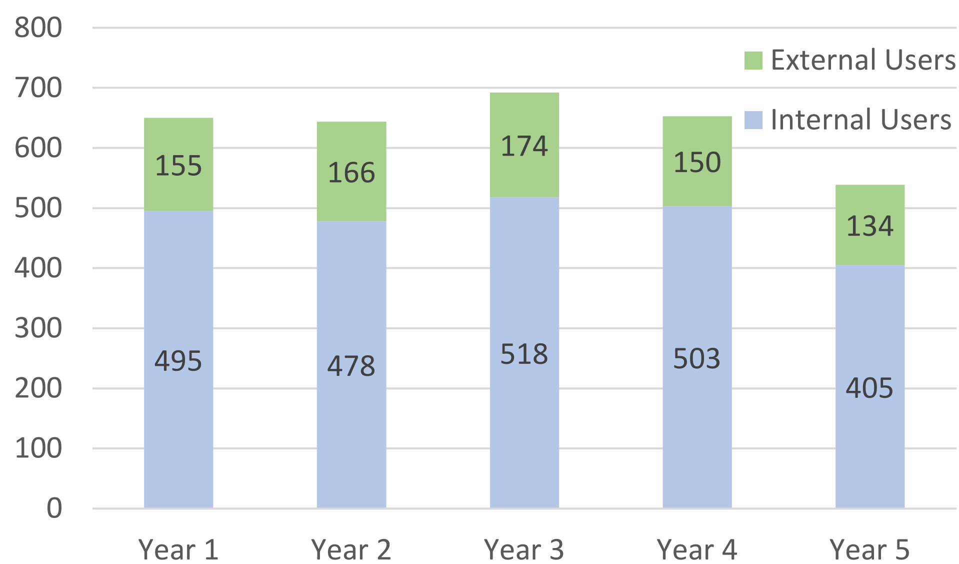
Notable accomplishments of SDNI's education and outreach efforts in 2019-2020 include (a) improvement in undergraduate STEM education with AR/VR technologies in collaboration with the Qualcomm Institute, (b) submission of an NSF IUSE (Improving Undergraduate STEM Education) education proposal ($300K for 3 years) to enhance experiential learning of STEM, (c) leading an NSF proposal ($2M for 5 years) in collaboration with a non-profit education content developer and 5 community colleges to promote STEM education and diversity, (d) development of integrated photonic education kit (IPEK) that includes fully-packaged cutting-edge silicon photonic devices and circuits with a turn-key operation to enhance learning experience for graduates and undergraduates to stimulate cross disciplinary convergent research, and (e) expansion of the scale and scope of SDNI's education/outreach efforts through "remote science labs" to bring nanotechnology to the K-12 education system.

To bring nanotechnology and its science contents to high school classrooms, we offered experiential learning whereby students and teachers could, from their own classroom, remotely control our high-end Scanning Electron Microscope (SEM) and be introduced to the world of micro and nanotechnology. Our assessment on remote science labs, based on feedback of teachers and students, has been extremely positive. The vast majority of the students were inspired by the nanostructures with revealing and striking details, when correlating them with optical microscope pictures they usually see in the high school labs. The mere fact that electrons can form images like light does has intrigued many high school students as a real-life demonstration of the "particle wave duality", one foundational concept in quantum physics. In 2019-2020, we have delivered remote labs to over 2500 high school students. The very strong demand (partly due to the pandemic) drove the need for SDNI to scale up the effort rapidly. What has been particularly helpful was that, in addition to Zeiss, Hitachi also joined our education/outreach effort by offering a free loaner SEM system and additional resources to enable us to support more science classes.

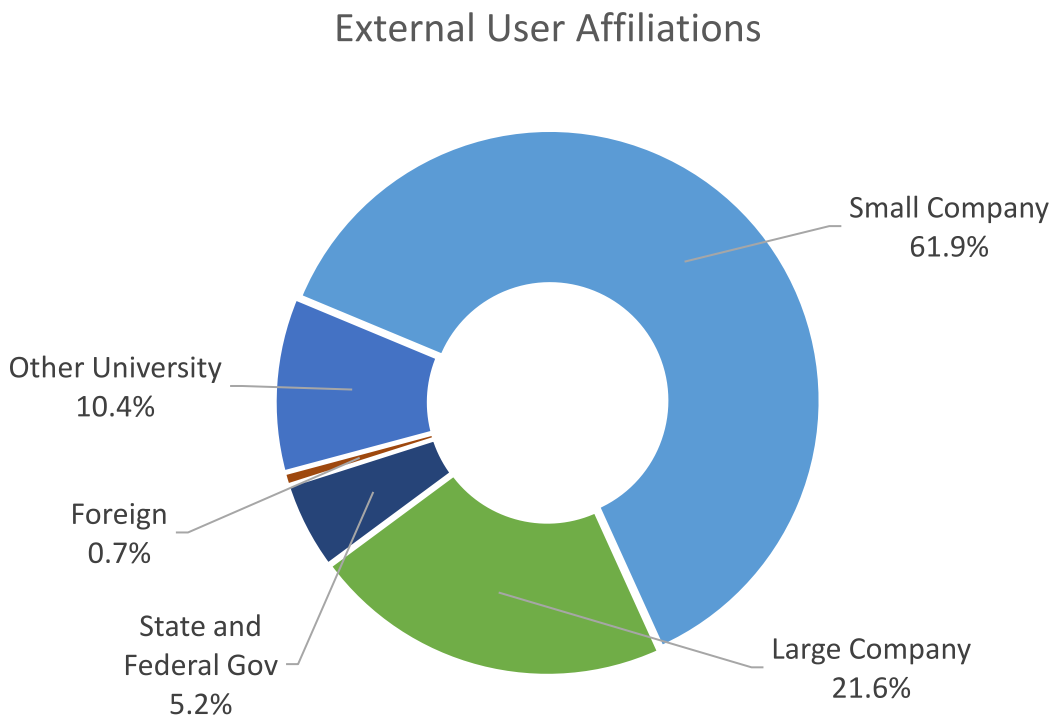
To share and exchange experiences with people who are also committed to STEM education, we organized an online education conference. Attendees included high school and community college science teachers, education staff from other NNCI sites, digital education content developers, and federal and state officials who are STEM education advocates. The valuable information obtained from the conference has led us to create new initiatives to further our STEM efforts.

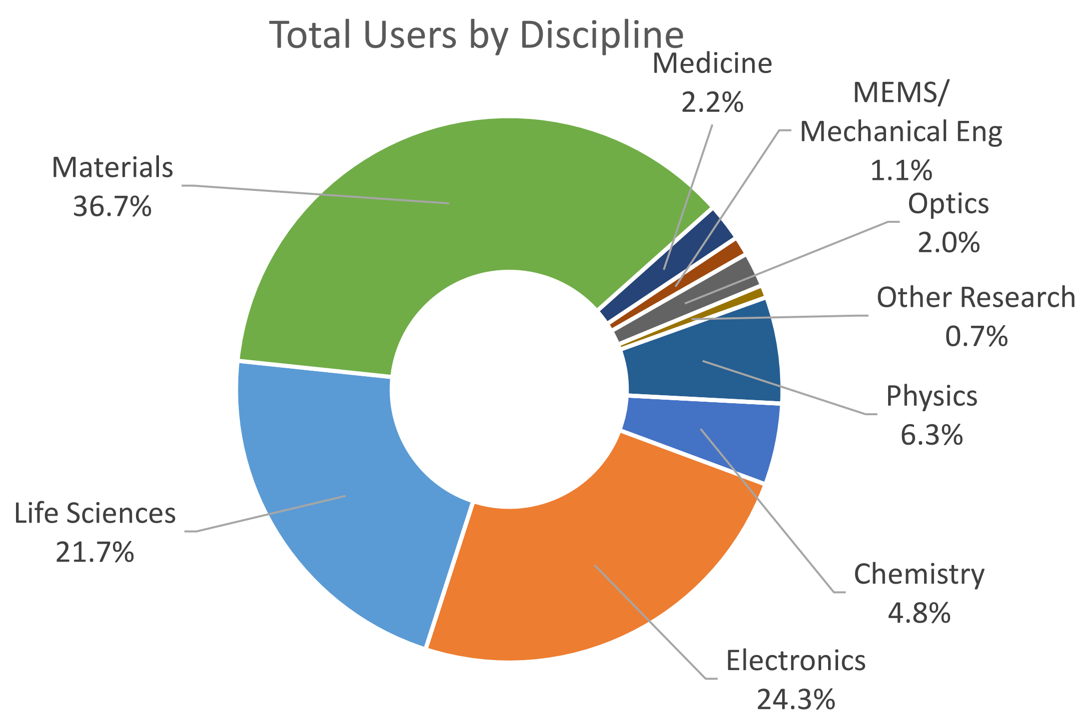
SDNI Site Statistics

Yearly User Data Comparison					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total Cumulative Users	650	644	692	653	539
Internal Cumulative Users	495	478	518	503	405
External Cumulative Users	155 (24%)	166 (26%)	174 (25%)	150 (23%)	134 (25%)
Total Hours	47,893	50,497	49,519	69,367	53,667
Internal Hours	40,890	38,890	39,372	56,393	41,316
External Hours	7,003 (15%)	11,607 (23%)	10,147 (20%)	12,974 (19%)	12,352 (23%)
Average Monthly Users	290	285	300	296	229
Average External Monthly Users	49 (17%)	56 (20%)	54 (18%)	50 (17%)	46 (20%)
New Users Trained	183	210	225	202	169
New External Users Trained	34 (19%)	50 (24%)	46 (20%)	40 (20%)	36 (21%)
Hours/User (Internal)	83	81	76	112	102
Hours/User (External)	45	70	58	86	92



SDNI Year 5 User Distribution





11.13. Soft and Hybrid Nanotechnology Experimental (SHyNE) Resource

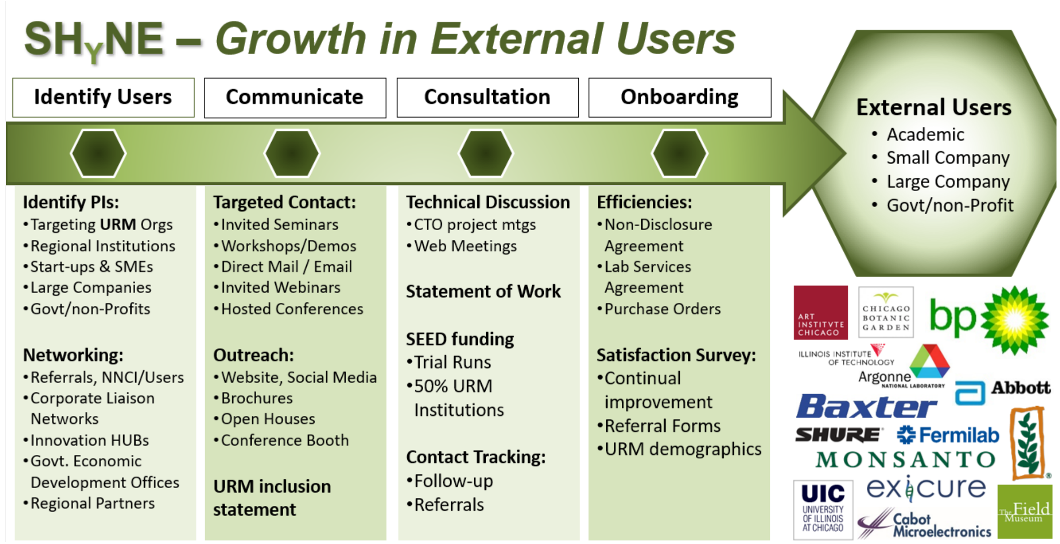
A joint venture between Northwestern University and University of Chicago, SHyNE Resource represents the Midwest within the NNCI, providing researchers from academia, non-profits, government, and companies large and small with access to world-class user facilities with leading-edge fabrication and characterization tools, instrumentation, and technical expertise within all disciplines of nanoscale science, engineering, and technology. Under the leadership of site director Professor Vinayak Dravid and co-director Professor Andrew Cleland, SHyNE Resource coordinates the integration of a diverse group of open-access nanoscale fabrication and characterization facilities across Northwestern University (NU*ANCE*, SQI, NUFAB, IMSERC, NUCAPT, JB Cohen XRD, PLD) and the University of Chicago (PNF).

Facility, Tools, and Staff Updates

SHyNE facilities are actively engaged in acquiring and upgrading key equipment within the facilities through a combination of internal and external funding mechanisms. In total, more than **15 new instruments** and numerous tool upgrades were installed in Year 5. **NUFAB**: Raith Voyager 50kV eBL; **NU*ANCE*:** JEOL JIB 4700 dual-beam FIB-SEM, Gatan K3-IS direct electron detector, Protochips Atmosphere gas injection TEM system, Protochips Axon drift correction, Gatan ELSA cryo-transfer TEM holder, **IMSERC:** STOE STADIVARI, Rigaku CU-Synergy, Rigaku MO-Synergy, Rigaku DW-Synergy, Netzsch STA, STOE STADIP; **Cohen XRD:** Anton-Paar XRK900; **ANTEC**: Cryo Mill, SPEX Sample Prep. Maintaining an active and engaged user base for SHyNE facilities is contingent upon the successful recruitment and retention of high-quality staff. Several new staff joined the SHyNE team in Year 5, two of whom are in newly created positions and many receive partial funding through NNCI. **NU*ANCE*** - Nathaniel Kabat - EPIC Research Associate, Elizabeth King - EPIC SEM Assistant Laboratory Manager, Tara Sadera - Program Administrator, Ruari McDonnell - Program Assistant; **IMSERC:** Benjamin Owen - Research Professor, Gabrielle Allison - Assistant Core Scientist, Sumanta Sarkar - Postdoctoral Research Associate.

