National Nanotechnology Coordinated Infrastructure

NNCI Coordinating Office Annual Report (Year 3)

April 1, 2018 – March 31, 2019

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NNCI Coordinating Office Annual Report 2019

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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 1st, 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.

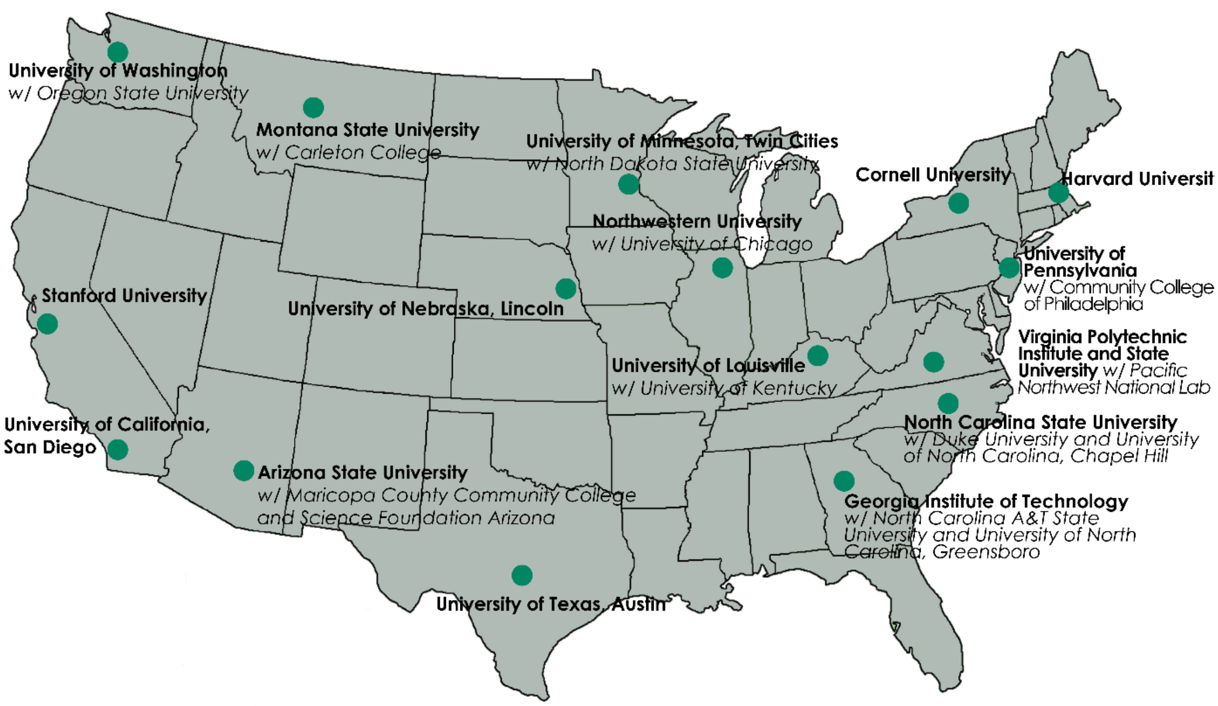


Figure 1: US Map with Locations of the 16 NNCI Sites

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 2,000 tools located in 69 distinct facilities. As will be detailed later in this report, these tools have been accessed by more than 13,000 users including nearly 3,400 external users, representing >200 academic institutions, >900 small and large companies, ~50 government and non-profit institutions, as well as 46 foreign entities. Overall, these users have amassed more than 1,000,000 tool hours, surpassing this milestone for the first time. During the third year, the network has trained more than 5,000 new users.

This report summarizes the activities and progress for Year 3 of the Georgia Tech Coordinating Office of the NNCI, from April 1, 2018 - March 31, 2019. NNCI sites are funded via separate cooperative agreements between NSF and each site, with reporting of site specific data and activities corresponding to Year 3 (October 1, 2017 – September 30, 2018).

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 (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).

Table 1: NNCI Sites, Locations and Facilities

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

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, Deputy Directors, and 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

NNCI Site Staff	
Site Directors	16
Other Site Leadership	38
New User Contacts	32
Program Managers	18
Facility Managers	59
Education/Outreach Coordinators	33
SEI Coordinators	8
Computation Coordinators	5
Safety/Facility Director/Technical Staff	30
Facility Administrative Staff	12

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, replacing Dr. Nancy Healy who held that role until June 2018. 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.

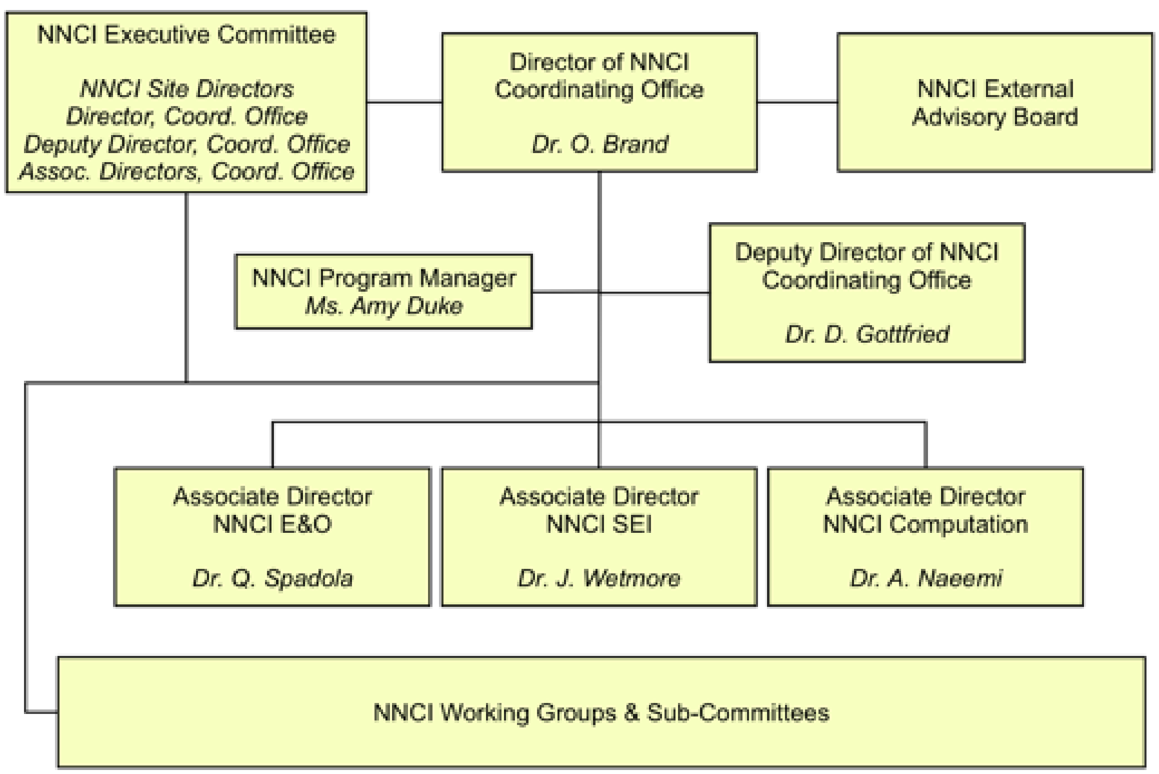


Figure 2: NNCI Coordinating Office Organizational Chart

The Coordinating Office staff is guided by an **Executive Committee** which includes the 16 NNCI site directors. The Executive Committee meet 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.

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). Finally, 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, research areas, and education and outreach (see Section 6).

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 listserve
- 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
- 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.

To learn more about the NNCI sites and their partners, the Coordinating Office started visiting the individual NNCI sites in 2016, with initial priority given to NNCI sites that were not part of the NNIN network. The goal of these visits was to get to know site staff, learn about the facilities and programs, share success stories, and discuss challenges. All site visits were completed in 2018 within approximately two years after formation of the Coordinating Office.

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. During year 2, one of the board members was unable to continue and was replaced by another with similar expertise, while another resigned due to time commitments. Table 3 shows the Advisory Board members and their affiliations as of January 2019.

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
Dr. Andreas Roelofs	Director, Center for Integrated Nanotechnologies Los Alamos National Laboratory
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 (Sept. 2018) is provided in Appendix 13.1.

4. Associate Director Reports

4.1. Education and Outreach

The mission of 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 the 3rd year, E&O coordinators reached more than 46,500 people (13 of 16 sites reporting). Across the network there are education and outreach efforts for students (K-12, community/technical colleges, undergraduate, graduate), educators (K-12 teachers, cc/tc faculty), the general public, and professionals. Activities for the general public that are not included in the number stated earlier include NanoEarth's collaboration with the *Pulse of the Planet* radio show (listenership of 220,000), SHyNE's NUCAPT's atom-probe field-ion microscope display at O'Hare airport, NNF's traveling nano museum exhibit (51,000 visitors), and CNF's *Nanooze* magazine and Epcot exhibit. The biennial *USA Science and Engineering Festival* also took place in 2017. Multiple sites participated at the NNCI booth and an estimated 5,000 people visited it during the event. In celebration of National Nanotechnology Day, sites hosted a number of events including tours, activities at schools, partnering with local science centers for celebrations, posting social media content, and organizing 100 billion nanometer dashes. Many also participated in the *Nanotechnology Applications and Career Knowledge (NACK) Network's Remotely Accessible Instruments for Nanotechnology (RAIN)* program, operating remote access sessions across the NNCI network.

To facilitate the sharing of information across the network, starting in August 2018 coordinators have begun participating in monthly calls. 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. This is also an opportunity for coordinators to connect over common interests and plan follow-up conversations. Additionally, the group has started a Slack workspace to further encourage collaboration and discussion. The page also has channels dedicated to each of the educational working groups. This allows people to easily post information and receive feedback from the entire community.

Across the network, E&O coordinators make an effort to reach groups historically underrepresented in STEM fields. Coordinators attend 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* to promote REU opportunities to students from URM serving institutions. 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 teachers, and provide information on teacher workshops and student programs. Effort is especially made to reach teachers and students from Title 1 schools (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.