User Base

SHyNE facilities served nearly 1500 unique users who logged nearly 140,000 hours of instrument time generating $3.6M in revenue. Northwestern and UChicago shut down in the spring of 2020 for nearly 3 months in response to the novel coronavirus pandemic. Over the summer, the labs opened in a restricted manner to allow for research to resume with adequate safety measures in place. Prior to the shutdown and subsequent restricted operations, SHyNE was on pace to continue double-digit annual growth. For Year 5, external users represented 12% of total users and 11% of revenue.

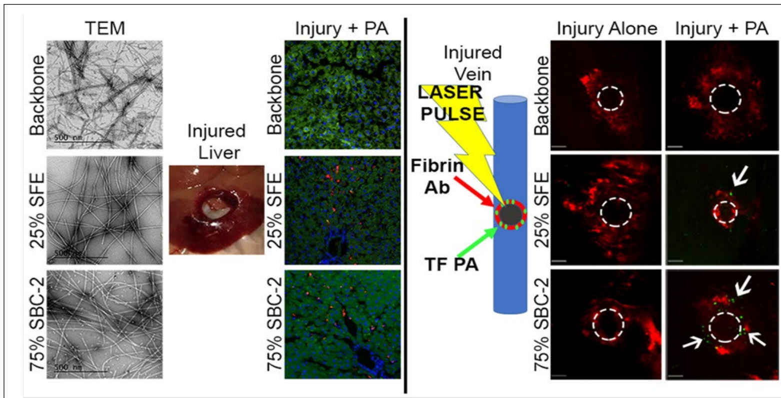


Schematic of comprehensive approach to meeting NSF-NNCI program goals.

SHyNE actively engages local and regional companies, colleges, universities, non-profit research organizations and governmental agencies to recruit new users. This is accomplished by a number of communication strategies including: exhibitions at conferences and trade shows, production of web portals, marketing videos and promotional materials, networking with alumni, coordination with university-wide corporate engagement and media relations offices, and an active social media presence. In Year 5, SHyNE continued managing a SEED (SHyNE External Experiment Development) funding program to recruit new external users by providing start-up grants for up to $2500 in facility usage. Three proposals were funded for new users from the University of Illinois at Chicago, Caporus Technologies, and Celadyne Technologies (early-stage startups). In Years 6-10, the primary programmatic focus will be on recruiting additional external academic users through a combination of efforts, including: an active marketing campaign, redevelopment of our web presence, and expansion of the SEED program.

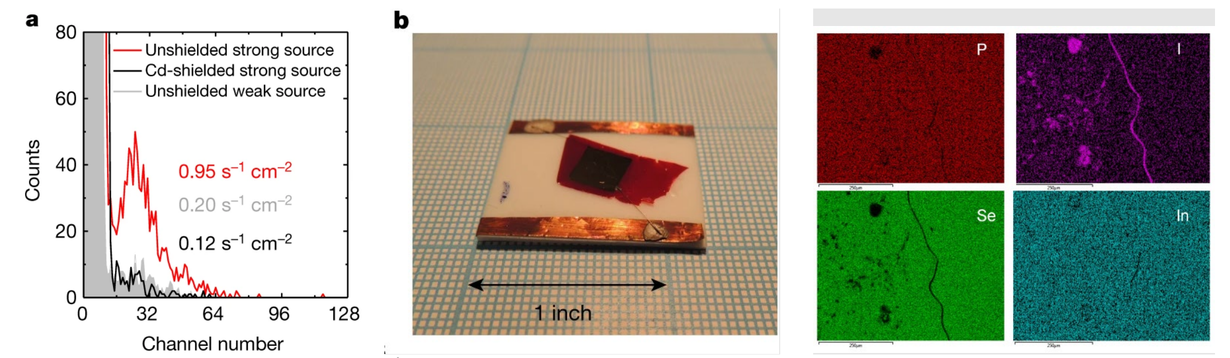
Research Highlights and Impact

The SQI Peptide Synthesis Core was utilized by the Kibbe lab at the University of North Carolina for the design and synthesis of peptide amphiphiles (PAs) used in this study. PAs were designed to target tissue factor (TF), a protein present in blood vessels, but only exposed after external damage. The goal was to develop a PA that could selectively and specifically localize to areas of active hemorrhage, making TF a suitable target.



Targeted peptide amphiphiles (PAs) form cylindrical fibers (left) that selectively target areas of active hemorrhage in rat liver (middle) and mouse leg (right). Klein et al., 2020 Development of Optimized Tissue-Factor-Targeted Peptide Amphiphile Nanofibers to Slow Noncompressible Torso Hemorrhage, ***ACS Nano 14 (6),*** *6649-6662*

The Scanned Probe Imaging and Development (SPID) core facility undertook a project to develop thermal analysis methods capable of determining the melting and crystallization temperature of $LiInP_2Se_6$, a promising material for the detection of thermal neutrons. This work also used the **EPIC** facility in **NU*ANCE.***



Binned pulse-height spectrum of a $^6LiInP_2Se_6$ device (shown in ***b****) exposed to a moderated Pu–Be source without shielding (red) and with Cd shielding (0.125 inch thick; black) and to a source ~5 times weaker (grey) for 300 V bias, 3 µs shaping time and 30-min measurements. The composition obtained from EDS from both orientations yielded the semiquantitative formula In1.1P2.0 Se6.0, which is consistent with the expected ratio of 1:2:6 determined from the crystal structure. Chica, D.G. et al. Direct thermal neutron detection by the 2D semiconductor $^6LiInP_2Se_6$.* ***Nature 2020****, 577, 346–349*

Education and Outreach Activities

Education and Outreach are critical parts of SHyNE's mission and include academic courses with laboratory components, monthly user meetings, an REU program, hands-on workshops, seminars, vendor symposia/demos, facility tours/demos (K-12, higher-ed, public) and related web and social media communications. In Year 5 we held several major workshops and short courses, assisted with **25 courses**, hosted **30+ seminars and exhibitions** and provided tours for **700 visitors**. SHyNE sponsored **four REU students** in a unique, facilities-focused REU program that exposed undergraduates to advanced instrumentation as a key component of their projects. In Year 5, **lectures and seminars** were held on Attolight Cathodoluminescence, Ellipsometry, Incucyte Image Analysis, Anti-peptide Antibody production and Nanoindentation for Mechanical Mapping of Healthy and Diseased Tissue. **Workshops and demos** were held for Horiba's LA-960, Bruker FT-IR, Raith VELION FIB, Direct Electron and Piuma Nanoindenter training and installation as well presentations from NanoMEGAS and GATAN. SHyNE also began a new partnership with **Science in Society (SiS)**, a Northwestern University research center dedicated to science education and public engagement through partnerships with Chicago-area schools and community groups. The center partners with urban K-12 teachers, administrators, and youth development agencies to create high-quality, long-term, impactful science learning opportunities for underserved youth. SHyNE technical and outreach staff are working with SiS to provide video content, live and/or

Tirzah Abbott, SEM Lab manager, provides an eye-opening demo to a group of 6-9th grade girls as part of the STEP program (Summer Technology & Engineering Program).

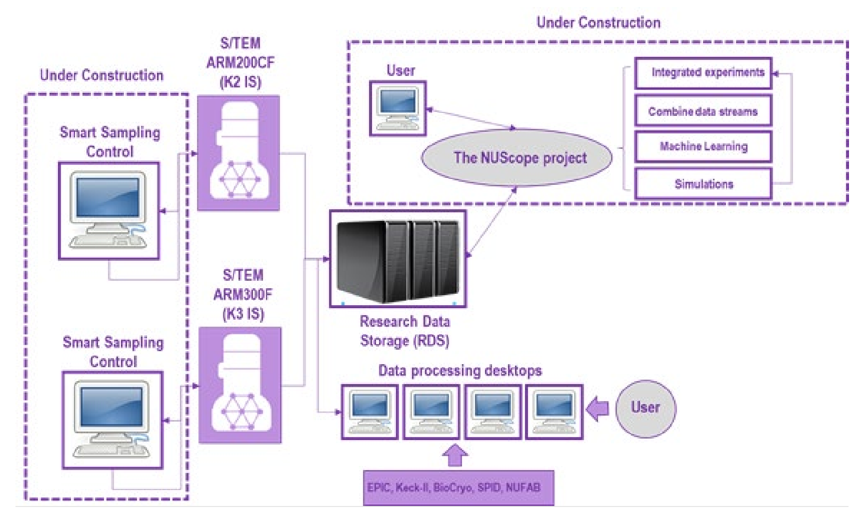
remote demos, informational material and more to help promote science in these groups. In an effort to extend our presence in **social media** and engage with the broader community, SHyNE has launched successful campaigns including our "Women in Nano" campaign which occurs annually in addition to a new Earth Day week-long campaign highlighting SHyNE facility users who focus on environmental research.

Societal and Ethical Implications Activities

SHyNE Resource, collaborating with Northwestern's Medill School of Journalism and the School of Communication, has established a novel Nano-Journalism focus within the existing Health, Environment and Science Journalism program. In 2019, we were excited to have Mohammad Behroozian join the team! Mohammad is a PhD student in Northwestern University's School of Communication working with Dr. Ellen Wartella's Children, Media and Human Development Lab, Mohammad studies educational media for wartime to inform productions for children living in warzones. He joins SHyNE as a Nanoscience journalist and content producer, responsible for creating educational content to excite youth about nanoscience and nanotechnology. Mohammad is currently producing two videos to highlight the OHM Sponge, an oleophilic, hydrophobic sponge with great potential for managing oil spills. He also began a series of short video interviews created for social media to discuss and highlight NU*ANCE*'s "Art of Science" Image contest winners and the science and thought behind winning entries. This series will also be expanded to include educational content for outreach to middle-school students.

Computation Activities

Computational Imaging Efforts in S/TEM at NUANCE: The large amount of data produced by novel direct detectors (Gatan K2-IS, K3-IS) recently installed, ~4Tb/hr, can no longer be effectively analyzed by human intuition and experience alone. Therefore, at NU*ANCE*/SHyNE, we are currently implementing innovative strategies for experiment design, execution, analysis, and sharing. In particular, over the past year we have made efforts to substantially reduce the collection time or radiative dose of conventional electron microscopy experiments.

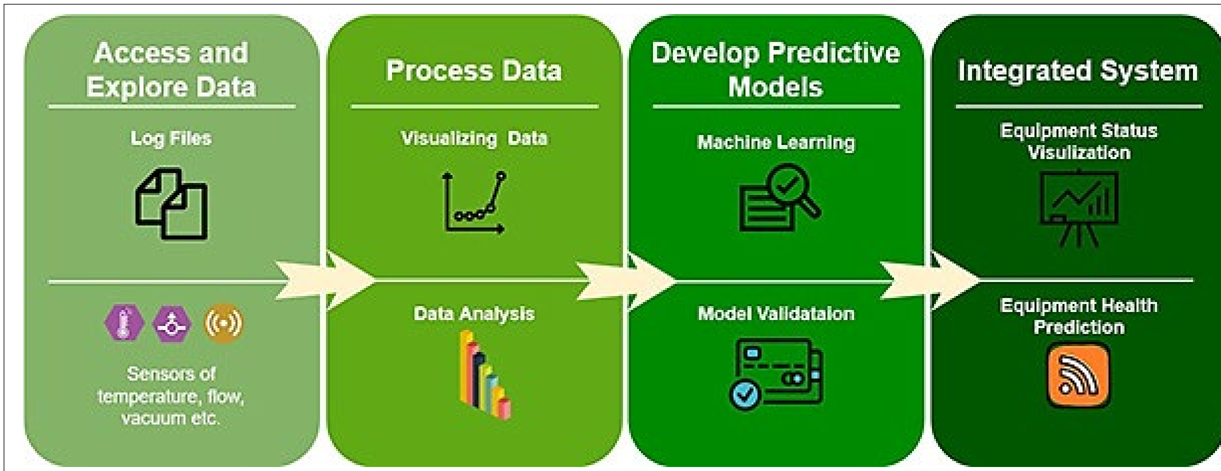


Schematic of data management workflow in support of various machine learning efforts in the characterization facilities.

A significant need exists for improved methods of collecting spatially resolved spectroscopic signals at electron doses low enough for the preservation of sensitive structures or subsequent investigation with a correlated technique, and/or for the acceleration of conventional spectrum images for the investigation of spatially confined biological-inorganic complex structures, engineered hybrid soft/hard ordered materials. Through development of "smart" sampling algorithm, we accelerate a low-dose experimental analytical imaging of materials that is applicable to arbitrary S/TEM imaging. In contrast to static sampling schemes or denoising, our method can produce spatially accurate spectrum maps at high speeds/low doses with weakly informative prior information, and no direct processing or manipulation of spectral data (no sparsity constraints). By maximizing the application of electron dose to areas with meaningful information or contrast on-the-fly, this approach may allow for the efficient characterization of radically larger regions of interest or materials/interfaces that are sensitive to accumulated dose.

Equipment and facility predictive maintenance system with artificial intelligence: With the continued advancement of sensor technology, equipment manufacturers are integrating more sensors into the systems to improve their reliability. Recording and interpreting the sensor readings are key when it comes to equipment maintenance and trouble shooting. However, the sensor data is not easily accessible and usually can only be understood by well-trained technicians. Based on years of equipment/facility maintenance experience, artificial intelligence and cloud technology, **Ying Jia NUFAB Research Associate**, has developed a central facility management system to store, display and analyze the sensor data in real time. Additionally, this system also evaluates the equipment's condition, predicts the future trends, and recommends maintenance!