Many sites participate in summer camps, high school student internship programs, after school programs, career fairs, and both off-site and on-site visits with school children. These activities help to introduce nanotechnology to children and show them that it is enabling consumer goods they use every day. Another important aspect of working with school children is ensuring they hear that there are opportunities to learn and contribute to nanotechnology work across both the educational spectrum and in whatever STEM discipline interests them. One example of a program in the network is Nebraska Nanoscale Facility's *Nanoscience After School Program* at a local middle school. The program served 20-25 middle school students at each of 9 sessions. Students learned about nanotechnology, nanomaterials, self-assembly, hydrophobic materials, and other STEM related topics. Not only did faculty from the University of Nebraska-Lincoln participate, but middle school students also had the benefit of learning from and interacting with undergraduates. The impact of the program was assessed and survey results show that all the students felt like they learned a lot through the experience. Additionally, 80% of the students answered "Do you plan to be a scientist or engineer in the future?" in the affirmative.

In order to help educators with integrating nanotechnology into their curriculum, many of the sites provide resources to K-12 teachers. These efforts include creating content, RET programs, hosting Educators in Residence, workshops, and attending teacher conferences to promote all the materials. Nano@stanford offers the *Nanoscience Summer Institute for Middle School Teachers*. Fifteen teachers from the area attended for 4 days to learn about nanotechnology and methods to teach it. Before the workshop the teachers were asked to rate their agreement with the statement, "I am comfortable in my understanding of nanoscience." Twenty percent were neutral, 25% somewhat disagreed, and 55% strongly disagreed with the statement. Following the workshop, 90% of the teachers somewhat agreed with the statement with 5% in strong agreement and 5% remaining neutral. In addition to the survey, the teachers created concept maps of nanotechnology both pre and post the workshop and their overall score doubled after the 4 days. There are currently plans underway for SENIC to use the workshop curriculum developed by nano@stanford (with changes to meet Georgia state standards) for a teacher workshop in summer 2019, with Angela Hwang from nano@stanford assisting for the first year.

All of the sites provide technical workshops, short courses, seminars, webinars, and/or symposia for undergraduates, graduates, post-docs, and other professionals. For example, KY MMNIN hosted the *Nanotechnology and Additive Manufacturing Symposium* in August. NanoEarth has the *Nanotechnology Entrepreneurship Challenge* which encourages students to solve sustainability problems with nanotechnology. All of the students that have participated in the undergraduate internship program from TNF have either entered the Master's program or found work in industry.

A joint site workshop between NanoEarth and MONT has led to a review/perspective paper on "nano-geo-enviro" convergent science and engineering.

Thirteen of the NNCI sites have REU programs. Each sites' REU information is listed on the NNCI website. Students who participate in NNCI REUs have the added bonus of being able to attend convocation. Ten sites were able to send students to the 2018 NNCI convocation which took place at RTNN. Forty-five REU and 6 international REU (iREU) students presented on their research and networked. As a continuation from the NNIN program, the coordinating office surveyed the students. Faculty and mentors are also surveyed in order to help with the selection process for CNF's iREU in Japan program. With all students responding to the survey, when asked to rate the overall quality of their individual REU programs, the student average was 4.5 out of 5. Additionally, the programs have made an impact on the students' "future educational and/or career choices" with an average score of 4.4. Comments from students include, "*I loved the research I was engaged with at Northwestern. I learned how to operate amazing instruments, and am looking forward to potentially going to graduate school in the same field.*" and "*I really enjoyed learning about a field that I did not have much knowledge in. This experience encouraged me to explore new fields and increased my confidence in my ability to navigate research and graduate school.*" Students gave the overall convocation experience a 3.9 out of 5, an "excellent" experience. Both as a technical as well as a networking experience, the student average was 3.8. One student shared, "*Overall, it was awesome! I got so much information about research and graduate school. I give this a 10/10 to anyone looking to do an internship in nanotechnology.*"

There is strong interest at many sites to serve community and technical colleges in their areas. Activities across the network include internship and REU opportunities, assistance with course development and access to facilities, remote access, tours, and workshops for educators. The report of the *Workforce Development* working group (Section 6.10), led by Dr. Ray Tsui from NCI-SW, includes information on industry surveys, site workshops to increase knowledge about nanotechnology and workforce needs for community and technical college instructors, working with industry groups, and summaries of activities at many of the NNCI sites.

The *K-12 Teachers/RET, Students, and Community Outreach* working group, led by Dr. James Marti from MINIC, has been engaged in determining the most effective way to disseminate resources for educators. Their report (Section 6.9) discusses possible requirements for materials that would be added to the NNCI Learn webpage and information on the multi-site RET proposal. Education and Outreach coordinators have discussed pointing educators to the NNCI Learn webpage, once the searchable database of educational materials is added to it, and then monitoring visits to the page as one metric to determine the impact of the network.

A major theme over the last year was how best to evaluate and show the impact of the sites' education efforts. In order to better understand the landscape across the network, sites have decided to add the same questions to surveys for various audiences. The report of the *Evaluation and*

Assessment working group (Section 6.11), led by Drs. Nancy Healy and Quinn Spadola from SENIC, includes information on the questions as well as on the evaluation workshop that took place during the 2018 NNCI annual meeting, and the efforts to share survey instruments across the network.

The *Technical Content Development* working group, co-led by Drs. Angela Hwang from nano@stanford and Maude Cuchiara from RTNN, is developing methods to educate users and assessing the results. Their report (Section 6.12) outlines the online courses being offered at RTNN and nano@stanford and information on who is taking advantage of these resources. Additionally, MANTH has developed a survey for non-traditional users in order to understand the most efficient way to deliver cleanroom training.

4.2. Societal and Ethical Implications

Nanotechnology holds great promise, but the NNCI CO 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 Coordinating Office is working to help all of the NNCI sites develop Societal and Ethical Implication (SEI) research and engagement programs. Associate Director Jameson Wetmore (also part of the NCI-SW site) is leading these activities.

In the initial year of the NNCI, 7 of the 16 NNCI sites had efforts in SEI. During this reporting period we have increased that number to 9 sites actively working in the SEI area. In addition to Jameson Wetmore and Ira Bennett at Arizona State, Lee Ann Kahlor has coordinated the efforts at the Texas Nanofabrication Facility. Jan Youtie heads up the work at SENIC at Georgia Tech. Daniel Ratner is leading the University of Washington effort. David Berube is coordinating the work in the Research Triangle Nanotechnology Network. Jim Marti is leading SEI at the University of Minnesota. Chad Goeser and Amy Morgan are coordinating SEI at Northwestern. David Mogk is doing SEI at the Montana Nanotechnology Facility. And Matthew Hull is leading the effort at Virginia Tech.

The work being done at these different sites spans a variety of activities. For instance, Lee Ann Kahlor has continued to work on the SEI training video that she has been developing and it is now shown to all users at the Texas facility. David Berube continues to assess the wide variety of programs developed in the Research Triangle Nanotechnology Network. And David Mogk is making a series of materials available online for those who want to teach ethics and nanotechnology in their own institutions.

The NNCI CO is working to foster the development and improve the quality of SEI programs across the NNCI. This year we have noticed a fair amount of confusion amongst reviewers during the NSF reverse site reviews about what SEI is and what its goals are. To address this, SEI leaders from across the NNCI worked together to develop a clearer explanation of our goals and methods. It reads as follows:

The NNCI works to better understand the social and ethical implications of nanotechnology research, development, and implementation. In these efforts we do work in both micro- and macro-ethics, with an emphasis in the latter since few science or engineering programs address those important issues. We look at both the social impacts of nanotechnology and the social aspects of nanotechnology. We address the variety of societal implications associated with nanotechnology, including social change, equity issues, economics and policy. And while we do include "environmental issues" on this list, because others spend tens of millions of dollars to study the impact of nanotechnology on the environment, they are not our primary focus. We envision numerous audiences of our work – including NNCI users, NNCI practitioners, policymakers, journalists, and the general public. And ideally we envision these groups as not simply consumers of our work, but as partners in developing that work. We want two-way discussions, not one-way communication, in an effort to advance toward the daunting goal (as outlined in the 21st Century Nanotechnology R&D act) of: "integrating research on societal, ethical, and environmental concerns with nanotechnology research and development, and ensuring that advances in nanotechnology bring about improvements in quality of life for all Americans."

The NNCI CO helps to host two major SEI training efforts every year. The first, a policy workshop in Washington, DC for graduate student scientists and engineers, is co-sponsored and largely funded through the Nanotechnology Collaborative Infrastructure Southwest (NCI-SW). In June 2018, 14 students from the NNCI met with over 25 policymakers, funders, regulators, lobbyists, and lawyers in the third Nano *Science Outside the Lab* (SOtL). This year we received more applications than any previous *Science Outside the Lab* program. We hosted students from 9 NNCI universities including four from Stanford, three from the University of Washington, two from Harvard, and one each from NC State, Duke, UNC Greensboro, Northwestern, Nebraska, and ASU. This year the students met with program managers at the NSF, researchers and regulators at the EPA, the US Chamber of Commerce, and the staff of Sen. Bernie Sanders.

Cathy Zhang, an Applied Physics PhD Candidate at Harvard, summed up her experiences in the following e-mail:

"I thoroughly enjoyed my week in the SOTL program, an eye-opening experience into how different policymakers and stakeholders interface and engage with science. Over the course of a week, our group spoke to people from all three branches of government and various lobbyists and funding agencies. It was absolutely amazing to experience this in DC where each conversation had a distinct backdrop -- the Supreme Court, the EPA, the Senate office. I walked in hoping to learn more about how the government uses scientific information to make funding decisions, but the program ultimately prompted me to reflect more deeply on the responsibilities that scientists have in both designing socially conscious research and sharing it in a way that avoids misconceptions."

This year's SOtL program will be held June 2-8, 2019. Again we will recruit graduate students from across the NNCI.

The NNCI CO also sponsored its second annual "Winter School on Responsible Innovation and Social Studies of Emerging Technologies" on January 3-10, 2018. The goal of this program is to train the next generation of SEI scholars. The Winter School brought together sixteen early career social science researchers for a week of learning a variety of research tools from around a dozen social scientists and other scholars. The first four iterations of the Winter School were sponsored by the Center for Nanotechnology in Society-ASU. During that time the program built up a respected reputation amongst SEI scholars around the world and a healthy alumni network. The NNCI is building upon this success and continuing the tradition. This year we were able to recruit NNCI students from Virginia Tech, Cornell University, NC State, and ASU. To broaden the perspectives on hand we also included students from Spain, Canada, China, and the Netherlands. The student and young faculty participants unanimously agreed that it was an important opportunity to reflect on and build their career.

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. 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 at various sites. In the past, these hardware resources served internal users only with the exception of the UT-Austin (TNF) computing cluster which can be accessed by external users with a nominal fee. This year, the *CNF Nanolab Computing Cluster* has become available to all users. The Nanolab cluster provides users the opportunity to use a wide range of modeling software 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. Slurm is the batch job queuing system. The staff would install new scientific codes on the cluster upon user request. More info can be found at http://computing.cnf.cornell.edu/Cluster.

On the modeling and simulation side, researchers at the University of Minnesota (MINIC) led by Professor Tony Low have developed *2D Material Properties*, a comprehensive database of electronic and optical properties of 2D materials and their heterostructures. Two dimensional materials and their heterostructures are promising materials for a host of novel devices and are subject of intense research globally. There are hundreds of different 2D materials and their mutations which lead to numerous heterostructures. Theoretical explorations of these materials therefore can be key in research and development of novel 2D materials and devices. Using first principle pseudopotential calculations based on the spin-polarized DFT within the generalized gradient approximation including van der Waals corrections and spin-orbit coupling, a comprehensive study of the band alignments of two-dimensional (2D) semiconducting materials are conducted to identify the possibilities of forming momentum-matched heterostructures. The database provides a periodic table for 2D heterostructures and includes tables summarizing various parameters obtained either theoretically or via experimental measurements. The database can be accessed via http://apps.minic.umn.edu/2D/.

Cu in CdTe Lab, published by Arizona State University (NCI-SW), is a 2D diffusion-reaction simulator of Cu migration in polycrystaline CdTe solar cells with Grain Boundaries, and currently has more than 58 users residing in North America, Asia, Europe, and Africa. More information can be found at https://nanohub.org/resources/predicts2d.

The NNCI Coordinating Office has started negotiating with major software tool vendors regarding discounted academic licenses for NNCI sites and waived tuition fees for NNCI academic users attending hands-on training workshops. Another major activity is to explore the utility of various software packages for wider adoption within NNCI. This is done by talking with vendors, surveying current academic users, and experimenting.

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. At the beginning of 2019 some of the chairs were changed and memberships were expanded, and this will be reflected in the reports in 2020. 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	Mike Hochella (NanoEarth)
Metrics and Assessment	Stephen Campbell (MINIC)
Global and Regional Interactions	Vinayak Dravid (SHyNE)
New Equipment and Research Opportunities	Kevin Walsh (MMNIN)
Entrepreneurship and Commercialization	Mark Allen (MANTH)
Building the User Base	Nan Jokerst (RTNN)

5.1. Diversity Subcommittee

Year three was a "watershed year" for this subcommittee. With discussions via e-mail, telephone, and at annual meetings, we came up with guiding principles which seem to be somewhat universal to NNCI and highly useful (see bullets to the two key questions below). We talked about these on the NNCI conference call that highlighted diversity efforts, and we have talked about these at annual meetings. The bottom line is that we have found that the NNCI network, overall, takes diversity issues very seriously, and that, in fact, such things are not an afterthought. In other words, most sites are not "forced" to execute diversity strategies, but they do because they see both intrinsic and extrinsic value in it.

First, in the last year, we were able to settle on a specific "statement of diversity" by which we have all agreed to abide. Some sites even put this credo on their home pages, e.g. SENIC and NanoEarth. This powerful statement, in its entirety, is included below. Second, as a network we seem to have settled on effective responses to two vital questions, as follows:

(1) How can NNCI increase the diversity of users and participants in education and SEI activities?

- Reduce barriers to entry for users classified as adding to diversity
- Offer cost assistance
- Offer internships
- Provide a Spanish homepage button to click
- Advertise on our homepages with videos
- Work with local college diversity offices

(2) What forms of marketing and recruitment can we use to reach a diverse user population?

- Utilize personal visits to schools that provide diverse users (e.g. HBCUs)
- Host targeted workshops
- Utilize societies that serve underrepresented demographic groups

It is not that all nodes need to satisfy or pursue each of these approaches above. A diversity-successful node may only relate to and work with one or two of these, or none of them if they can be enriched in terms of diversity by a similar idea that best fits their demographic/location.

The net result is that diversity subcommittee chair Michael Hochella asked each node to submit a snapshot of their diversity effort from the last year. There is nothing like seeing actual examples to exhibit the seriousness through which we view our diversity ideals, and to have one of those "feel good" moments of remarkable, heartfelt accomplishment. See below for impressive examples of what we feel are exceptional diversity activities.

For next year, there are at least two important forward-looking needs and ideas concerning diversity in the NNCI network. First, just as we have been sharing certain technical resources, activities, and ideas across the network, we have to learn how to do the same thing with diversity initiative activities. Second, we need to start pushing for and collecting press coverage of our diversity activities. This helps a great deal by exposing the general public to the idea that there is no level of science or technology where diversity issues can't be incredibly important.

There was one final issue this past year. Subcommittee chair Michael Hochella is formally retiring from Virginia Tech on February 1, 2019. He will still have a position at Pacific Northwest National Laboratory, and he will apply for University Distinguished Professor Emeritus status at Virginia Tech, which should be granted in the spring. Although not Director of NanoEarth anymore (Prof. Mitsu Murayama will take over that role), he will still play the important role of advisor to NanoEarth, and still be the Director of User Recruitment for NanoEarth. Jacob Jones (RTNN) has agreed to accept the role of chair of the Diversity Subcommittee.

NNCI statement of diversity and inclusivity, in the arenas of both node staff and node users:

> The NNCI embraces diversity and welcomes, recruits, educates, employs, serves, and engages a diverse group of users, students, faculty, and staff with a wide variety of backgrounds, perspectives, interests, and talents, creating a community of teachers, learners, and researchers that exemplifies the best in all of us – in our intellectual pursuits, our diversity of thought, our personal integrity, and our commitment to excellence.

We believe that diversity includes the individual differences among people, including:

- Gender
- Social, racial, or ethnic backgrounds
- Disabilities or handicaps
- Socioeconomic class
- Gender identity or expression
- Sexual orientations
- Appearance or personal characteristics
- Political affiliation and opinion
- Language
- Religion or beliefs
- Economic circumstances
- Philosophical outlooks
- Veteran status
- Life experiences

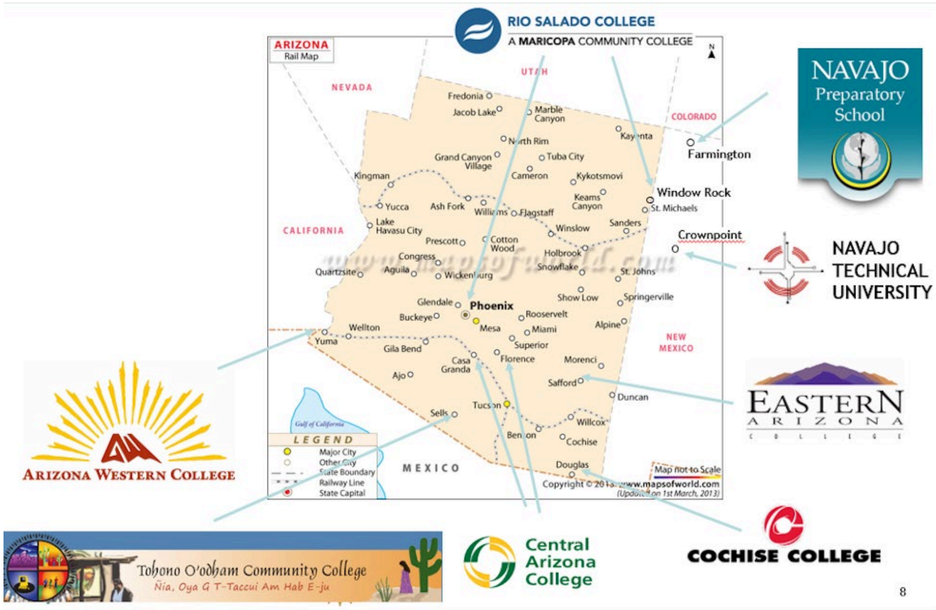
All of these characteristics, both singularly and in combination, contribute to the richness of the NNCI community.

The 10 examples below are extraordinary, highly innovative highlights concerning or demonstrating diversity within NNCI.

Note: These examples below are representative of the whole of the NNCI. Examples are given by the name of the host university, in alphabetical order.

(1) Arizona State University

One of the things that NCI-SW does with their REU program is to identify participants from rural community colleges with high minority student enrollments. These students have very different backgrounds to the usual REU participants in the NNIN and NNCI that would typically all come from prestigious schools in the US. The students from well-known schools may be better prepared, but chances are they will be successful with or without the REU experience. In contrast, for the students from rural community colleges the REU can be a life-changing event. NCI-SW has seen this year after year, when students who have never been out of the state before come to them with questions such as how do they get their luggage on the plane. For these students the thought of flying to Atlanta or Ithaca, for example, to attend convocation is overwhelming and at the same time exhilarating. The REU program opens doors for these students in a way that would be almost impossible without the NSF NNCI funding.



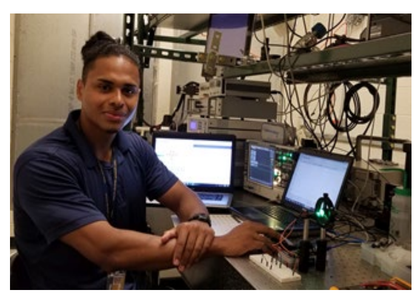
Some of the rural community colleges that NCI-SW has worked with over the years.