Currently, over one hundred sensors of eight cleanroom capital equipment are monitored by the system at the same time. NUFAB equipment managers can use this system to 1) check equipment parameters over a certain time range, for example, the chamber base vacuum over last year, 2) select individual process and check the time dependent parameters, for example, the plasma power in a deposition process, 3) predict equipment maintenance with machine learning models. The system has been deployed and can be accessed by facility managers anytime and anywhere.

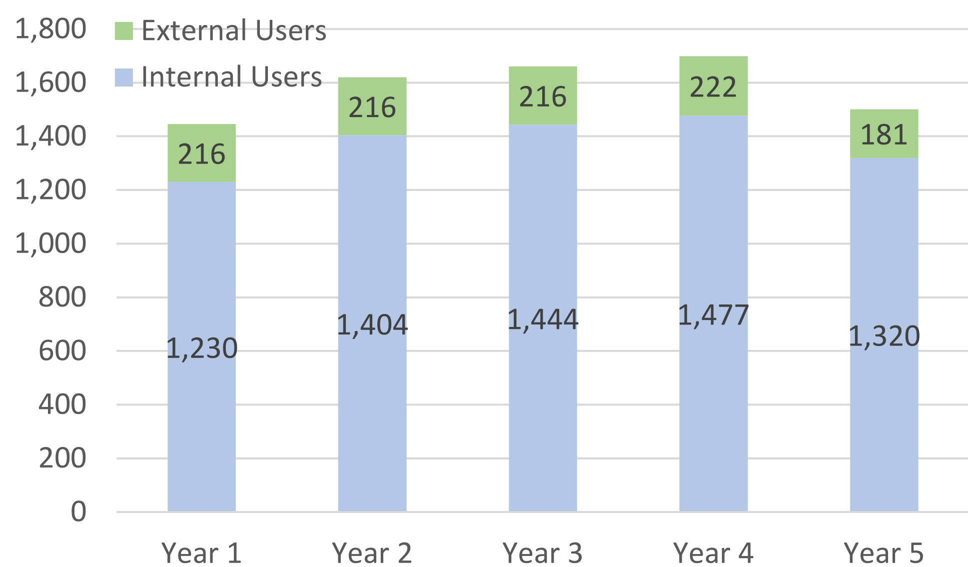


Schematic of data analytical system for monitoring systems health and predicting failure of critical systems and component and other noteworthy events.

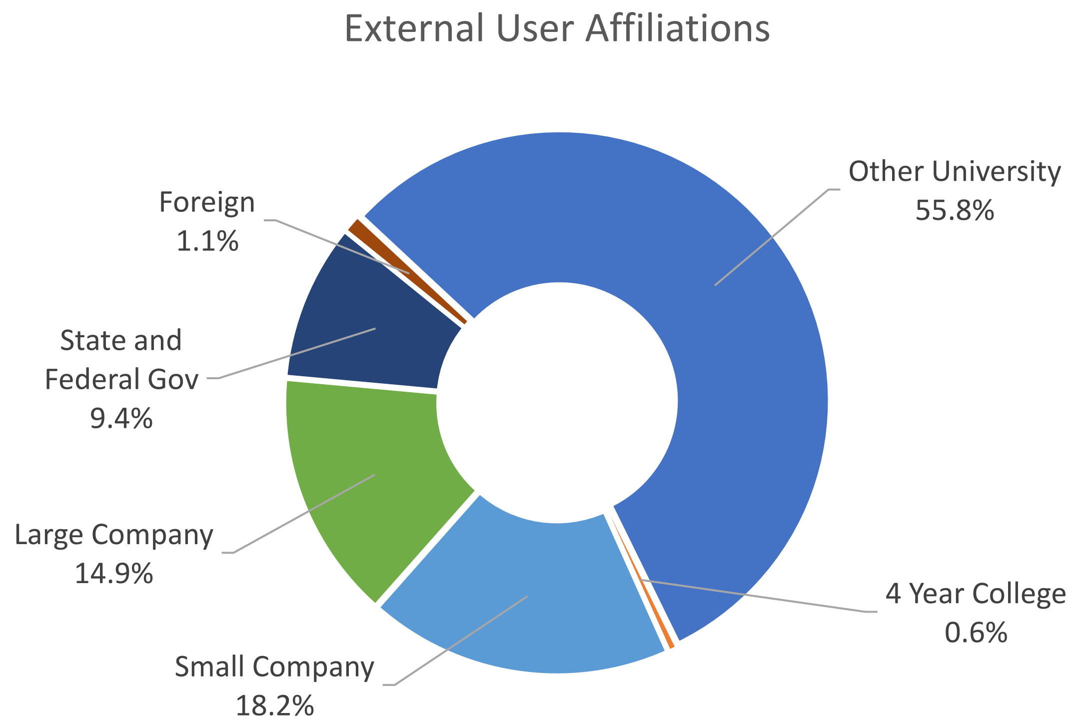
In summary, Shyne/NU*ANCE* implementations are synchronized with the rise of artificial intelligence ecosystems and associated machine learning algorithms to accelerate innovation in a wide variety of scientific disciplines. We expect that in the coming years, the latest data analysis tools and techniques will gain a greater foothold into facility environment and drastically revolutionize this environment in ways that leave it better positioned to address major scientific challenges.

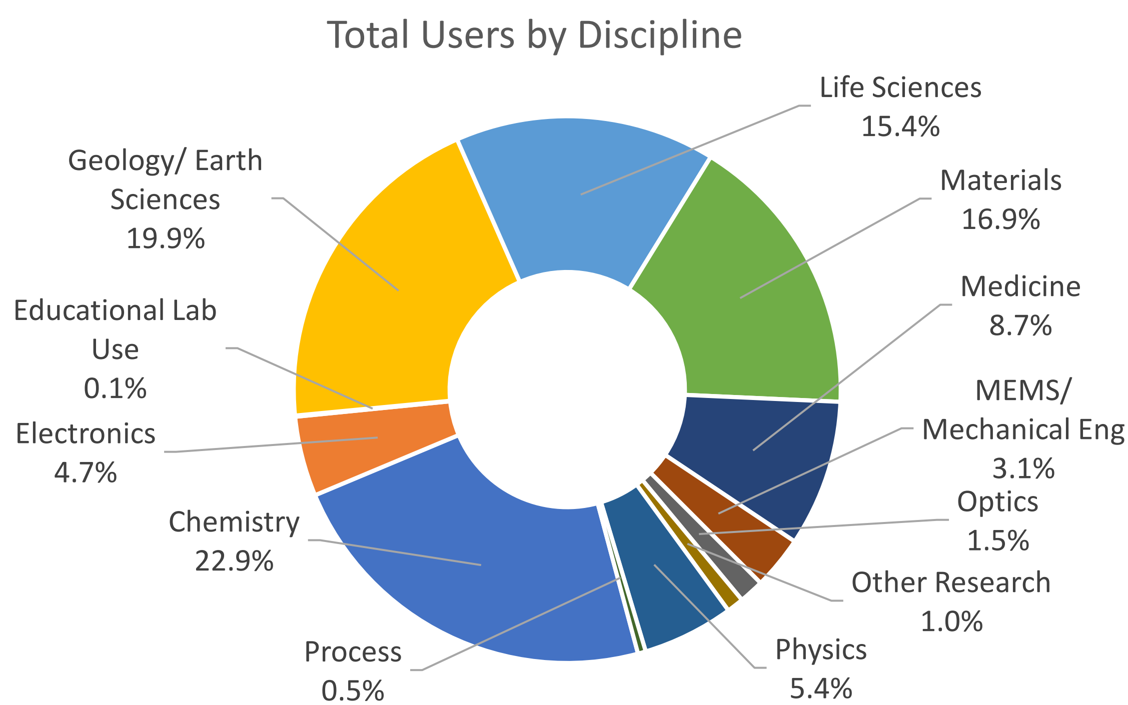
SHyNE Site Statistics

Yearly User Data Comparison					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total Cumulative Users	1,446	1,620	1,660	1,699	1,501
Internal Cumulative Users	1,230	1,404	1,444	1,477	1,320
External Cumulative Users	216 (15%)	216 (13%)	216 (13%)	222 (13%)	181 (12%)
Total Hours	138,000	132,673	137,375	202,844	139,175
Internal Hours	128,838	127,127	131,206	192,434	132,177
External Hours	9,162 (7%)	5,545 (4%)	6,169 (4%)	10,410 (5%)	6,998 (5%)
Average Monthly Users	679	802	797	829	606
Average External Monthly Users	54 (8%)	54 (7%)	52 (7%)	61 (7%)	41 (7%)
New Users Trained	699	698	605	649	340
New External Users Trained	152 (22%)	140 (20%)	86 (14%)	120 (18%)	66 (19%)
Hours/User (Internal)	105	91	91	130	100
Hours/User (External)	42	26	29	47	39



SHyNE Year 5 User Distribution





11.14. Southeastern Nanotechnology Infrastructure Corridor (SENIC)

Over the past year, SENIC has continued to facilitate the "one facility, two locations" mindset and partnership between Georgia Tech and JSNN. The two locations have also continued to exchange best practices and lessons learnt in responding to the COVID-19 pandemic, in particular "Return to Campus" protocols, new user orientation (offered virtually instead of in-person) and remote equipment training videos.

Facility, Tools, and Staff Updates

Georgia Tech completed several construction and renovation projects in the Pettit Microelectronics Building, in addition to faculty-specific renovations. Three Pettit laboratories were retrofitted in April 2020 for the relocation of (1) the Laser Micromachining Lab (2) the IEN Packaging Research Center Assembly Lab and (3) the IEN Packaging Research Center Reliability Lab. IEN continues to support the Georgia Tech cleanroom master plan for the consolidation of the IEN toolset from the Pettit Building to the Marcus Building and development of possible nanotechnology incubator space. During NNCI Year 5, IEN's Micro/Nanofabrication Facilities added or replaced three staff members: a Process Equipment Engineer I for support of organic cleanroom tools and users, a Research Engineer for support of micromachining and micro/nanolithography activities, and a Process Equipment Engineer assisting with the relocation of the IEN Packaging Research Assembly and Reliability Labs. The Materials Characterization Facility (MCF) at Georgia Tech has continued to become more accessible and capable over the past years. For example, MCF made a concerted push to make the two high-resolution TEMs more useful to the user community by partnering with Georgia Tech research administration and individual faculty members to add hardware totaling >$2M to enhance TEM in-situ and analytical capability. JSNN continued to strengthen its Facility and Technical Support team, with the addition of one full-time and three part-time staff members to help meet the growing demand in fabrication, microscopy, analytical chemistry and remote service requests. This team is also responsible for providing user consultation, training, process and characterization support, remote jobs and data analysis, if requested by the user. JSNN has created special project spaces to address specific user/research needs, such as a battery research lab, a hydroponics lab, and a custom wet processing bay in the cleanroom to address one of its industry user's specific needs.

Since the start of SENIC in 2015, Georgia Tech and JSNN have installed 58 new tool purchases, upgraded 32 pieces of existing equipment, rebuilt 3 tools using in-house resources, and developed 26 new processes on existing equipment. New tool purchases or upgrades in the past year include:

Lithography/Direct Patterning: Heidelberg MLA150 #2, ASYS Printer, PixDro LP50.

Deposition: MRL Furnace Nitride and Oxidation, AJA Nitride Sputterer, Veeco ALD Fiji G2 (photo at right), SEMCO PECVD, CHA Dielectric Evaporator (upgrade), IEN ALD System (upgrade).

Etching: STS AOE Pro, Advanced Vacuum RIE System II (controls upgrade).

Imaging & Metrology: Renishaw Confocal Micro Raman System, Bruker Icon AFM, JEOL JEM-2100 Plus w/ Oxford Max80 Aztec EDS (photo at right), Bio-Rad QX200 Droplet Digital PCR (ddPCR), Perkin Elmer DMA 8000, 4-Point Probe, KLA Tencor P6 Profilometer, Probe Station with Micromanipulator, Alpha-SE Ellipsometer, Filmetrics F20-UV, Bruker EDS, In-situ TEM measurement upgrade (Protochips Poseidon liquid cell holder and Hitachi heating holder).

Lastly, a number of tools were upgraded and/or operationalized at JSNN in Year 5, including 11 tools which were put on UPS to reduce downtime, a new high-speed rotor for the ultracentrifuge, and PC/controls upgrade for VP SEM, Raman and PVD. The BSL3 lab at JSNN is in the process of being recommissioned and certified to carry out BSL3 level work.

User Base

In Year 5, marketing of SENIC continued through the website (http://senic.gatech.edu/), as well as additional promotional and communication efforts through email and social media, with SENIC-specific efforts on Facebook, LinkedIn, and Twitter. Collateral marketing materials, such as SENIC-branded bookmarks, brochures, and banners, have also been produced during the five-year program. SENIC used targeted marketing based on geographical area (southeastern US academic and company profiles) and discipline of work (electronics, MEMS, biomedical, materials, chemistry, environmental, etc.) using LinkedIn Text Ads (pay per click ads). A periodic SENIC newsletter was initiated in 2018 and is emailed to over 3,000 current and potential users along with other stakeholders. Typical issues contain articles about SENIC, information about new programs such as Catalyst, an interview with an external user, spotlights on equipment and SENIC technical staff, current education and outreach activities, and other announcements.