(2) Cornell University

Since 1989, the Nellie Whetten Award is given to outstanding young women whose research was conducted in CNF, and whose lives exemplify Nellie's commitment to scientific excellence, interdisciplinary collaboration, professional and personal courtesy and exuberance for life. With the award given this year, for the first time the winner was invited to speak at CNF's annual meeting. It was decided that these exceptional women should begin to serve as role models for successful women in science and engineering.

(3) Georgia Tech

REU Program: SENIC's Education and Outreach programs at Georgia Tech are particularly focused on reaching underrepresented minorities (URM). Their recently-funded *NSF Research Experience for Undergraduates* program had its first cohort of interns during summer 2018. The focus of the program is to reach students from southeastern institutions who have little to no research experience as well as URMs. The interns for 2018 were 27% female, 46% URM, and 91% had no prior formal research experience. One of our 2018 interns, Biya Haile (left), is an Ethiopian immigrant who transferred to Georgia Tech after the REU program. Biya is a mechanical engineering major and continues his research in the lab of Dr. Oliver Brand and the IEN cleanroom. Ronald Reliford (right) from Northwestern State University of Louisiana is spending the fall semester as an intern at NIST. Ronald credits his summer REU experience with his successful application to the NIST program.



High School Students: Georgia Tech collaborates with Atlanta Public Schools' (APS) Gifted and Talented program by placing high school interns in faculty labs with graduate student mentors to undertake research. APS is a minority serving district (82% black, 11% white, 3% Hispanic). In 2018 they hosted four African-American students (three males and one female). These students presented their research experience during a Capstone Event in early April to members of the Capstone committee, fellow classmates of the Gifted and Talented program, and mentors and staff of IEN. Leslie O'Neill, who manages this program for SENIC, co-presented this program in a session at the College Board Conference "A Dream Deferred" in mid-March to 40 attendees who were interested in starting similar programs at their institutions.

In September of this year, Georgia Tech also hosted 90 high school students in the APS Pipeline Program. The students came to Georgia Tech's campus for the day and engaged in seminars about nanotechnology, SAT/ACT test prep, resume writing, and getting ready for college.

(4) Montana State University

MONT investigator Dr. Connie Chang with graduates Shawna Pratt and Esther Oloff.

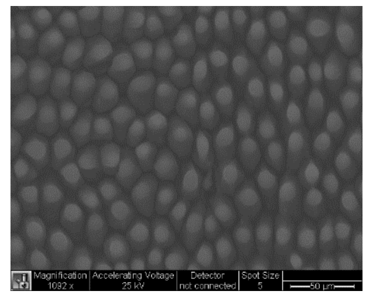
Montana State University and MONT are committed to increasing the representation of women in engineering. A major component of that strategy is hiring women into faculty positions and other positions of leadership within the College. Furthermore, MONT has historically hired student staff with approximately 50% gender balance. This year they celebrated the accomplishments of four of their female PIs who are finding success as engineering researchers, mentors and role models for our women students. **Prof. Connie Chang** (Chemical and Biological Engineering) leads a group working on drop-based microfluidics. She received an NSF Career Award (Grant# 1753352) in 2018 applying colloidal engineering to study biofilms. **Prof. Anja Kunze** (Electrical and Computer Engineering) leads a group studying neuronal development in engineered micro-environments, and **Prof. Stephanie McCalla** leads a group using microfluidics to study RNA, DNA and protein separation, detection, and quantification, and mass transport in living systems. Both Prof. Kunze and Prof. McCalla have been recommended for funding for NSF Career Awards that will start in 2019. And, **Dr. Sarah Lukes**, who is developing new active optical devices, began work on an NSF SBIR Phase II project, "Fast Focus and Zoom in Microscopy" (NSF Grant# 1819493). Dr. Lukes' company Agile Focus Designs has more than 50% female employees. Success at Montana State University in recruiting, supporting and graduating women in STEM was recently celebrated with a recruiting video archived on YouTube (https://youtu.be/unjkT_593b0). Prof. Chang features in that short film. MONT continues to promote diversity in all of its forms as they work to make our nanotechnology facilities accessible and welcoming to all.


Student Cara Robertus with MONT investigator Dr. Stephanie McCalla.

Women in STEM at MSU.

(5) North Carolina State/Duke University/University of North Carolina

The RTNN actively builds the user base and reaches out to include diverse students and researchers in this growth process. We are currently cultivating relationships with youth organizations in our state to help expand our reach to K-12 students outside the Research Triangle and into rural areas. In May 2018, the RTNN, in partnership with the Triangle Women in STEM, Duke's Pratt School of Engineering and Trinity College of Arts and Sciences, Credit Suisse, and IBM, hosted over 100 North Carolina girls as well as Girl Scouts and their families at Girls STEM Day @ Duke. These young women were able to get significant hands-on time in the facilities, including a scanning electron microscope (SEM) and earn badges in forensics, digital photography, and robotics for their work.



RTNN staff also traveled to Fayetteville, North Carolina to engage with science classes at John Griffin Middle School in March 2018. Fayetteville is home to Fort Bragg, one of the largest army bases in the United States. Greater than 60% of students enrolled at John Griffin are underrepresented minorities in STEM, and the majority of students have at least one parent actively serving in the military. Over three days, more than 600 6-8th grade science students as well as 10 special needs students learned more about nanotechnology and had the opportunity to use both a light microscope and a desktop SEM.

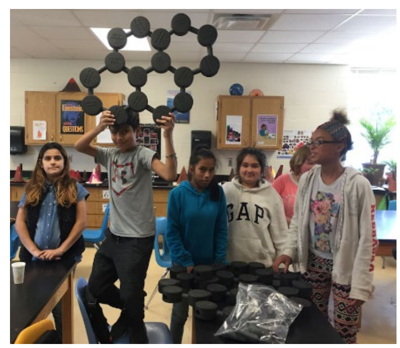
(6) Virginia Tech

NanoEarth, each year attracts underrepresented and non-traditional users through their MUNI (Multicultural and Underrepresented Nanoscience Initiative) program. MUNI provides full financial support for underrepresented individuals and groups to visit our facilities for both research and educational purposes. In MUNI's third year, NanoEarth organized and paid for the research and/or educational visits for 58 underrepresented individuals from 21 different institutions all over the country, from community colleges through R1 universities.

(7) University of Minnesota

One area in which MINIC has increased lab user diversity is through their laboratory internship program, which is run at MINIC's Nano Center located at the University of Minnesota. The internship is intended to provide an advanced lab experience in nanoscience and applied nanotechnology for external students of the physical and life sciences. They have targeted program recruiting to qualified students enrolled in local community or technical colleges, allowing them to offer the opportunity to a larger pool of women and students of color. The three laboratory internship winners in Spring 2018 were recruited from Saint Paul Community and Technical College, a local two-year institution.

(8) University of Nebraska



The Nebraska Nanoscale Facility (NNF) led an after-school diversity program initiative this past year (2018). This program targeted middle school student populations in four Title 1 schools and included Harry Potter themed nanoscience hands-on activities and STEM/NANO kit experiences. Many undergraduate student assistants working with the program were also from a variety of ethnicities and the initiative supported their communication and teaching skill development. The photo shows students with an assembled structural model of graphene.

(9) University of Texas, Austin

TNF at the University of Texas at Austin has been targeting under-represented minorities (URM) and women in the REU program. For example, in 2017 they selected two URMs and one woman out of the five positions available. In 2018, four out of the five REUs were women, as listed below, along with their affiliations.

- Ms. Ashlee Heuston – Univ. of California, Berkeley
- Ms. Rachel White - North Carolina State University
- Ms. Morgan Bergthold - Davidson College
- Ms. Emily Deville - Baylor University

Their NNCI-funded technical staff is well represented by women and URMs. For instance, two out of three technicians in their cleanroom funded by NNCI are URMs. They are:

- Ricardo Garcia (Hispanic)
- Johnny Johnson (Black)

In addition, our NNCI-funded Accounts person, Gerlinde Sehne, is female.

Among the leadership of the NNCI TNF Staff:

- Dr. Sarmita Majumder, TNF NNCI Coordinator (female)
- Dr. Priymavada Jadaun, Education and REU Coordinator (female)
- Prof. Lee Ann Kahlor, TNF Co-PI and SEI Director (female)

(10) University of Washington

This past year NNI has expanded on campus experiences for first nation engagement, hosting 33 Native American students in 4 workshops as part of Native American Student Day on March 29, 2018. On April 20, 2018, NNI hosted 11 8th & 9th grade students from the Paschal Sherman Indian School for a variety of events on campus, including a hands-on unit on nanotech and clean energy and a hands-on tour of the Molecular Analysis Facility, including a demo of the SEM. Over the past year we have focused our recruitment efforts on local tribal nations to identify candidates for our cleanroom internship program. NNI successfully recruited and employed two students from the Puyallup Indian Tribal school who joined the NNI Summer internship program. We are proud to report that one of these students subsequently joined the University of Washington and is now in his second year. The student, Mr. Cian Fox, continues to work as a paid intern for the WNF and has joined as NNI's part-time program coordinator for First Nation Engagement.

Members: Mike Hochella (Virginia Tech, Chair), Jacob Jones (NC State, Co-Chair), Chris Ober (Cornell), Jim Pfaendtner (Univ. of Washington), Beth Pruitt (Stanford), and Bob Westervelt (Harvard).

5.2. Metrics and Assessment Subcommittee

The Metrics Subcommittee was charged with addressing three questions:

- What is the definition of "user" and what constitutes measured usage of a site?
- What are the best quantifiable metrics for measuring site performance, based on categories of site usage, site productivity and impact, education/outreach/SEI, and network contributions?
- What assessment methods can be used to indicate the combined impact of the NNCI network as "greater than the sum of its parts"?

During year two of NNCI, the committee discussed the site performance metrics and found them to be adequate. A possible deficiency was identified for metrics to evaluate the performance of nodes working together to provide services to users and other nano researchers. This type of metric directly evaluates activities that impact the third charge area. In year three, after discussion with site directors and the coordinating office, it was felt that the network should highlight the nodes that organize and participate in such activities in the annual report (see Section 9.1) and at the annual meeting, but that a new metric was not warranted.

During year three of NNCI, the committee began discussing three new topics. The first was improving node compliance with NNCI's publication reporting. It was noted that some nodes have much better compliance than other nodes. The committee contacted the nodes with a high degree of compliance (Cornell, RTNN, and Northwestern) and solicited their best practices. The answers were condensed into a one-page guide (see below) that was distributed to all NNCI nodes. We expect that this will help improve the network's performance in this important metric.

The committee has also discussed the development of a unified reporting system for user's funding source information. The committee distilled the pilot studies conducted by Cornell and Georgia Tech and studied how each of these would be applied at the committee's home institutions (Minnesota, Texas, Virginia Tech, and Nebraska) to determine the level of difficulty associated with each of the metrics. Getting the needed information for some questions was quite straightforward, but for others it proved highly problematic. The anticipated low response rate from the latter would distort their impact at NSF. This data has now been tabulated. We expect to discuss the results and make a final recommendation in January 2019, providing sufficient time for the metrics to be incorporated in the year four site reports.

Finally, the committee has begun discussing how to better measure the overall impact of NNCI, a topic raised by the External Advisory Board (EAB) at the annual conference in September 2018. While the current publications metric captures academic impact, it does not measure economic or commercial impact. The EAB suggested that this new metric would ideally measure the impact of NNCI on start-ups, spin-offs, and large companies, by both geography and technology area. Such discussion must involve participation of the Entrepreneurship and Commercialization subcommittee. We expect this discussion to take up most of the remainder of the current NNCI year's activity for the Metrics Subcommittee.

Publication Acknowledgement Compliance Best Practices

As reported by the Coordinating Office in the summer of 2018, the rate of compliance for acknowledging NNCI support in publications varies widely from site to site. Naturally, the outcome depends on how the search is done, so it is important that we design the acknowledgement to be detected in any reasonable search. The metrics subcommittee discussed how best to assist the nodes in improving their performance. It was decided to put together a best practices list to provide suggestions for nodes. To gain additional perspectives, the directors of the nodes with the highest success rates were contacted and asked for their process. While it varies from site to site, the following are common steps that have been mentioned.

- Placing the desired wording on the web site. Suggested wording has been provided by the Coordinating Office. Note that the wording should include the term NNCI and the grant number, and the language must be easy to cut and paste from the website. Example wording: *This work was performed in part at the [Site Name], a member of the National Nanotechnology Coordinated Infrastructure (NNCI), which is supported by the National Science Foundation (ECCS-Grant #).*
- Place reminders where the users will see them frequently. Some put signs up on the doors to the facility or inside the facility. Others used a reminder as a screensaver on lab computers, and reminders in the newsletter. Basically you can't have too many reminders.
- One facility gives out "best paper" awards each year with cash prizes, but require nominations to have included the acknowledgement statement.
- The acknowledgement statement can be included in the documentation necessary to start work in the facility. New users and perhaps the advisor may have to sign off on receiving this notification and agreeing to provide the acknowledgement.

- Messages should be sent out periodically. Best practice seems to range from quarterly to annually. In this message faculty are reminded of the need for the acknowledgement and why retaining NNCI support is so important. One successful facility said that they actually check the papers that are reported so see if they are in compliance. If not, the faculty member gets a special reminder.
- This reinforces the idea of what one facility called "creating and maintaining a culture of compliance". The faculty and users need frequent reminders of the benefits of NNCI. This can be done through our promotional materials, events, short courses, faculty meetings, university events, etc. The more that the users appreciate the facility and the support that it receives from NNCI, the more likely they will include the correct acknowledgement statement.

Everyone agreed that achieving a high level of compliance is a difficult and time consuming task. It is also viewed as a high priority task to ensure continued NNCI support.

Metrics Committee: Steve Campbell (Minnesota, Chair), Sanjay Banerjee (Texas), Mike Hochella (Virginia Tech), David Sellmyer (Nebraska), David Gottfried (Georgia Tech/CO)

5.3. Global and Regional Interactions Subcommittee

Preamble: There are complementary nanoscience/nanotechnology initiatives within the US from other Federal agencies (and foundations) that are in the works for more than a decade. These include, for example, DOE Nanoscale Science Research Centers (NSRCs) at five geographically distributed locations, among other nano-x institutes and initiatives. Several of these nano-initiatives are approaching a sense of maturity while some others are perhaps in soul-search mode as the nanoscale science and technology further diversifies and grows.

Looking outwards, with increasing physical and virtual connectivity across the world, nanoscience and nanotechnology continues to be a global enterprise. The broad societal challenges facing humanity encompassing energy, environment, water, food and health (to name the major ones) are not only global challenges but that they have a strong nanoscience/nanotechnology component, and would benefit immensely from a coordinated and collaborative effort across the globe.

Activities and Plans: The Global and Regional Interactions (GRI) subcommittee was formulated with the underpinning that NNCI should coordinate to leverage (and vice versa) other local, regional and global nano-initiatives, share good practices and feed off each other to enhance overall impact of nanoscience and nanotechnology. In the third year of the NNCI program, the GRI subcommittee held several meetings to discuss both existing activities at NNCI sites as well as potential future endeavors for NNCI in the context of regional, national and international activities. In Year 2, the GRI Subcommittee surveyed the NNCI sites and found a large array of existing programs connecting sites with a range of external organizations including both local and regional institutions as well as national and global interactions. During Year 3, the GRI subcommittee focused primarily on two key initiatives: the development of a proposal for a staff exchange program and the development of plans for network-to-network interactions.

There is a huge opportunity to leverage the extensive expertise housed within the sixteen NNCI sites to provide in-depth training for NNCI staff and beyond. This expertise spans a wide range of topics including specific fabrication or characterization equipment, nanoscience focus areas (e.g. photonics, sensing, etc.), education and outreach strategies and facility management and operations. Currently, most sites offer short courses and workshops at their sites in some of these areas for local user participation. This program seeks to establish a clearinghouse for such activities, make them available for staff across the network and provide a cost-sharing mechanism for travel support. As a secondary goal, such a clearinghouse can serve as a single access point for non-NNCI participation in these educational opportunities. The GRI subcommittee has submitted this proposal to the NNCI Coordinating Office and will work to implement in Year 4.

In Year 3, the CNF site submitted a Dear Colleague Letter to NSF on behalf of NNCI related to the establishment of a program to promote international network-to-network collaboration. This ultimately resulted in the recently announced *Accelerating Research through International Network-to-Network Collaborations (AccelNet)* program. The GRI Subcommittee, led by the NNI site, is actively involved in assembling a proposal for this program.

Members: Vinayak Dravid (SHyNE, Chair), Karl Bohringer (NNI), Bob Westervelt (CNS), Chris Ober (CNF), Bruce Alphenaar (KY-MMNIN), Ben Myers (SHyNE, Secretary)

5.4. New Equipment and Research Opportunities Subcommittee

One of the biggest challenges for the NNCI network is maintaining a comprehensive set of tools and equipment for its large internal and external user base. There are two distinct aspects to this challenge. The first aspect is acquiring new state-of-the-art equipment as new tools are developed and become commercially available. There are potential funding mechanisms to address this need, as the federal government has appropriate opportunities such as the NSF MRI program or the DOD DURIP program. The Equipment and Research Subcommittee surveyed the NNCI sites and collected data about pending NSF MRI proposals (see Table 5). This information was shared with Dr. Larry Goldberg (NSF NNCI Program Officer) so that he was aware of those requests generated by the NNCI members.

Table 5: MRI Proposals Submitted by NNCI Sites (Data Collected April 2018)

Site University	Tool Requested	Funding Amount	Tool Description
KY MMNIN U of Louisville	Deep Reactive Ion Etcher	$412,636	Tool used to etch patterns in silicon (will replace our failing 20yr old DRIE system)
KY MMNIN U 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.
NCI-SW Arizona State U.	Inductively coupled plasma, time of flight mass spectrometer	$697,595	ICP-TOF-MS for single nano-particle analysis
NNF	Attocube	$550,000	Low-T, high field scanning probe system

University of Nebraska-Lincoln			
MANTH U. 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.
RTNN NC State U.	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
RTNN NC State U.	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.
CNF Cornell	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
Stanford	Empyrean X-ray Diffractometer from PANalytical	$654,089	For Nondestructive Characterization of Energy Materials in Cross-Disciplinary Research
SHyNE Northwestern University	eBL System	$994,000	Dedicated Electron-Beam Lithography
SHyNE Northwestern University	High energy Single Crystal XRD	$669,620	Single Crystal X-Ray Diffractometer
SENIC Joint School of Nanoscience and Nanoengineering	Illumina NextSeq 550	$498,929	High throughput DNA sequencing system
SENIC Joint School of Nanoscience and Nanoengineering	Zeiss Xradia 510 Versa	$1,108,126	3D X-ray Microscope for digital material design and engineering
SENIC	Hitachi Focused Ion Beam Instrument	$967,940	Focused Ion Beam Instrument for Nanoscale Machining and

Georgia Institute of Technology			Manipulation of Diverse Materials, Structures, and Devices
CNS Harvard	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)
MONT Montana State U.	200 kV cryo-electron microscope (Talos Arctica)	$2,421,477	Structural biology atomic models for macromolecular assemblies in mulitple confromations
MONT Montana State U.	Inductively Coupled Plasma-Mass Spectrometer (ICP-MS)	$639,325	For characterization of microbial communities, elemental cycling, biocorrosion
NNI U. of Washington	Nanoindenter	$454,179	Acquisition of an advanced nanoindentation system for multidisciplinary research and training
NNI U. 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.
NNI U. 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
NNI U. of Washington	Biophysical imager	$390,785	Instrument Development: A nanoscale, unbleachable orientation and postiion sensor for biophysical imaging
NNI U. of Washington	SQUID Magnetometer	$333,879	MRI: Acquisition of a Cryogen-Free MPMS3 SQUID (Semi-Conducting Quantum Interference Device) Magnetometer
NNI Oregon State University	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.