User growth, particularly from non-traditional areas that have not used nanotechnology core facilities in the past, requires dedicated marketing and outreach programs. Since the start of NNCI, SENIC has streamlined its user recruitment efforts based on feedback from the annual user survey on how users learn about SENIC and sharing of best practices among sites. In 2018, the NNCI subcommittee on "Building the User Base" identified awareness, accessibility and affordability as the three key limitations for growing the user base. To create SENIC **awareness**, we use websites, SENIC newsletter, social media presence, and visits to universities and companies in the southeast, particularly along the I-85 corridor. To facilitate these visits, we recruit current and past users at these institutions as "SENIC Ambassadors" who assist with organization and local promotion. To target the **accessibility** challenge, we have significantly expanded our remote work capabilities, where staff is performing the work on behalf of the user rather than the user doing the work on site. Seed grant programs seek to address the **affordability** challenge, and SENIC continues to support the IEN Facility Seed Grant Program and the Catalyst Program.

Finally, an initiative started in 2018 that addresses all issues of awareness, accessibility and affordability is the Southeastern Nano Facility Network (SENFN), a regional network of nanotechnology facilities. During fall 2018, SENIC contacted more than 30 nanoscale fabrication and characterization facilities located at universities in the southeast US (GA, SC, NC, FL, TN, AL, LA, and AR) to solicit interest in forming a regional network and hosted a meeting at Georgia Tech. The second annual SENFN meeting was hosted by Oak Ridge National Lab on Nov. 14, 2019 attended by 37 representatives from 13 institutions and the third meeting was hosted by

Georgia Tech virtually on December 9, 2020. Topics of discussion included operational, financial and personnel challenges in the COVID-19 era.

In support of its vision to strengthen and accelerate discovery in nanoscience and nanoengineering across the US, SENIC established the Catalyst Program, modelled after the RTNN Kickstarter program. This funding program allows researchers limited (up to $1000) free access to the SENIC facilities to aid in research, obtain preliminary data, conduct proof-of-concept studies, or for educational purposes. We have funded 17 of 21 proposals, with several others waiting for access as facilities reopen. Awards were made to new researchers from Clemson, UNC-Charlotte, Duke, Elizabeth City State (HBCU), Clark Atlanta (HBCU), Georgia State (PBI), Kennesaw State, Auburn, and Wheeler High School (60% URM).

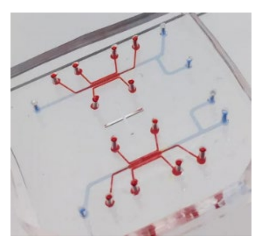
During the fifth year of the NNCI program (Oct. 2019 - Sept. 2020), the SENIC facilities have served 1057 individual users, including 207 external users representing 93 companies, 23 colleges and universities, and 6 other institutions. Several users have accessed capabilities at both SENIC locations with minimal difficulty. The majority of users access the facilities on-site, although 191 users obtained services remotely (14% increase compared to Year 4), and some users operated in both on-site and remote fashions. Monthly users averaged 373 (a significant drop compared to Year 4 due to facility shutdowns), and on average 21 new users were trained each month (248 total during the reporting period).

As part of a network-wide NNCI effort, SENIC participated in the annual user satisfaction survey. The online survey was emailed to all IEN and JSNN users and received 96 responses (as of Dec. 31, 2020). Overall, the results are very positive with high levels of satisfaction (>90% somewhat or extremely satisfied) for most assessment criteria, and 100% would refer SENIC to a colleague. The overall site rating was 4.6/5.

<u>Research Highlights and Impact</u>

Notable <u>new</u> academic users of the SENIC facilities this past year come from Alabama A&M University, University of California-Berkeley, University of Florida, University of North Carolina-Wilmington and University of Missouri, while <u>new</u> industry users include Halocarbon Life Sciences, Alacrity Semiconductors Inc., VX Aerospace, Honda Jet, Syngenta, RTI International, and Gilbarco to name a few. Some example research highlights include:

Brain Interface with Bloodstream on Precision Chip (Y-T Kim, Georgia Tech)

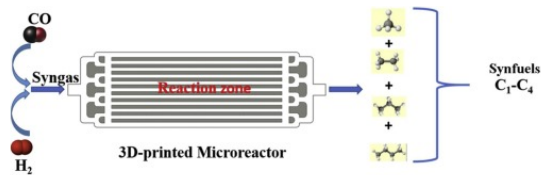


Researchers at Georgia Tech have engineered a way of studying the blood-brain barrier more closely and assisting drug developers. In this work, the researchers cultured the human blood-brain barrier on a chip, recreating its physiology more realistically than previous chips. This research was funded by several NIH grants and published in *Nature Communications*.

3D-Printed Device Traps for Cancer Cells (F. Sarioglu, Georgia Tech, with collaborators at Emory University)

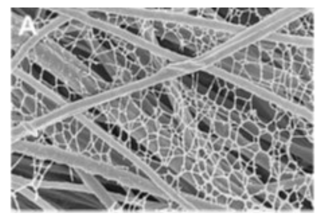
Finding a handful of cancer cells among billions of blood cells in a patient sample is difficult. Researchers from Georgia Tech with collaborators at Emory University used a 3D printed device to trap the white blood cells and filter out smaller red blood cells, leaving behind the tumor cells, which are then used for disease diagnosis. This research was supported by a seed grant from Integrated Cancer Research Center at Georgia Tech and published in *Lab on a Chip*.

Fischer-Tropsch Studies in 3D Printed Microreactors (D. Kuila, NCA&T)



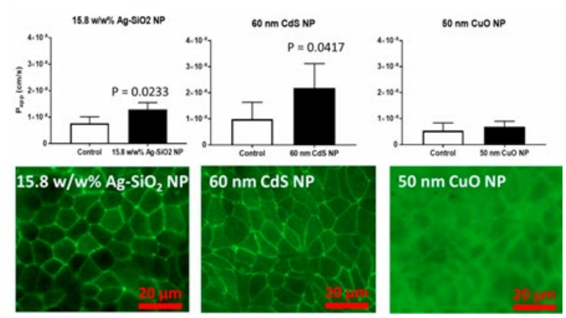
Researchers at NCA&T used SENIC facilities to conduct Fischer-Tropsch studies in 3D-printed stainless steel microreactor coated with cobalt-based bimetallic-MCM-41 catalysts. Fischer-Tropsch synthesis, which collectively refers to syngas conversion to synthetic crude oil, is an excellent chemical process for converting syngas to alkanes. Research was funded by NSF and UNC General Administration and published in *Catalysis Today*.

Controlled Drug Release from Nanonet-Nanofibers (N. Bhattarai, NCA&T)



Researchers at NCA&T synthesized nanonet-nanofiber electrospun meshes (NNEMs) of polycaprolactone (PCL)–chitosan (CH) for high payload delivery and controlled release of a water-soluble drug, namely Diclofenac Sodium (DS). DS-NNEMs also enhanced cell adhesion, viability, and proliferation in the nanonet-nano fiber network through the controlled release of DS. This research was funded by NSF and published in *Nanoscale* (cover art publication).

Investigation of Gastrointestinal Integrity on Exposure to Metal, Metal Oxide, and Metal Sulfide Nanoparticles (T. Fennell group, RTI International)



Using fully differentiated Caco-2 cells, the perturbation of intestinal barrier function and cytotoxicity were investigated for 20 metal, metal oxide, and metal sulfide nanoparticles (NPs). RTI used SENIC facilities for nanoparticle characterization and for in vitro digestion studies. The results illustrated that while many metal, metal oxide, and metal sulfide ENMs do not adversely affect monolayer integrity or induce cytotoxicity in differentiated Caco-2 cells, a subset of ENMs may compromise the intestinal integrity. This research was funded by NIH and published in *Nanoimpact*.

Scholarly impact can be measured indirectly with more than 630 publications, presentations, and patents benefiting from SENIC facilities in CY2019. Using a Google Scholar search, approximately 170 of these 2019 publications (and nearly 500 publications since 2015) were found to have acknowledged the SENIC NSF award number (ECCS-1542174). Additional impact of SENIC is indicated by centers and other large programs that are enabled by the supported core facilities. During Year 5 the **Scalable Molecular Archival Software and Hardware (SMASH) project** was awarded up to $25 million to develop scalable DNA-based molecular storage techniques by the Intelligence Advanced Research Projects Activity's (IARPA) Molecular Information Storage (MIST) program and the NIH-funded **Atlanta Center for Microsystems Engineered Point of Care Technologies (ACME POCT)** participated in the RADx (Rapid Acceleration of Diagnostics) program, with the aim of increasing COVID-19 testing capabilities.

ACME-POCT serves as the Test Verification Core of RADx and Georgia Tech's SENIC facilities, staff, and faculty make up the Engineering Sub-Core for prototype design evaluation and assessment.

While economic impact can be difficult to quantify, here are select examples from Year 5:

- **ResonanceDx, Inc.** is an early-stage medical diagnostic start-up that was spun out of research conducted at Georgia Tech and Emory University. This company used SENIC facilities to fabricate sensors to generate preliminary data, which resulted in awards from the NIH RADx and NIH RADx-NEXT SARS-COVID-2 programs.
- **Alcorix**, a start-up located in Plainfield, IL, develops micro- and nanofabricated X-ray optics components and is preparing to launch a series of brain-implant probes for neurotransmitter sensing. This company uses SENIC's fabrication resources which resulted in two SBIR/STTR grants from NSF and NIH, in addition to two journal publications in preparation.
- Additional SBIR grants were awarded to **3iNano, AxNano, Kepley Biosystems**, and **Kampanics LLC**
- The SENIC website includes "success stories" (https://senic.gatech.edu/success-stories-and-testimonials/) of industry users in key application areas such as electronics, materials, and biomedical.

Education and Outreach Activities

SENIC's vision for education and outreach is focused on the development of a strong workforce capable of meeting the needs of a growing nanotechnology-enabled economy. This year through our programs, we reached more than 4,800 individuals from young children through adults. This is a drop from previous years due to the pandemic. The COVID-19 pandemic forced cancellation of many E&O programs, including the NSF REU program SENIC Undergraduate Internship in Nanotechnology (SUIN), a newly funded NSF RET program and high school summer programs at IEN and JSNN. JSNN is home to the NIH Maximizing Access to Research Careers (MARC) Undergraduate Student Training in Academic Research (U-STAR) Fellowship program. This program annually offers 2 students underrepresented in biomedical sciences research opportunity, focused workshops and courses to prepare them for graduate school. Additionally, JSNN hosted two interns this past year (less than the normal four/year) from Forsyth Technical Community College's Nanotechnology and Biotechnology programs. Georgia Tech, inspired by JSNN's program, started their own paid, technical college internship in spring 2020. In addition to these internships, SENIC provides opportunities to students through work in the facilities as assistants. This past year, an additional 35 students (3 high school, 2 graduate students, and 30 undergraduates) worked in Georgia Tech facilities.

The Graduates in Nanotechnology (GIN) group and JSNN's Materials Research Society Chapter continue to host events. These two student groups have teleconferenced events including a discussion on entrepreneurship and one on preparing for a post-doc. This past year, GIN hosted several outside seminar speakers including Prof. Sharon Glotzer (University of Michigan) and Dr. Debra Rolison (Naval Research Laboratory) with an opportunity for students to have lunch and less formal conversation with the speakers. The student organizer of the GIN seminars shared that it was thanks to this opportunity that she met Prof. John Rogers and will be starting a post-doc in his lab at Northeastern University this spring. Each academic year, JSNN hosts a weekly seminar and IEN hosts a bi-monthly seminar series entitled Nano@Tech. Both seminar series pivoted to virtual in response to COVID-19. IEN's NanoFANS Forum, a biannual symposium at the intersection of life sciences and nanotechnology was held in October 2019, with over 100 attendees joining sessions focusing on "Medical Electronics: Flexible & Wearable." In response to in-person sessions being canceled due to COVID-19, the spring NanoFANS was a series of virtual webinars held over the month of May on "Nanotechnology in Infectious Diseases (Diagnostics/Therapeutics)." SENIC also offered a Technical Webinar Series from April through June to provide further outreach to users during the pandemic. Due to the pandemic, spring and summer short courses were canceled. However, there were two short courses in fall 2019 on Microfabrication and TEM with 18 and 6 attendees, respectively. Students from JSNN are provided scholarships (using SENIC funds) to attend Georgia Tech workshops.

SENIC has been active in providing outreach to K-12 students, teachers, and the general public. The summer 2020 Nanotechnology Summer Institute for Middle School Teachers program was conducted virtually. A new cohort of 15 teachers from across Georgia participated in 4 hours per day of virtual instruction for 4 days. Classroom supplies were mailed to teachers in advance to facilitate hands-on activities. Over the past year, SENIC continued to attend/offer workshops at the GA STEM Forum (Oct. 2019), the GA Science Teachers Association Conference (Feb. 2020), and GT's Center for Education Integrating Science, Mathematics & Computing workshop for Georgia Career, Technical, and Agricultural Education middle and high school teachers (Oct. 2019). Unique to JSNN is the NanoBus (now called the STEM Ride), an after-school mobile hands-on laboratory. Due to the pandemic, only 565 students were able to board the STEM Ride before its activities were canceled in March 2020 (currently on hold). In response to the pandemic, new virtual activities have been introduced. SENIC at GT offered two 5-day virtual nano camps for middle school aged children during summer 2020; the students spent one hour a day learning about nanotechnology and working through activities. SENIC also hosted a competition for middle and high school students, *SENIC SuperHeroes*. We challenged area middle and high school students to create drawings/cartoons that depict our local heroes as nanotechnology superheroes. In August 2020, SENIC also began offering virtual hour-long class trips for middle and high school students. Staff are invited to join a teacher's virtual classroom and present an introduction to nanotechnology with demonstrations. In August and September, over 500 students have seen the virtual presentation. New to SENIC at JSNN in 2020 (started in August) is the Hitachi remote SEM program, which engaged K-12 students in a virtual hands-on experience. JSNN participated in two outreach events co-organized by RTNN. Lastly, in honor of National Nano Day, JSNN hosted a virtual roundtable on "The Impact of Industry 4.0 on Academia, Industry, and Society."