NanoEarth	None
MINIC	None
SDNI	None
TOTAL	**$18,523,557**

The second aspect of this challenge is the replacement of "workhorse tools" such as sputtering systems and mask aligners. These pieces of traditional fabrication equipment are certainly less sexy than state-of-the-art items, such as cryo-TEMs and Nanoscribe Systems, but are nevertheless vitally important to perform micro/nano/mems research. Since these tools are indeed "less sexy", they tend to be more difficult to obtain through equipment research programs such as the NSF MRI and DOD DURIP. This subcommittee surveyed the NNCI sites and compiled a list of each site's top two workhorse tool needs (Table 6). This list was also shared with Dr. Goldberg should additional funds become available as NSF.

Table 6: Workhorse Equipment Needs of the NNCI Sites (Data Collected May 2018)

Site	Top Priority	Cost	Second Priority	Cost
KY Multiscale	DRIE for silicon	$750,000	6 Tube Furnaces for 8" wafers	$900,000
Cornell	E-beam Evaporator	$285,000	Die Bonder	$275,000
SDNI	PVD System	$700,000	Deep Oxide Etch	$750,000
MANTH	E-beam Lithography System	$2,000,000	SEM for cleanroom	$800,000
MINIC	Maskless Aligner (Heidelberg)	$400,000	DRIE for silicon	$800,000
MONT	Contact Aligner with Backside	$302,000	Dicing Saw	$76,000
NanoEarth	JEOL SEM	$1,500,000		
NCI-SW	ICP Etch System	$425,000	Desktop SEM for proposed NNCI Outreach Initiative	$45,000

NNF (Neb)	Camera for SEM	$180,000	E-beam Lithography System	$1,000,000
SHYNE	ICP RIE	$485,000	Field Emission SEM	$500,000
NNI	Spray Acid/Solvent System	$800,000	E-beam Evaporator	$180,000
RTNN	DRIE for Silicon	$850,000	Apex SLR RIE	$450,000
SENIC	EVG Wafer Bonder	$400,000	Large Sample AFM	$200,000
Nano@Stanford	SEM	$600,000	PVD System (evaporator)	$275,000
TNF	Chem Mech Polishing (CMP) System	$575,000	SQUID Magnetometer	$489,000
CNS (Harvard)	NEXSA XPS/UPS System	$500,000	PECVD System	$460,000
TOTAL		**$10,752,000**		**$7,200,000**

Members: Kevin Walsh (KY MMNIN/Louisville, Chair), Jacob Jones (RTNN/NCSU), Yuhwa Lo (UCSD), Mark Allen (Penn), Stephen Campbell (Minn), David Dickensheets (Mont State), Karl Bohringer (Wash), Vinayak Dravid (NW), Oliver Brand (Georgia Tech CO)

5.5. Entrepreneurship and Commercialization Subcommittee

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

The Committee met in April 2018 to discuss Assessment of NNCI Site and Network Economic Impact. The Committee discussed how best to determine the economic impact of NSF's investment in our NNCI sites. Topics of discussion included (i) whether there exists a set of quantitative metrics we can develop, analogous to the metrics associated with our cleanroom usage, that can be used to determine this; (ii) how best to communicate commercialization successes enabled by NNCI; (iii) the use and effectiveness of seed grants; and (iv) workforce development and student training impact on commercialization.

Metrics: The Committee acknowledged the difficulties in trying to assess the work of industry partners and the contribution of NNCI facilities to those partners' future products. However, there may be some proxy measurements that are useful, including: (i) publicly-accessible SBIR/STTR databases; (ii) site-initiated startup companies and/or seed grant awardees that are funded in subsequent private or grant funding rounds; and (iii) self-reported (by industry users) job creation and/or job supported numbers. Scaling this from anecdotal to a full economic impact valuation might be challenging without professional outside assistance (e.g., hiring a consulting company charged with a full economic impact assessment).

Communication: The Committee discussed that there is also substantial value in collecting commercialization 'nuggets' in much the same way that we currently collect scientific nuggets from our users. These nuggets would be examples ranging from anecdotal to quantitative, of how NNCI helps to achieve nanotechnology commercialization. Suggestions to achieve this include (i) ad hoc outreach to get industry users to provide information; (ii) preparation of very short (20 second) video testimonials from users; and (iii) leveraging site web resources to run business success stories on site and the Network home page.

Seed Grants: Most sites have some sort of seed grant program functioning, and most sites felt that this was an effective use of resources to grow and support external industry users, especially smaller companies. Seed grants were typically aimed at smaller companies and substantial resources were often utilized to assist these companies with subsequent SBIR funding, including (in addition to preliminary data collected through the use of the seed grant) letters of support for SBIR grants stating facility availability; scientific support in preparing grant applications, typically by leveraging site-wide commercialization offices; industry fora that discuss how NNCI sites can be effectively utilized to promote industry research and development; and exploitation of other complementary programs (some NSF-funded) such as I-CORPS.

Workforce Development: We discussed multiple approaches to workforce development, including placing local site students in industry, hosting 'career fairs' for local industry looking to hire in this area, and following students after graduation to understand how NNCI-supported facilities aided in their future career development.

Committee deliberations were presented to the Advisory Board at the 2018 NNCI Meeting in Seattle. The feedback of the advisory board was very supportive, especially in the area of metrics and communication. Given this, the next activities of the Committee will focus on the best way to disseminate network-wide best practices to achieve these goals.

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

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 has 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 and training, (2) particular process technologies, such as lithography or characterization (although these are only examples of possible topic areas), (3) research areas of nanoscience and nanoengineering, in particular those targeting "non-traditional" disciplines, such as bio, geo and environmental sciences, and (4) education and outreach activity. Most of these working groups began in Year 1, while new ones were added in Year 2 and 3. Additional topics will 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, which might be further supported through certificates earned when participating in related workshops, for example, and this is being explored.

Table 7: NNCI Working Groups

Working Group Topic	Working Group Lead(s)
Network Support Working Groups	
Equipment Maintenance & Training	Meredith Metzler (Univ. Pennsylvania)
Vendor Relations	Mike Khbeis (Univ. Washington)
Environmental Health & Safety	Nasir Basit (Northwestern) Greg Cibuzar (Minnesota)
Technical Working Groups	
XPS/UPS	Carrie Donley (UNC) Walter Henderson (Georgia Tech)
E-Beam Lithography	Devin Brown (Georgia Tech)
Etch Processing	Vince Genova (Cornell)
Atomic Layer Deposition	Michelle Rincon (Stanford) Xiaoqing Xu (Stanford) Mac Hathaway (Harvard)

Photolithography	Pat Watson (Penn)
Additive Manufacturing	Tim Gornet (Louisville) Ed Tackett (Louisville)
Imaging and Analysis	David Bell (Harvard)
Education and Outreach	
K-12 and Community	Jim Marti (Univ. Minnesota)
Research Experience for Undergraduates	Lynn Rathbun (Cornell)
Workforce Development and Community Colleges	Ray Tsui (Arizona State)
Evaluation and Assessment	Nancy Healy (Georgia Tech) 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 3, sites or groups of sites hosted numerous technical workshops related to processing or research topics (see Section 9). 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. Two of these programs in Year 3 featured concurrent meetings of working groups, with financial support (up to $1000 travel funding each for 5 attendees) provided by the Coordinating Office.

- NNCI Direct Write Workshop, Stanford University (July 12-13, 2018) – Attended by members of the Photolithography working group.
- NNCI Etch Symposium, Stanford University (Oct. 10-11, 2018) – Attended by members of the Etch Processing working group.

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

6.1 Equipment, Maintenance, and Training

Represented by NNCI sites Penn, Stanford, UT-Austin, Cornell, UNC Chapel Hill, and University of Washington, this working group is tasked with sharing expertise on how to keep complex equipment in nanofabs properly operating by considering the characteristics of tools, how they are maintained, and how researchers operate them.

Communication was conducted through email exchanges and one-on-one phone conversations. One important topic discussed among the group members was the collection and dissemination of common lore in vacuum equipment troubleshooting and maintenance. Much of this information is not readily available in literature or the web. For instance, tracking pumping curve characteristics can be used to understand the health of etch or CVD systems. The plan is to finalize one example to use as a model to instruct maintenance staff at NNCI sites.

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

6.2 Vendor Relations

This year, the vendor relations working group was again focused mainly on cost reductions and efficiencies when working with vendors. One of the benefits of having a collective working group is to be able to share openly typical price points and apply volumetric pricing across multiple nodes within NNCI. Despite this, there are some challenges to this effort including differing nodes contractual obligations and limitations as some sites are much more flexible in procurement than others. For example, U Penn has the flexibility to re-sell items without any additional overhead, while UW, a state institution, has mandatory use taxes and overhead applied to all items that are re-sold. Therefore, it is much more cost effective for a site like U Penn to operate as a clearing house for bulk purchases. This effort was piloted this year with the addition of Charlie Veith at U Penn, who applied this concept to cost sharing larger volume orders of electron-beam lithography (EBL) resists. Often these resists cost thousands of dollars for just a few hundred milliliters of material and suffer short shelf lives. The vendor relations group sees this as a prime opportunity to work with sole source vendors and guarantee a set volume per year and have small volume batches dispatched and drop shipped from the vendor based on local site demands. This is far more favorable than a site having to re-pack and redistribute; however, U Penn is also piloting this for some more common cleanroom consumables. Additionally, the ability to share price points for common materials and chemicals has been valuable in putting pressure on vendors to compete, resulting in lower prices against ever increasing price pressures on consumables in our industry.

In addition to consumables, the working group obtained blanket discounts of 10% for field service support from ClassOne Equipment. In addition, SCIA Systems is offering a 10% discount on new ion beam etching systems as well as service, with the caveat that sites are willing to do collaborative development work. While these discounts are good, some vendors have hesitated to make blanket discounts for NNCI citing that they often will offer deeper discounts during the equipment negotiation phase of discussions. Regarding such negotiations, often the vendor asks that the terms and pricing considerations remain confidential.