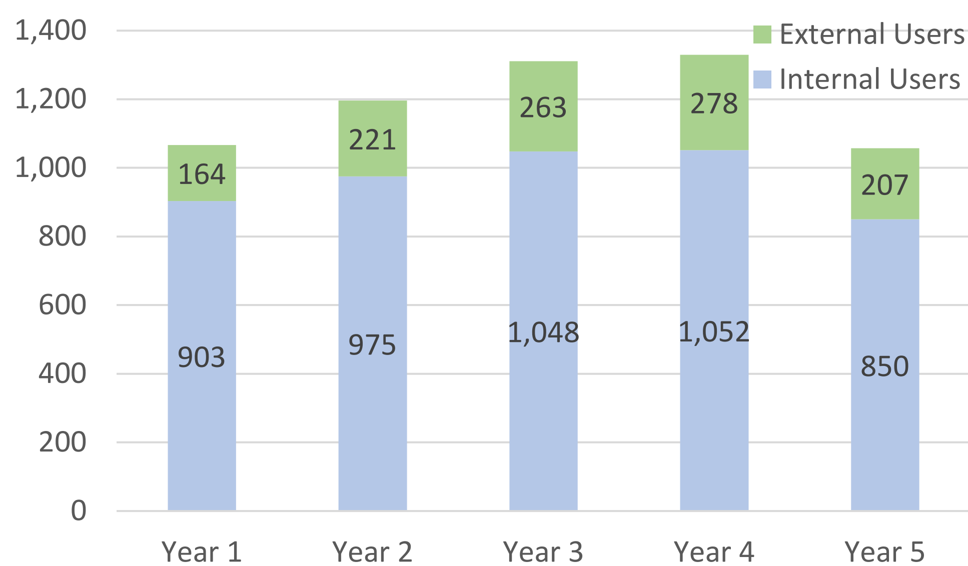
Societal and Ethical Implications Activities

The aim of the SEI work at SENIC is to increase attention to application of nanotechnology, while still attending to social and ethical implications. At the suggestion of the NSF Reverse Site Review panel, we conducted an evaluation using concept mapping to measure the effects of the SEI program, including an SEI training video, "8 Things You Need to Know About the Social Implications of Nanotechnology Research". The assessment used concept mapping to measure understanding of concepts among 11 REU students who were interning at Georgia Tech over the summer of 2019. The students were asked to complete concept maps before and after the program interventions, and 7 of the 11 REU students were found to recognize more SEI concepts after the interventions. Concepts associated with the environment, economy, geopolitics, and education and retraining were particularly more prevalent after the intervention. Post-intervention concept maps had three more social and ethical implication concepts on average than the baseline maps, a statistically significant difference. These results suggest that an explicit program of interventions does improve understanding of the various dimensions of SEI over and above existing preconceptions about these concepts before the video and interactive exercises.

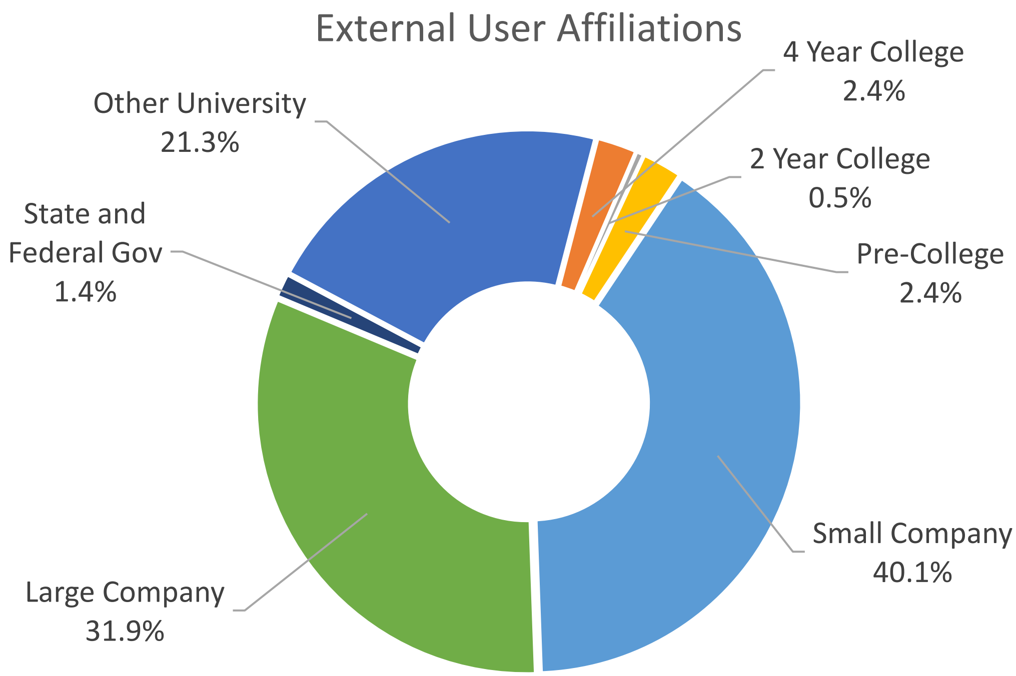
SENIC Site Statistics

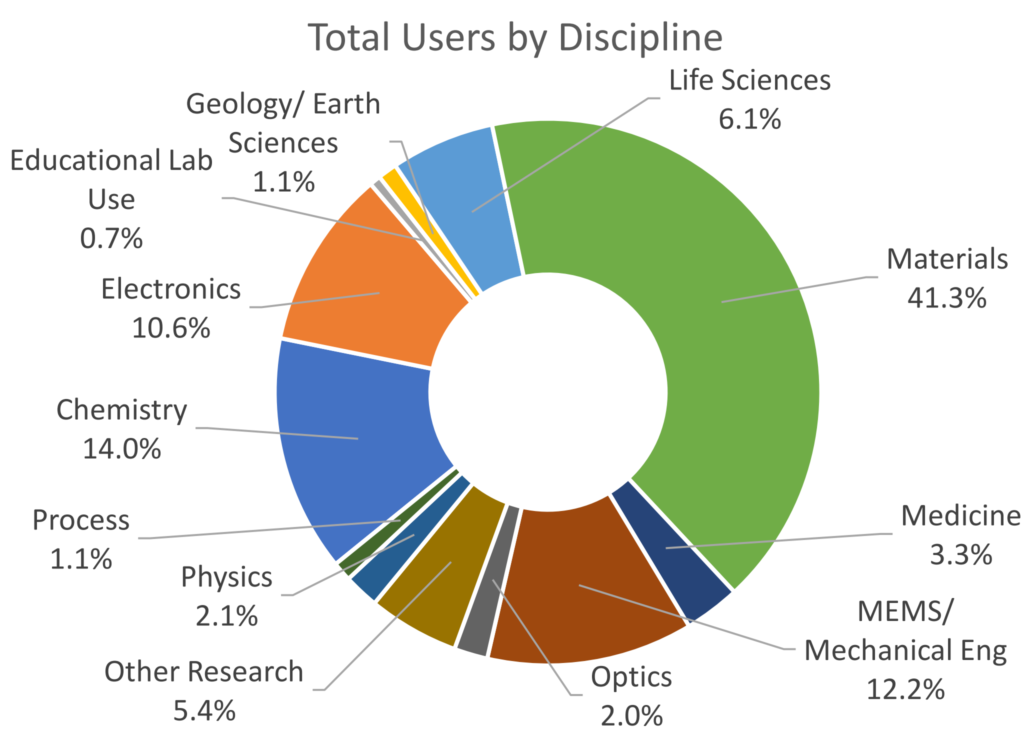
Yearly User Data Comparison					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total Cumulative Users	1,067	1,196	1,311	1,330	1,057
Internal Cumulative Users	903	975	1,048	1,052	850
External Cumulative Users	164 (15%)	221 (18%)	263 (20%)	278 (21%)	207 (20%)
Total Hours	79,581	85,275	99,118	101,571	66,611
Internal Hours	71,659	73,499	85,730	88,282	58,620
External Hours	7,922 (10%)	11,733 (14%)	13,388 (14%)	13,289 (13%)	7,991 (12%)
Average Monthly Users	447	498	546	576	373
Average External Monthly Users	60 (13%)	63 (13%)	83 (15%)	89 (15%)	51 (14%)
New Users Trained	313	313	386	502*	248
New External Users Trained	67 (21%)	110 (35%)	123 (32%)	132 (26%)	45 (18%)
Hours/User (Internal)	79	75	82	84	69
Hours/User (External)	48	53	51	48	39

*Starting in Year 4, SENIC began adding new users of the Materials Characterization Facility to this metric.



SENIC Year 5 User Distribution





11.15. Texas Nanofabrication Facility (TNF)

Facility, Tools, and Staff Updates

TNF invested heavily in advanced plasma etching, deposition, and ion milling systems during Oct. 1, 2019 –Sept, 30, 2020. A novel roll-to-roll atomic layer deposition system on flexible substrates, and a roll-to-roll etch system has been installed in 2020. Other major upgrades include:

- JEOL Aberration Corrected TEM (funded by Univ. of Texas) ($3M)
- Kurt J Lesker PVD E-beam evaporator ($290k)
- AJA International Ion Milling System ($275k)
- VK-X1100 Optical profilometer for TMI facility ($120k)
- Park NX10 Atomic force microscopy tool for TMI facility ($100k)

A centralized NNCI-TNF website has been developed aggregating information from all three constituent centers. Available information includes all equipment accessible by NNCI-TNF users, basic tool descriptions, compatible process materials, step–by-step usage procedures, and corresponding fees. To streamline tools access, a web-based reservation system is accessible online for every tool. A simple user access procedure has been adopted for the three components of TNF with a central user profile database and registration portal.

We have enhanced tool training by providing video training on the reservation website for the heavily used and sophisticated tools such as electron beam lithography (JEOL, e-line Raith, and Zeiss SEM), and Fiji ALD since Fall 2019. The training videos have been shot and edited by a freshman undergrad student. The video training for the video is provided by UT graduate students who are experienced TNF users. With COVID-19 training restrictions, video training modules for other tools such as AFM and evaporators are being developed. The videos will be made available to other interested NNCI sites with similar tools.

To support the business operations in TNF, the original management system that was delivered at the inception of NNIN-MRC was restructured. Sedona Visual Controls, Inc., the company who developed the original system, created a new LabVIEW based-system, called Labaccess, to provide access control to tools. Labaccess hosts a centralized database of the three TNF centers (MRC, TMI and NASCENT) and compiles quantitative data for reporting to NNCI. This system is also responsible of the tool reservation website maintenance. The online scheduling system manages tool access. We have added a new capability on the reservation website, called the "**tool status**", which will be refreshed each morning to show the list of the tools which are in operation or under maintenance. We have also restructured our training and troubleshooting request via UT generalized software service. In Fall 2018, TMI implemented a new software system, the Facility Billing Software (FBS) by Priority Software which produces TMI invoices and database to feed the data into Sedona database at MRC for the TNF report. FBS is a fully integrated usage tracking and billing application designed especially for monitoring the charge back recovery of facilities and service centers within a university or research institution.

Staff: NNCI TNF at UT Austin provide shared equipment access for users to conduct their research. Research users have access to equipment after face-to-face training and certification sessions. To keep up with the training demands for new users and current users who want to expand their equipment usage capabilities, we have maintained a model comprising of hiring undergrad and graduate student as part-time lab technicians. Currently, we have 3 undergrad part-timers, and hired 2 more graduate students. These part-timers are freshman or sophomore undergraduates and graduate students from UT Austin Colleges of Engineering and Natural Sciences.

In addition to the undergrad and grad lab technicians, the highly skilled training staff also provide user support for both standard and advanced fabrication or characterization techniques. They propose innovative and unique solutions to solve user's complex scientific challenges. With over 800 unique users utilizing the shared facilities per year, training sessions are organized every weekday. TNF has a total of 19 full-time technical staff at MRC (3 Ph.D. s, and 7 technicians and engineers), TMI (5 Ph.D. s and 1 technician) and NASCENT nm-Fab (3 Ph.D. s).

User Base

The Texas Nanofabrication Facility (TNF) at the University of Texas at Austin (UT) is composed of the Microelectronics Research Center (MRC), the Texas Materials Institute (TMI), and nanomanufacturing fab (nm-Fab) developed under an NSF ERC program. NNCI-TNF (composed of MRC, TMI and nm-Fab facilities) has 22,000 sq. ft. cleanroom space (class 100 and 1000) and 20,000 sq. ft. of labs.

The MRC cleanroom provides extensive nanofabrication capabilities, TMI provides state-of-the-art metrology tools, while the nm-Fab has developed and provides novel nanomanufacturing tools in the areas of roll-to-roll manufacturing (deposition and etch), and high speed, large area nanoimprinting. TNF is well positioned geographically in the Austin high-tech hub, within the Dallas/FortWorth-Houston-San Antonio triangle, with no competing universities having comparable infrastructure in nanotechnology in this region of the country. Since Texas, in general, and Austin in particular, has a strong industry base in nanotechnology, TNF has a large external user cohort, especially in terms of small companies. We also serve academic institutions in Texas, and the neighboring states (Oklahoma, Arkansas, etc.). We also have users from other parts of the US, and the rest of the world. We have enabled and fostered breakthrough nano-innovation in the areas of electronics, healthcare and energy, all of which have significant presence in the South West, while establishing educational activities in nanotechnology directed at engaging underrepresented minorities (URM), particularly Hispanics and women.