Vendor engagement was a large part of the NNCI Annual Meeting this year. Since the NNI site was hosting both the NNCI event and a concurrent educational event called NAMIS, an international weeklong summer school for graduate students, vendors were relied on heavily to fund student stipends and expenses for NAMIS as well as NNCI extracurricular events.

In November 2018, the vendor relations working group chair, Michael Khbeis from NNI, will be moving into a new position in industry. The working group will elect a new chair and continue focusing on engaging vendors for reducing capital expenditures as well as lab consumable costs.

Members: Michael Khbeis (University of Washington), Ana Maria Sanchez (Louisville), Andrew Wayne Ott (Northwestern), Matthew Hull (Virginia Tech), Noah Clay (UPenn), Charles Veith (UPenn), Eric Johnston (UPenn)

6.3 Environmental Health & Safety

The EHS working group proposes the following recommendations in each category. During the next year we plan to refine these and add more based on further discussions.

Emergency Procedures

Evacuation Plan

- Post evacuation plan with rally point information.
- Follow stop, assess, evacuate (stop whatever you're doing, assess emergency, evacuate in quick but orderly manner).

Emergency Equipment (safety showers/eye wash, fire extinguishers, fire alarms, toxic gas alarms, emergency phones, first-aid kits, etc.)

- Show all new users the locations of emergency equipment during "hands-on cleanroom training." Demonstrate the operation of each as much as possible. Make sure first-aid kits and chemical spill kits are replenished as needed.

Emergency Response Teams

- The facilities that have these should have a plan for coordination under the command of their local fire department.

Safety

Chemical Safety

- SOPs (standard operating procedures) should be required and approved by staff before allowing any chemicals in the cleanroom.
- Facility should provide all PPE (personal protective equipment)/
- Facility should provide labels for use with unattended chemical processes.

Chemical Waste

- Waste should be segregated to avoid hazardous reactions.
- SOPs should clearly mention how the waste is collected.
- Only trained and certified staff should remove the waste.

Hazardous Gas Safety

- Must have properly maintained toxic gas management system.
- If "red alarm" indicating hazardous leak goes off, evacuate immediately through the closest available exit.

Process Equipment/Instrument Safety

- Equipment training should be provided by staff emphasizing the safety.
- After repair/maintenance, make sure all equipment panels are properly closed before putting the equipment online.

Incidents

Major Incident Response (Active shooter, Major chemical spill, Lab user in safety shower, Severe weather, Lab fire/smoke, Earthquake, etc.)

- These are generally in the purview of your university's EHS and police department and the plan should be made in coordination with them.

Minor Incident Response

- Facility staff and 24/7 users should be trained for incidents like minor spills, etc.

Incident Reports

- All incidents, major and minor, should be documented. Generally, EHS has specific forms and procedures established for incident reporting.

New Material Requests

Hazardous Materials

- Consult safety datasheets (SDS) before approval.
- Consult multiple SDS and additional resources for chemicals with NFPA (National Fire Protection Association) or HMIS (Hazardous Materials Identification System) ratings of 3 or 4.

Hazardous Reactions

- Ask users for published references of same or similar reactions, like journal papers, etc.
- Consult a chemist. If no chemist is on your staff, EHS department may have one on their staff.

Buddy Rule

When and Where

- Buddy rule is recommended for hazardous chemical area when staff is not present.

Enforcement

- Having security cameras and/or door entry logs can help in enforcement.

Safety Training

University Safety Office (EHS) Training

- University environmental health and safety (EHS) departments generally offer several trainings such as laboratory safety, chemical safety, hazardous waste management, cryogenics, radiation, compressed gases, etc. All of these trainings applicable to your facility should be required for all users.

Site-specific Training

- In addition to the above, each facility should also offer online and "hands-on" or "walk-through" safety and protocol training.

- But even more importantly, a daily staff supervision and correction goes a long way in developing a safe working culture.

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
Laura Scholer-Bland	EHS Georgia Tech	Chemical Safety (Hazard Assessments-chemical/process reviews, procedure development)
Mark Walters	Shared Materials Instrumentation Facility (SMIF) Duke University	Research facility management, cleanroom fabrication, XPS, SEM, TEM

6.4 XPS/UPS

The NNCI working group on x-ray and ultraviolet photoelectron spectroscopies (XPS and UPS) is led by Carrie Donley (RTNN) and Walter Henderson (SENIC). The group's main activity is a listserv/online forum that allows members to communicate with each other regarding issues related to instrument maintenance, interpretation of data, and other related issues. All ten NNCI sites with XPS instruments are currently participating. In addition, XPS/UPS experts from outside the NNCI have been recruited to participate in order to leverage a greater pool of expertise in this area.

Members:

Name	Site	University
Recep Avci	MONT	Montana State University
Dmitri Barbash	--	Drexel
Dongmei Cao	--	LSU
Hugo Celio	TNF	UT Austin
Xinqi Chen	SHyNE	Northwestern
Matthew Dabney	--	Cornell

Carrie Donley	RTNN	UNC
Gerry Hammer	NNI	University of Washington
Walter Henderson	SENIC	Georgia Tech
Chuck Hitzman	nano@stanford	Stanford
Jacek Jasinski	KY MMNIN	U Louisville
Timothy Karcher	NCI-SW	Arizona St.
Paul Lee	--	U of Arizona
Tom Mates	--	UCSB
Ben Meyers	SHyNE	Northwestern
Mitsuhiro Murayama	NanoEarth	Virginia Tech
Robert Opila	--	University of Delaware
Jonathan Shu	--	Cornell
Fred Stevie	RTNN	NCSU
Mark Walters	RTNN	Duke
John Wilderman	--	University of New Hampshire
Dmitry Zemlyanov	--	Purdue
Elaine Zhou	RTNN	NCSU

6.5 E-Beam Lithography

Working group purpose and mission: An NNCI EBL Working Group was established for all EBL tool owners in the NNCI network to participate. The first meeting was held on 7/18/2016. Initially, the purpose and goals included 1) identifying what EBL tools exist in the network at which NNCI sites, 2) identifying who the staff are that are responsible for these tools. That has been long established, however there have been some staff changes and tool changes since the group started, and so this update is provided. Another one of our ongoing purposes is to share information between tool owners including recent breakthroughs or any problems tool owners are having they would like help with. We continue to do that.

Working group held meetings: All meetings so far have been held via WebEx hosted by Georgia Tech. In 2018, the working group met on 6/18/2018, 9/12/2018, and 10/17/2018. There was an attempt to hold a face-to-face meeting concurrently with the NNCI Annual Conference that was held at the University of Washington, however not enough people could make it. We plan to hold a face-to-face meeting sometime in 2019, possibly at the next NNCI Annual Conference to be held at Harvard.

Working group email list: To help with communications, a working group email address was set up though the Georgia Tech Listserv service. All working group members are able now to contact all other EBL tool owners through that email address. For now, it is a closed email group for only the tool owners. Occasionally tool owners will send out emails asking for help with problems. For example, one email thread helped a tool owner with HSQ adhesion issues and another helped with conductive polymer anti-charging integration issues.

Working group webpage: A working group web page was established on the NNCI website at https://www.nnci.net/working-groups. This is a public forum to allow anyone interested to contact working group members, pose a question on the Public Forum, or for the working group to post news information.

Members:

Name	University Facility (Site)
Devin K. Brown (lead)	Georgia Tech, Institute for Electronics and Nanotechnology Micro/Nano Fabrication Facility (SENIC)
Talmage Tyler	Duke University (RTNN)
Gerald Lopez	University of Pennsylvania, Singh Center for Nanotechnology (MANTH)
Jiandong Deng	Harvard University, Center for Nanoscale Systems (CNS)
Alan Bleier	Cornell NanoScale Science & Technology Facility (CNF)
Amrita Banerjee	Cornell NanoScale Science & Technology Facility (CNF)
Brian Wajdyk	University of Kentucky (KY MMNIN)
Peter Duda	University of Chicago, Pritzker Nanofabrication Facility (SHyNE)
Kevin Roberts	University of Minnesota (MINIC)
Marylene Palard	Texas Nanofabrication Facility (TNF)
Shane Patrick	University of Washington (NNI)
Rich Tiberio	Stanford Nano Shared Facilities (nano@stanford)
Maribel Montero	UC San Diego, Nano3 Cleanroom Facility (SDNI)

6.6 Etch Processing

The objective of the Etch Working Group is to provide an interactive forum for all 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. Identification 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 current communication paths of a LinkedIn-NNCI Etch Group and an NNCI Etch listserve, we have established 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 capabilities listing. In addition, there is a public forum for etch related questions/answers and discussion.

Last December during a scheduled teleconference, Vince Genova (Cornell) along with Usha Raghuram (Stanford) and Ling Xie (Harvard) decided to co-organize the 2018 NNCI Etch Symposium. The 2-day symposium was held at Stanford in October 2018 and was attended by more than 100 people from academic, industrial, and government research sites. Day 1 was primarily for NNCI etch personnel in which each site was asked to report on their current etch capabilities, and also to provide an interactive forum for discussion of etch related process and equipment issues. The following NNCI sites participated in the symposium: Cornell, Harvard, Stanford, Pennsylvania, U. Washington, Georgia Tech, Minnesota, Texas, Arizona St., Louisville, U. Chicago, UC San Diego, and Montana St. Non-NNCI sites participating on Day 1 included U. Michigan, U. British Columbia, and MIT-LL.