This partnership of centers is more than an aggregate of shared facilities. It is a network of 25 professionals (technicians, engineers, and staff), 6 of whom were supported by NNCI. During the past five years, users at TNF have provided ~$1.3M$ of annual user fees annually. UT provides ~1.2M$/year of staff and facilities support. The NNCI investment of ~$990k was leveraged ~ 4:1.

The successes of TNF from October 1, 2019- Sept. 30, 2020 include:

- *Science to Scalability:* Integrated MRC (nanodevice prototyping) with TMI (state-of-the-art characterization) and nm-Fab (nanodevice manufacturing) to facilitate innovation in seed stage, as well as small and mid-size companies (SMCs) by building on our track record of technology incubation in Texas. The nm-Fab did prototyping and small-scale manufacturing for outside companies.
- *Innovation Ecosystem:* Focused on enhancing commercial success of SMCs by connecting them to an innovation ecosystem including the Longhorn Startup undergraduate entrepreneurship course at UT, the Austin Technology Incubator (UT's official startup incubator), and NSF I-Corps program, for which UT is an official node.

- *Engaged URM in NNCI-TNF*: Since Texas has a large Hispanic population, and Oklahoma has a large Native American population, we targeted these populations as part of our effort to engage underrepresented minorities and women. We offered 5 REU students hands-on-training in our cleanroom, and targeted women and underrepresented minorities in 2015-2019.
- *Leveraged the Dell Research Hospital:* We started a collaboration with the medical research groups in Houston, Dallas and San Antonio areas by partnering with the Dell Medical Research Hospital established in 2014, in the area of healthcare electronics and nanomedicine.

Research Highlights and Impact

Work done at TNF has led to multi-institution, and multi-NNCI site high impact papers in *Nature* and *Science*. NNCI has also enabled technology development by small companies, many supported by SBIR and STTR grants from NSF, DoD, etc. Several of these address the NSF Big 10 Ideas, or other federal initiatives.

Approximately 150-200 papers are published each year by the internal and external users of TNF, many of them in high impact journal such as *Nature* and Nature group, *Science*, *Phys. Rev. Letters*, *Phys. Rev. B*, *PNAS*, *Nano Letters*, and *ACS Nano*.

Education and Outreach Activities

Since 2016, one of the major activities of the nm-Fab has been the creation and distribution of low cost, Portable Nanotech Labs (PNLs) in a variety of online courses for industry, and also for UT Austin undergraduate students in traditional on-site courses, and this will be continued under TNF. The creation of these PNLs was the outcome of an NSF-funded I-Corps Learning program that the NASCENT PI (Sreenivasan) completed in 2015. The creation of each PNL has required careful thought and planning as each PNL must have a cost of less than ~$150 for its use in online and onsite courses to be financially viable. By completing several nmFab-fabricated PNLs, a large number of students (including external users) have become outside users of the nm-Fab service center. Over the past several years students have completed multiple portable nanotech labs in each of the following courses:

- A UT-Austin undergraduate "Freshman Signature Course" titled *Nanotech Demystified*. This course is offered by the College of Undergraduate Studies to onsite undergraduate students.
- An elective course offered to onsite upper-level undergraduates and master's level graduate students titled *High Throughput Nanofabrication*. This course is cross listed in the departments of Mechanical Engineering and Electrical & Computer Engineering.
- A three-course online graduate certificate program titled "Hands-on Nanotechnologies" offered by the nm-Fab Center to bachelor's degree-holding engineers and scientists in industry, as well as to a small number of undergraduate students at partner institutions such as Southwestern University and St. Edward's University. This certificate program is comprised of three courses:
    - *Nanofabrication and Nanomaterials (taught by S.V. Sreenivasan)*
    - *Nanodevices (taught by Sanjay Banerjee)*
    - *Challenges in Frontier Nanoelectronics (taught by Larry Dunn)*
- A number of short courses offered to industry by the nm-Fab Center, including *An Introduction to Nanotechnology* and *Nanoimprint Lithography*.

The number of outside users of nm-Fab through the PNLs over the last several years include 77 from industry and 4 from academia.

We regularly host tours of our cleanroom and nanotech labs for K-gray. In addition, popular lectures on nanotechnology to senior citizens are given once or twice a year by TNF faculty. For example, Banerjee gave lectures on Nanotechnology and hosted cleanroom tours to the UT Osher Lifelong Learning Institute for 50+ year olds (https://olli.utexas.edu/) and Learning Activities for Mature People (LAMP) programs in 2019 and 2020. Similar programs including hands on nanotechnology-based workshops were held periodically yearlong for Middle and High school kids from the Austin School District as well as for the STEM explorer students of Austin Community College. These included:

Girl Day at TMI facility: This STEM Festival is an annual free event hosted by the Women in Engineering Program (WEP). Girl Day gives elementary and middle school students a chance to explore STEM through grade-appropriate, hands-on activities hosted by volunteer scientists, engineers, and STEM enthusiasts from over 160 student organizations, research centers, corporate partners and community organizations. It is specifically designed for girls, but boys are also welcome.

Arranged a hands-on demo program for the high school students: 20 students from a local high school participated in the program. Our undergrad lab technicians have participated in the program as a host. We have arranged a guided tour inside the cleanroom for the participants. The demo consisting of a lecture by our part-time undergrads about their experience and a video of the state of art fabrication procedure of the semiconductor industry. The students took challenges to make innovative circuits with squishy dough (both insulating and conducting), and lemons. The nails, coins and the wires were provided to connect the circuits.

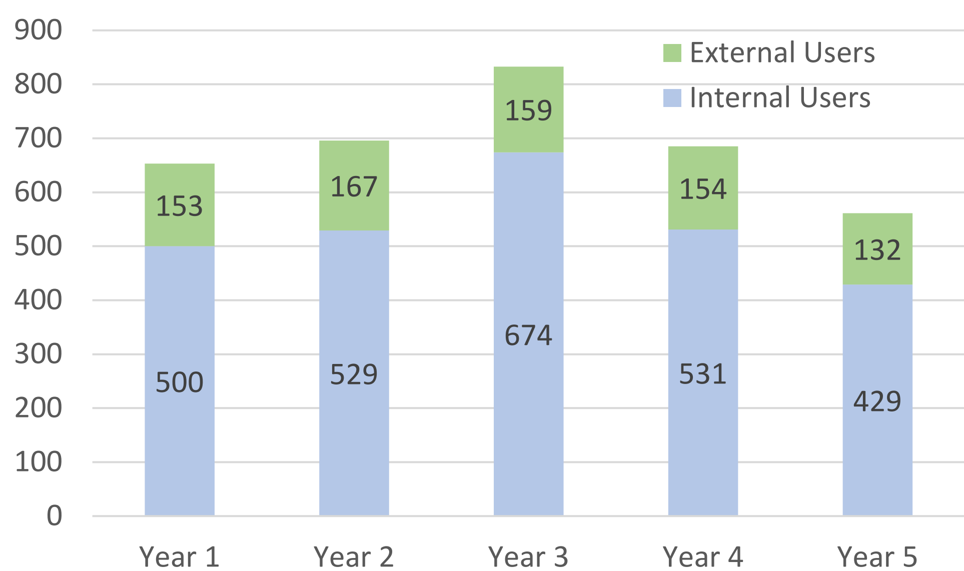
Societal and Ethical Implications Activities

Prof. Lee Ann Kahlor, a science communication expert at the University of Texas at Austin, has led the societal and ethical implications (SEI) team for NNCI-TNF. Her team produced an SEI education video available on-demand via YouTube at https://www.youtube.com/watch?v=4wz8Kifsd4U. The content of that training video was developed using an evidenced-based process which relied on interview data from scientists who were interviewed during the NNIN funding cycle (Kahlor, Dudo, Liang, Lazard, AbiGhannam, 2016), focus groups with NNCI REU students, focus groups with SEI researchers at the other NNCI nodes, and the extant literature on SEI related to nanotech and a variety of other sciences. Throughout the development and subsequent piloting of the training video at the Austin node, the SEI team has been collecting qualitative and quantitative data. The team's post-training survey data suggests that the video developed at UT-Austin increases scientists' awareness of the SEI of their work (beyond the micro-social level, i.e., within their labs), at least immediately following their viewing of the video. A summary of the development and pilot-testing of the training video was published in *NanoEthics* (Kahlor, Li, & Jones, 2019). The project has been presented at each stage of development to the SEI nodes through the annual meetings and virtual conferences with members, and it has influenced the development of a tailored training program at the SENIC node at Georgia Tech.

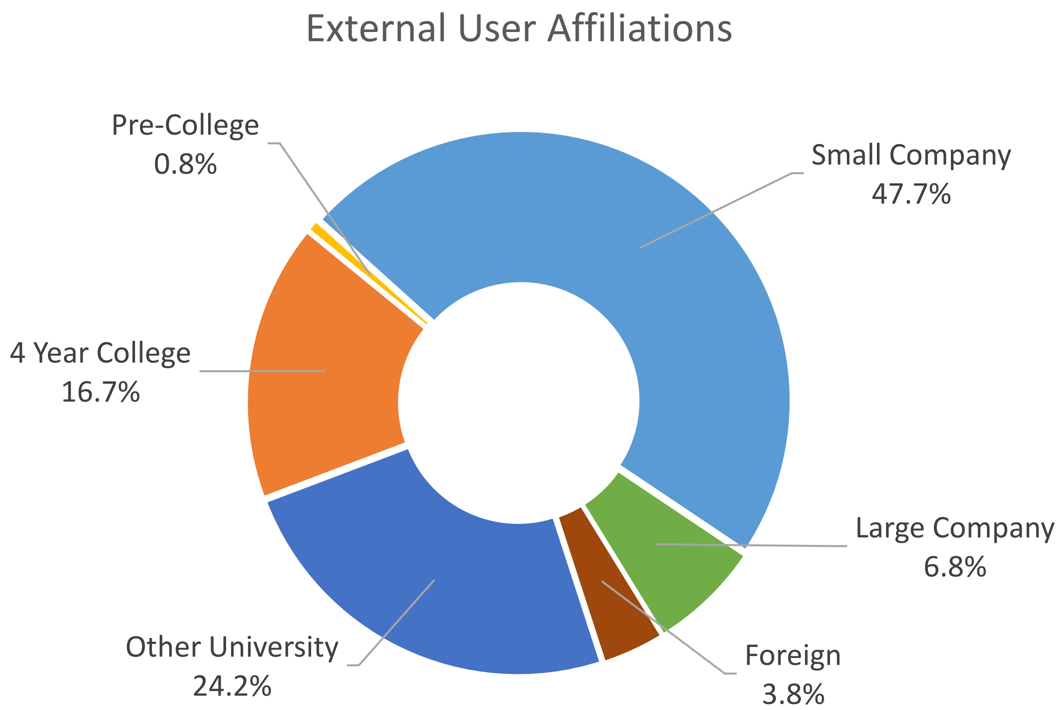
Building off this success the SEI team has conducted a follow-up study focusing on the role of ethical leadership in the trainees' various organizations. Because most science is conducted by groups of scientists, rather than independent researchers, scientists can influence one another by actively participating in ethical behaviors. The research is focused on perceptions related to ethical leadership in hopes that we might develop additional training that will help the trainees to have a better understanding of not just SEI, but also how to lead through example in creating an ethical environment within one's organization. The training targets every scientist who uses the facilities at NNCI-TNF, regardless of their roles and positions. Following the same model as our initial training video, future training in "ethical leadership" will extend each scientist's view of their organization and attendant ethics, even if the trainee is not yet in a leadership position within the organization. The theoretical framework for this approach to SEI training was presented at the annual conference of the American Association for the Advancement of Science in February 2020. Following feedback from that conference, initial data to support an ethical leadership approach was submitted for publication in *Science and Engineering Ethics*.

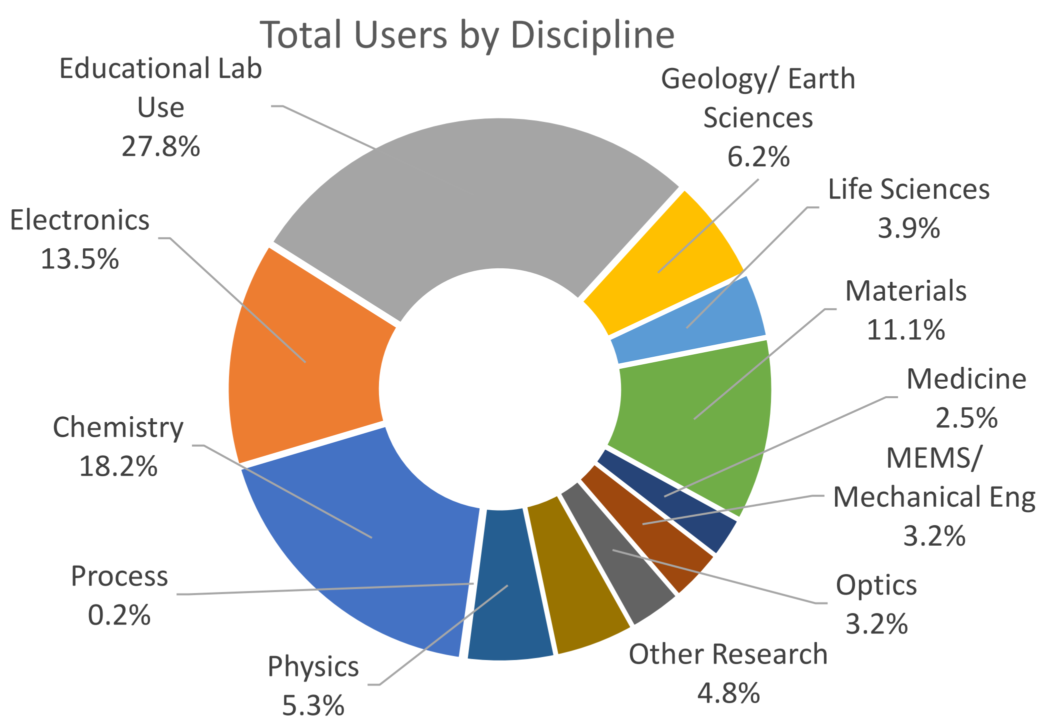
TNF Site Statistics

Yearly User Data Comparison					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total Cumulative Users	653	696	833	685	581
Internal Cumulative Users	500	529	674	531	429
External Cumulative Users	153 (23%)	167 (24%)	159 (19%)	154 (22%)	132 (24%)
Total Hours	67,570	58,354	63,645	65,166	38,229
Internal Hours	53,484	45,952	46,464	48,254	28,263
External Hours	14,084 (21%)	12,402 (21%)	17,181 (27%)	16,912 (26%)	9,966 (26%)
Average Monthly Users	244	272	287	315	216
Average External Monthly Users	45 (18%)	50 (19%)	59 (21%)	65 (21%)	45 (21%)
New Users Trained	99	193	80	62	34
New External Users Trained	48 (48%)	45 (23%)	33 (41%)	29 (47%)	16 (47%)
Hours/User (Internal)	107	87	69	91	66
Hours/User (External)	92	74	108	110	76



TNF Year 5 User Distribution





11.16. Virginia Tech National Center for Earth and Environmental Nanotechnology Infrastructure (NanoEarth)

Facility, Tools, and Staff Updates

Based on NanoEarth / PNNL-EMSL collaborative agreement, EMSL will offer special access to several of EMSL's specialized capabilities to users recommended by NanoEarth. Effective from January 2020, this special access does not require EMSL's standard merit review process and provides instrument access any time for a period up to 30 days (a summary list of available instruments will be provided upon request)

User Base

NanoEarth is designed for users in the Earth and environmental sciences and engineering fields, but many other scientists and engineers accomplish important research in related fields using our labs and instrumentation. In the case of NanoEarth, Earth and environmental science and engineering related users have included those in the fields of chemistry, mechanical engineering, civil engineering, medicine, materials, electronics, and physics.

NanoEarth's MUNI (Multicultural and Underserved Nanoscience Initiative) provides financial support for individuals engaging with NanoEarth for research or educational purposes. In our fifth year, we supported 48 MUNI participants from 33 different organizations, including high school students, undergraduate and graduate students, professors, governmental researchers and professionals, and industry users.

Research Highlights and Impact

Discussed below are one academic and one industry highlight from this year. Additional highlights are described in the slides provided.

Leading Academic Highlight – The *New York Times* described NanoEarth's Deputy Director Linsey Marr as "one of the world's leading experts on airborne transmission of viruses" and has relied on her heavily for their coverage of the COVID-19 pandemic. In addition to performing research on the efficacy of homemade masks (medRxiv preprint: https://doi.org/10.1101/2020.11.18.20233353), she has been a key public-health figure in the fight against COVID-19 for numerous media outlets and has been active on Twitter (@linseymarr) to keep the public informed. She excels at taking complicated scientific concepts and describing them in a way that the general public understands. For example, to help people visualize the aerosols we generate by breathing, she compares them to cigarette smoke and when asked about indoor versus outdoor air, she developed an analogy of putting a drop of dye into a glass of water (indoors) versus into the ocean (outdoors).

Leading Industry Highlight – Based in part NanoEarth's demonstration of the effectiveness of Micronic Technologies' MicroEvap™ purification technology, Micronic received $3M in seed round investment from the Center for Innovation Technology and the Pearl Fund. Micronic is a small, woman-led company in Southwest Virginia. Their work with NanoEarth demonstrates the application of an industrial zero-liquid discharge (ZLD) technology for scalable, filter-free removal of nanoparticles from aqueous media. Gold, titanium, and silver nanoparticles – all of which were present at ppm concentrations in a mixed laboratory waste stream – were reduced in product water by more than 99.8%. The work completed with NanoEarth resulted in an invention disclosure, multiple proposals including SBIR, and support for securing private investment.

Education and Outreach Activities

NanoEarth has a very active and robust Education and Outreach (E&O) program. A few highlights are included below.

- NanoEarth continues our partnership with Jim Metzner (multiple radio media major-award winner, plus multiple NSF, Grammy Foundation, and Fulbright grants) with 10 new shows developed for ***Pulse of the Planet*** this year about nano-related research and technology, and how it is changing the world, very much built for public consumption in a highly constructive format. ***Pulse of the Planet*** highlights the most interesting projects that come to us from external users, local site researchers, and impactful research at other NNCI sites with those individuals personally interviewed for each episode. This year's episodes featured Greg Lowry (Carnegie Mellon University), Paul Schroeder (University of Georgia), and Linsey Marr (Virginia Tech). ***Pulse of the Planet*** is heard on over 265 NPR radio stations by 1.1M listeners per week; additionally, these 10 new shows were downloaded over 22,000 times in Jan-Sept 2020. A full list of episodes with links to each program, which credit the National Science Foundation by name, are available on the NanoEarth website.
- In partnership with WITec, NanoEarth hosted the **Confocal Raman Imaging Workshop** which provided an introduction to operational principles and instrumental configurations relevant to confocal Raman imaging along with associated techniques suitable for correlative measurements, such as AFM, SNOM, and SEM. During the workshop speakers from Virginia Tech covered various aspects of Raman imaging in their fields of application. Speakers from WITec demonstrated the latest advances in instrumentation development. The workshop also included instrument demonstrations where attendees could bring their own samples to be analyzed.
- **Air, Land, and SEE – a Transdisciplinary Exploration of Science, Technology, and Art** at the Virginia Tech Science Festival: Coordinating with the Mid-Atlantic Aviation Partnership (MAAP), the Virginia Tech Drone Park, the Institute for Creativity, Arts and Technology (ICAT), the School of Performing Arts (SOPA), and the Freshwater Mollusk Conservation Center (FMCC), NanoEarth participated in an exciting transdisciplinary experience for attendees of the Virginia Tech Science Festival. Attendees had the opportunity to experience the making of an immersive documentary about endangered species conservation that illustrates the tension between humans, technology, and our planet. The documentary, which is being developed by Matthew Hull and Justin Perkinson, is scheduled for completion in 2020, but the process of making it is a spectacle in itself. From immersive 360-degree underwater video and aerial drones to spatial audio and nanotechnology, this exhibit will include visual and hands on experiences that gave attendees a first-hand look at Virginia Tech's "Beyond Boundaries" mission in progress. The VT Science Festival had over 6,000 attendees. A staff member counting Air, Land, and SEE exhibit visitors counted approximately 1,300 including children of all ages, students, faculty, and members of the local community.
- **Nanoscience Professional Development Workshop for High School Teachers**: In light of the COVID-19 pandemic, NanoEarth took the lead in reimaging our annual professional development workshop for high school science teachers into a month-long, virtual event throughout the month of July. The workshop, held in partnership with the Virginia Tech

Nanoscience program, awarded teachers continuing education credit and provided practical methods for including nanoscience concepts in their curriculum. Teachers received a package of educational laboratory supplies to follow along with laboratory demonstrations from their own homes. Weekly group meetings, office hours, and discussion sessions were combined with pre-recorded lessons, demonstrations, and assignments that teachers could complete at their own pace. In addition to discussing nanoscience topics from chemistry, physics, biology, and environmental science lenses, the workshop highlighted various online learning technology platforms including Zoom, Google Meet, Google Classroom, Canvas, and Slack. Discussions focused on how activities could be held in an in person, physically-distant classroom, but also virtually. A general introduction to nanoscience and nanotechnology was covered as well as specific subjects such as encapsulation, self-assembly, memory metal, cross-linked and ring polymers, ferrofluid, nanoparticles in sunscreen, unit cells and crystal structures, super hydrophobicity, heat transfer, nanoscience in the environment, and careers in nanoscience. Application areas such as environmental remediation, energy, optoelectronic devices, and nanomedicine were also discussed.

- **HBCU/MSI Research Summit**: NanoEarth participated in the virtual 2020 HBCU/MSI Research Summit organized by Virginia Tech's Office of Recruitment and Diversity Initiatives. The summit provides an opportunity for faculty, students, and administrators to explore research opportunities and potential collaborations between historically black colleges/universities (HBCUs), minority serving institutions (MSIs), and Virginia Tech. Through these partnerships we seek to enhance the quality of research and graduate education by placing equity, diversity, and inclusion at the forefront of our pursuit of excellence. Our goals in hosting the annual research summit include: 1) Research: fostering cross-institutional research partnerships between HBCUs, MSIs and Virginia Tech; 2) Recruitment: Providing current HBCU and MSI students with a preview of Virginia Tech's graduate programs, allowing Virginia Tech graduate programs a key opportunity to recruit prospective students; and 3) Shared Degrees: Facilitate discussions about the feasibility of shared degree programs between the HBCUs and MSIs and Virginia Tech programs.
- **NanoTechnology Entrepreneurship Challenge (NTEC) and NTEC-MUNI launch**: NanoEarth awarded funds to three teams to support student-led entrepreneurship. One of the student teams was from Fayetteville State University (FSU), an HBCU based in Fayetteville, NC. This award marked our first project combining entrepreneurship and engagement of underrepresented groups and minorities (Impact: 3 teams, 6 students, 3 faculty mentors); one VT-based team is developing a solution for measuring COVID-19 in respired breath. The pandemic impacted their programs significantly, but each team insisted on overcoming these challenges and pursuing their interest in nanotechnology entrepreneurship.

<u>Innovation and Entrepreneurship</u>

NSF supported the development and successful demonstration of programs that: 1) effectively recruit NNCI industry users, and 2) support nanotechnology entrepreneurs. Collectively, these programs helped launch the **NanoEarth Innovation Ecosystem**, which is recognized as a model for translational nano Earth/environmental science and engineering [Hull, M. Industrial Revolution or Opportunities Lost: the Nanotechnology Entrepreneurship Challenge. Invited presentation at the Quadrennial Review of the US National Nanotechnology Initiative, 31 July

2019, National Academies of Science, Engineering, and Medicine, Washington, DC]. NSF support enabled NanoEarth to engage hundreds of industry representatives, many of whom are considered non-traditional NNCI users in areas such as geosciences and soil remediation, water treatment, agriculture, industrial hygiene, and endangered species conservation. Most notable is NanoEarth's collaboration with Micronic Technologies, Inc., a small woman-owned business located in Bristol, VA, which led to a joint invention disclosure and new nano-related market opportunities for Micronic's MicroEVAP™ technology. The NSF-funded NanoTechnology Entrepreneurship Challenge (NTEC), supported dozens of student entrepreneurs pursuing applications of nanotechnology to solve global sustainability challenges. The program resulted in multiple invention disclosures and student-founded companies including MIST – Mangrove-Inspired Sustainable Technologies™ and Mantis Biomaterials™. In 2019, the NTEC program was featured at the Quadrennial Review of the US National Nanotechnology Initiative as an example of the enduring benefits of NSF support for US nanotechnology leadership.

Societal and Ethical Implications Activities

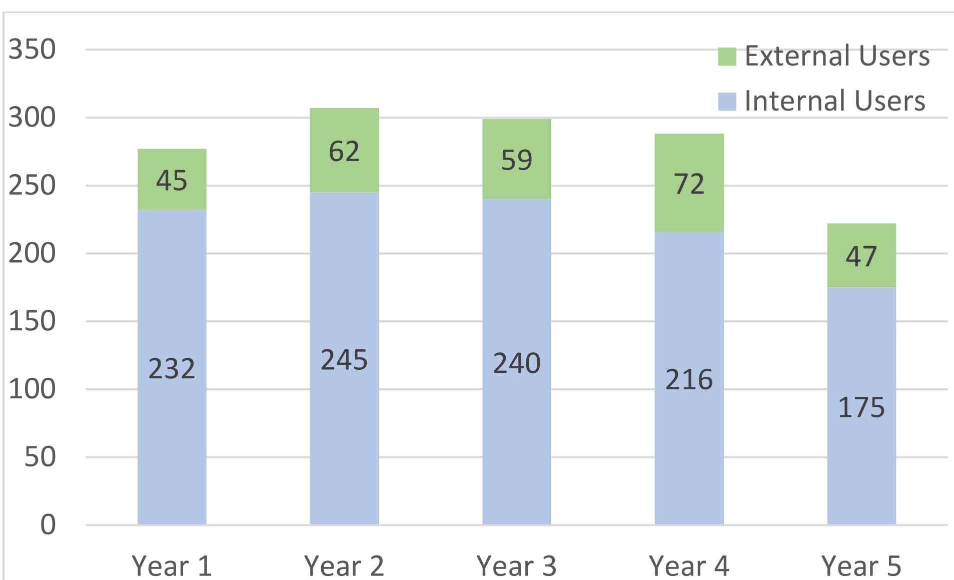
NanoEarth participates in Societal and Ethical Implications (SEI) of nanotechnology activities that are coordinated across participating NNCI nodes under the direction of Professor Jamey Wetmore of the Nanotechnology Collaborative Infrastructure Southwest (NCI-SW) node. SEI activities initiated within NanoEarth include: 1) engagement with diverse and underrepresented groups, 2) empowerment of individuals and social change through nanotechnology entrepreneurship, and 3) earth and environmental nanoscience in the service of society. These activities were shared with representatives from other NNCI nodes during the NNCI annual meeting, and will help form the basis of inter-node SEI activities in the future.

Computation Activities

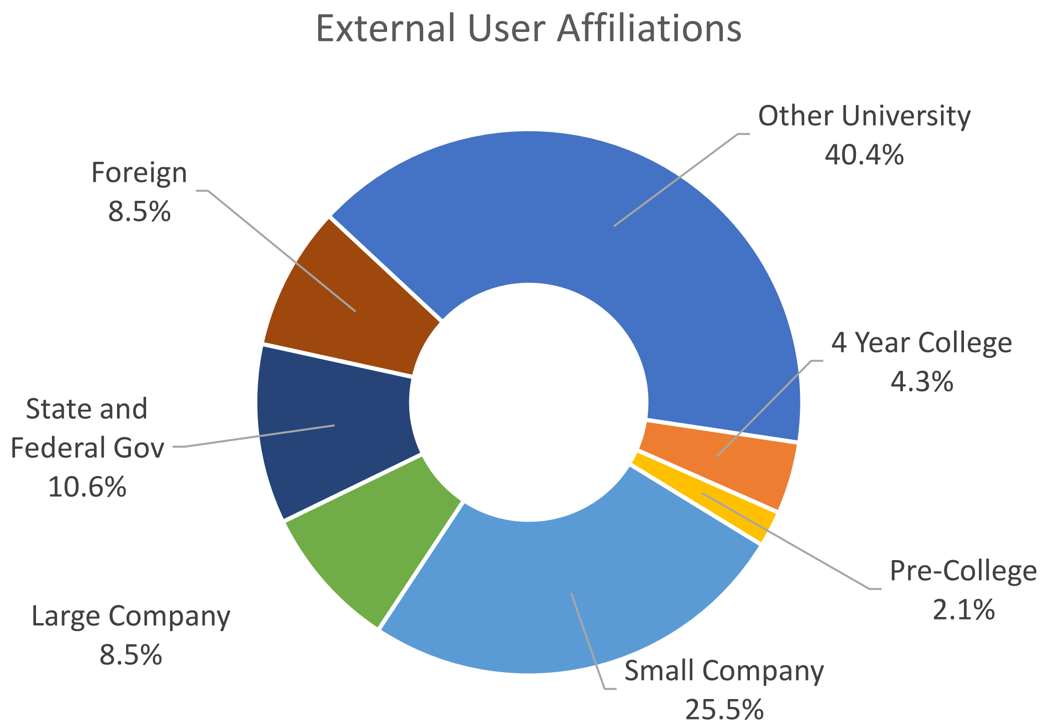
NanoEarth Associate Director for Innovation and Entrepreneurship Matthew Hull continues to manage access requests for users of the Nanotechnology Consumer Products Inventory (CPI) (www.nanotechproject.org/cpi/). While the inventory no longer receives funding support from the Pew Charitable Trusts, NanoEarth faculty, staff, and students have played a vital role in sustaining this critical nanoinformatics resource.

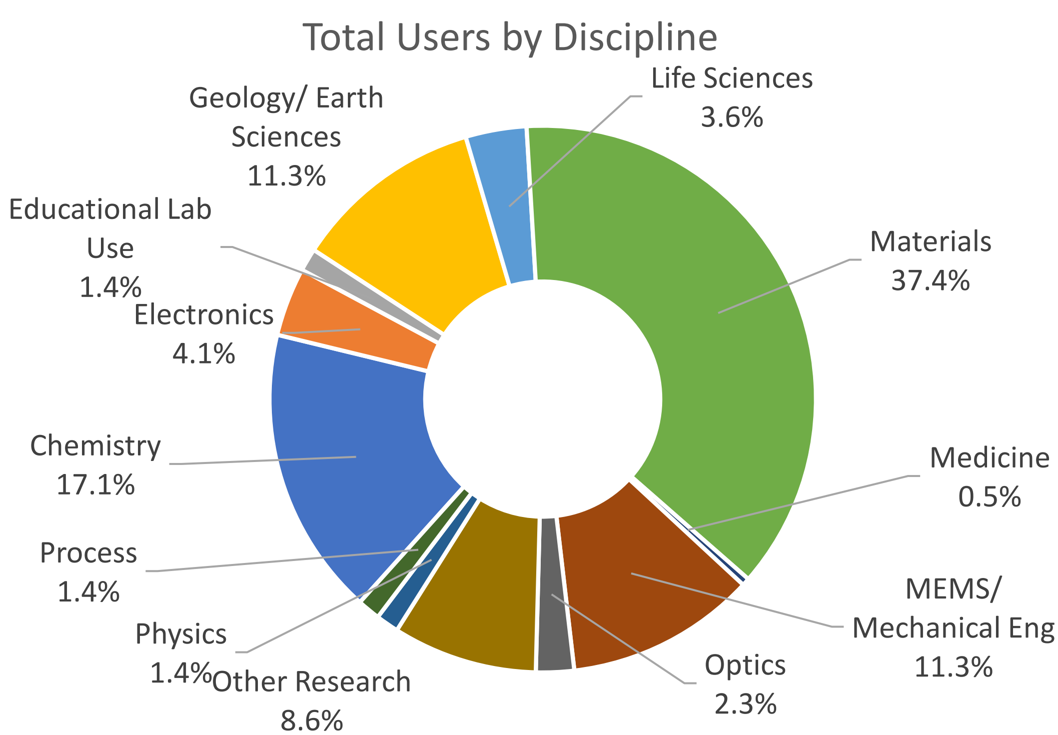
NanoEarth Site Statistics

Yearly User Data Comparison					
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Total Cumulative Users	277	307	299	288	222
Internal Cumulative Users	232	245	240	216	175
External Cumulative Users	45 (16%)	62 (20%)	59 (20%)	72 (25%)	47 (21%)
Total Hours	7,627	18,056	16,455	15,291	10,710
Internal Hours	6,196	14,277	14,073	11,622	8,174
External Hours	1,431 (19%)	3,779 (21%)	2,382 (14%)	3,669 (24%)	2,536 (24%)
Average Monthly Users	78	90	93	91	61
Average External Monthly Users	9 (12%)	14 (15%)	13 (14%)	18 (20%)	10 (16%)
New Users Trained	277	134	94	80	49
New External Users Trained	45 (16%)	27 (20%)	0 (0%)	0 (0%)	0 (0%)
Hours/User (Internal)	27	58	59	54	47
Hours/User (External)	32	61	40	51	54



NanoEarth Year 5 User Distribution





12. Program Plans for Year 6

While Year 6 marks the start of the 5-year renewal of the NNCI, many of the programs for the Coordinating Office (see Section 2 for details) will remain the same as in the first five years. The Coordinating Office will continue to: (1) promote and market the NNCI and its sites, (2) assist users in finding appropriate resources across the network and beyond, (3) coordinate site activities and share best practices across the network and beyond, (4) assist the sites wherever possible, and (5) serve as the main interface with the NSF. Thereby, the overarching goal remains to ***make the network greater than the sum of its parts*** to the benefit of our user communities.

The roles of the Coordinating Office (CO) were defined in the NSF program solicitation:

- "The Coordinating Office will be responsible for establishing a comprehensive web portal to ensure close linkage among the individual facility websites such that they present a unified face to the user community of overall capabilities, tools, and instrumentation."
- The Coordinating Office "will also work with all sites in ways to guide users regarding which site or sites, which instruments, and which processes would enable users to complete their projects most successfully."
- "The Office will help to coordinate and disseminate best practices for national-level education and outreach programs across sites, as well as the instruction and study of social and ethical implications of nanotechnology."
- The CO "will seek to harmonize capabilities for modeling and simulation in nanoscale fabrication and characterization across sites, and provide effective coordination with the NSF-supported Network for Computational Nanotechnology (NCN)."
- "The Office will work with the individual sites to establish uniform methods for assessment and quantifiable metrics of overall site performance and impact, including those for educational and outreach activities."
- The CO "will help to share best practices and laboratory safety and training procedures across all sites. It will engage all sites in a planning process to explore emerging areas of nanoscale science, engineering, and technology that can lead to future growth of the external user base."
- The CO "will coordinate the acquisition needs for specialized instrumentation across all sites to enhance new areas of research growth."
- "The Office will also coordinate data management across all sites"
- The CO will coordinate "the dissemination of shared knowledge to research, education, and technology communities"
- The CO will enhance "connections with other nationally funded academic centers or networks and facilities supported by government, the private sector, and international partners."

Starting in Year 6, the CO added a fourth Associate Director, Dr. Matt Hull from Virginia Tech, to initiate and coordinate network wide activities in the area of innovation and entrepreneurship. The other three Associate Directors of the CO will continue to coordinate activities in Education & Outreach, Societal and Ethical Implications, and Computation across the network. Besides continuing to support Subcommittees and Working Groups, as well the NNCI website and the NNCI Annual Conference, the CO will assist in establishing Research Communities, which are a new network-wide effort for Years 6-10. In prioritizing its programs in view of the limited resources, the CO considers recommendations from the NSF, the NNCI Advisory Board, the NNCI Executive Committee, as well as the NNCI Subcommittees, Working Groups and Research Communities. The CO appreciates the strong support from all sites in making the network more than the sum of its parts and counts on continued site support for Year 6.

A number of specific activities planned for Year 6 are highlighted below:

- *Associate Director for Innovation and Entrepreneurship:* In Year 6, the CO has added a new Associate Director for Innovation and Entrepreneurship (AD I&E) in response to the need for promoting and facilitating translational activities. In Year 6, the new AD I&E will survey and highlight ongoing I&E activities at the sites, start an industry speaker seminar series, and offer an entrepreneurship component to interested REU programs.
- *Associate Director for Computation:* In Year 6, a priority is to start an on-line seminar series on Computational Methods in Nanotechnology, targeted to experimentalists.
- *NNCI Website*: The CO will continue to add new and revise existing content to the nnci.net webpage. Facilities and tools will be updated based on changes accompanying the NNCI site renewals. The contact pages will be used to connect potential users with appropriate sites.
- *NNCI Annual Conference:* The 6th NNCI Annual Conference will be hosted by SHyNE and held at Northwestern University in Evanston, IL, November 1-3, 2021. The current plan is that this year's conference will be a hybrid event with in-person events for those who can travel accompanied by live streaming for those who cannot. We will adjust our plans based on how the pandemic evolves during the year and specific national and local conditions.
- *REU Convocation*: The Year 6 REU Convocation (unfortunately, last year's REU programs and the convocation were cancelled because of the pandemic) will take place in a virtual format in early August because of ongoing uncertainties associated with the pandemic.
- *Subcommittees and Working Groups*: The CO will revisit leadership and membership of the subcommittees and working groups. This also provides an opportunity to review currently covered topics, and sunset existing or start new subcommittees and/or working groups. As an example, subcommittees on Next-Generation Nano Infrastructure and Research & Funding Opportunities have been proposed. Subcommittees and working groups will be encouraged to report outcomes of their work, including recommendations and particular programs, via the NNCI webpage, at conference calls with the NNCI Executive Committee, and at the NNCI Annual Conference. Limited funds are available to support working group events, such as targeted symposia and workshops.
- *Research Communities*: Proposed in Year 5, five Research Communities will start activities in Year 6: "Transform Quantum", "Understanding the Rules of Life", "Growing Convergence Research", "Nano Earth Systems" and "Nano for IoT". These research communities are described more fully in Section 9.2.
- *Staff Exchange Program*: Originally proposed by the Global & Regional Interactions Subcommittee, the CO will revisit the idea of a staff exchange program in Year 6 after staff exchanges were not possible in Year 5 because of the pandemic. Funds to support this program have been included in the CO renewal budget.

- *NNCI Staff Awards:* The CO plans to continue the successful NNCI-wide staff awards program started in Year 3 to promote staff and recognize excellence in areas of user support, technical activity, and education and outreach.
- *Workshops*: The CO will continue incentivizing sites to collaborate via symposia and workshops. A budget has been established to financially support workshops that involve and benefit multiple NNCI sites (see also Subcommittees and Working Groups).
- *User Survey:* The CO will administer this survey again in summer 2021.
- *Data Collection and Reporting:* The CO will continue to collect statistical data on network usage and report these data to the NSF as part of the annual reporting. In Year 6, the collection of data on funding sources supporting research done at NNCI sites that was done in Year 4 for the first time on a network level will be refined and repeated. In addition, the CO will explore the collection of information on degrees awarded to NNCI users.
- *NNCI Impact:* The CO will continue to work with the Metrics and Assessment Subcommittee to define NNCI societal and economic impact metrics, collect those metrics and disseminate them as appropriate. The goal is to better showcase, using quantitative and qualitative data, the societal and economic impact of the NNCI and, thus, complement the data collected on the scientific and scholarly impact of the network.
- *NNCI National and International Connections:* As a focus effort for Years 6-10, the CO will work with NNCI sites and the Global and Regional Interactions Subcommittee to connect with other nationally-funded as well as international "nano" networks and facilities supported by government, the private sector, and international partners. The goal is to promote capabilities, improve user support, share best practices and develop strategies for future infrastructure programs.
- *Prioritization of NNCI CO Funds:* With more and more requests for financial support from the CO, the CO will review how it spends its annual budget and, together with the Executive Committee, prioritize its resources to impact the programs that help the network be more than the sum of its parts.