Day 2 was open to all from the industrial, academic, and government research communities. It consisted of talks from universities and technical presentations from vendor researchers. The academic talks included:

- "Directional Diamond Etching" – Haig Atikian (Harvard)
- "Pulsed ICP Etching of Silicon with HBr" – Vince Genova (Cornell)
- "Plasma Damage"- Jim McVittie (Stanford)
- "Crystal Orientation Dependent RIE" – Ling Xie (Harvard)

The vendor presentations included:

- "Semiconductor Scaling in the Era of Data Explosion" – Joydeep Guha – Applied Materials
- "Plasma Dicing and F.A.S.T. CVD" – David Lishan – Plasmatherm
- "Atomic Layer Etching-Rethinking the Art of the Etch" – Keren Kenarik – Lam Research
- "ICP Etching of Compound Semiconductors" – Peter Wood – Samco
- "Deep Oxide Etching" – Arthur McGeown – SPTS
- "Atomic Layer Etching" – Craig Ward – Oxford Instruments
- "Vapor Phase Etching of Sacrificial Materials-Maximizing Their Performance – Tony Ohara –Memsstar

The above Day 2 presentations are posted on the Stanford Nanofabrication Facility website at https://snfexfab.stanford.edu/community/events/nnci-2018-etch-workshop. Non-NNCI universities attending Day 2 were Princeton, UC Berkeley, U. Michigan, U. British Columbia, and UC San Francisco. Vendor exhibits were held each day to explore new equipment offerings and to allow attendees to have discussions with the equipment suppliers. Results of a survey given to workshop participants indicated a desire to have an on-site etch workshop every year and to host it at sites on a rotating basis. Vendor sponsorship of the symposium allowed us to offer some assistance with travel expenses to one attendee from each participating NNCI site. The overwhelming impression from the participants is that the symposium not only promotes communication between universities, but is also a mechanism for learning about new developments in etch related technology.

Future events of the NNCI Etch Working group are being co-organized by V.Genova (Cornell), Usha Raghuram (Stanford), Ling Xie (Harvard), and Sarmita Majumder (U.Texas) and include:

- An on-site 2-day workshop to be held tentatively in November 2019 at Harvard, the week of the fall MRS conference in Boston, so that we can attract leading vendors in the R&D etch market to the workshop for presentations on their latest developments in etch processes and equipment. A cited critical need is for Atomic Layer Etching to meet the stringent requirements of high performance III-nitride and 2D materials based device development. In addition, there will be invited technical talks by NNCI and non-NNCI sites on specialized topics in etching. In 2020, the venue for the Etch Symposium will be the University of Texas-Austin. It is our hope to have an etch symposium each year to foster interaction among the NNCI sites and to keep all informed on the latest developments in etching.
- A "Zoom" teleconference will be held for all interested network sites midway between the on-site symposiums to collectively discuss any equipment or process issues, along with any new process developments. The next teleconference will likely be held in April or May 2019 so that we can provide additional input on the upcoming onsite symposium at Harvard.
- The continued use of the NNCI-Etch mailing list and the NNCI Etch Working Group page to provide a continuous forum for discussion and announcements.

Some photos from the 2018 NNCI Etch Symposium at Stanford:



Members:

Cornell University (V. Genova, J. Drumheller, T. Pennell, J. Clark)
Harvard University (L. Xie, K. Huang)
Stanford University (U. Raghuram, J. McVittie)
Georgia Institute of Technology (T. Averette, H. Chen)
University of North Carolina (B. Geil)
University of Louisville (E. Moiseeva, J. Beharic)
University of Minnesota (T. Whipple)
University of Nebraska (J. Hua)
University of Pennsylvania (M. Metzler, G. Kim, H. Yamamoto)
University of Texas-Austin (R. Garcia S. Majumder)
University of Washington (M. Morgan)
Arizona State University (S. Ageno, S. Myhajlenko)
UC San Diego (X. Lu)
Montana State (J. Heinemann)
Virginia Tech (D. Leber)
U. Chicago (P. Duda, C. Posada)

Non-NNCI members who would like to be added to the NNCI-etch listserve are:

University of Michigan (Kevin Owen)
University of British Columbia (Kashif Awan)
MIT Lincoln Labs (Jeffrey Dalton)

6.7 Atomic Layer Deposition

The NNCI ALD Working Group is co-chaired by Malcolm Hathaway from Harvard University and Michelle Rincon from Stanford. This year the NNCI ALD mailing list was updated to facilitate communication among the member sites. We also worked with Vince Genova to generate the list of the ALD film capability for each site. The information was published on the NNCI website to serve as an additional resource to site visitors. We are planning to hold an ALD Working Group symposium at Harvard in 2019, with the dates tentatively planned for Ocotber3-4. The format will be similar to the symposium that was held last in 2017, where there will be one day of NNCI staff specific topics and knowledge sharing, and one day of a public forum, where researchers, staff, and industry will attend talks regarding ALD research topics, equipment, and have networking opportunities.

Members of NNCI ALD/MOCVD Working Group	
Bernd Fruhberger	University of California San Diego
Bob Geil	University of North Carolina
Fred Newman	University of Washington
Vince Genova	Cornell University

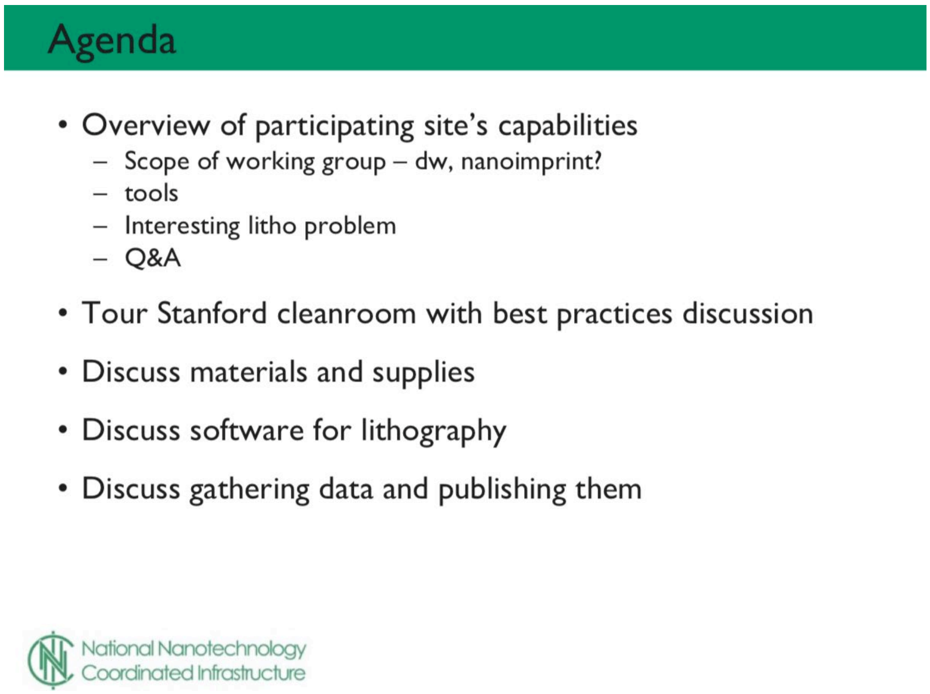
Malcolm Hathaway	Harvard University
Jesse James	University of Texas at Austin
John Ciraldo	Northwestern University
Julia Aebersold	University of Louisville
Meredith Metzler	University of Pennsylvania
Michelle Rincon	Stanford University
Matthew Oonk	University of Michigan
Stefan Muhajlenko	Arizona State University
Phil Hummer	Montana State University
Xiaoqing Xu	Stanford University
Tony Whipple	University of Minnesota
Anna Mukhortova	University of Chicago
Xuekun Lu	University of California San Diego

6.8 Photolithography

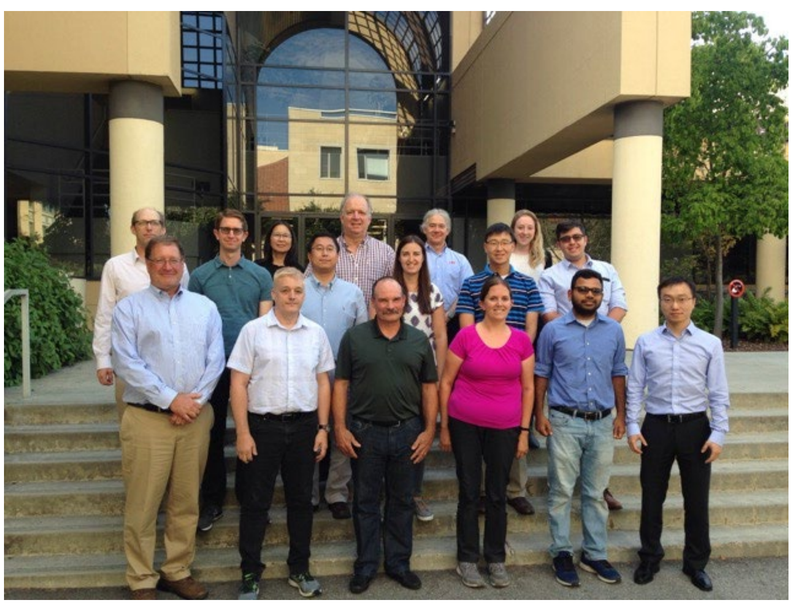
The NNCI Photolithography Working Group is composed of representatives from 10 NNCI sites and is charged with sharing photolithographic techniques and processes with member sites and the larger research community. With the help of the Coordinating Office, a working group mailing list was created. The working group also now has a presence on the NNCI website: a forum for lithography questions and a repository of meeting presentations and other documents are now available to anyone online.

Several members convened a teleconference in May 2018 to flush out goals of the group. Capabilities at each site were reviewed and an outline of how to disseminate the lithography capabilities of each site was considered. The topic of meeting in-person in some form was also discussed; it was suggested that we hold a meeting that precedes the Stanford Direct-Write Symposium in July and coincides with SEMICON.

A one-day workshop was organized and held on July 12, 2018. Representatives from 9 NNCI sites plus engineers from UC Berkeley joined in the discussion. In the morning, representatives from the sites described the photolithography capabilities of their respective sites in detail. In the afternoon, discussion and presentation topics included data preparation strategies, sharing vendor information about photoresists and other consumables, and simulation software for steppers. The agenda is available on the NNCI website and is summarized in below.



Travel expenses for the participants were partially paid for by funds from the Coordinating Office and from equipment vendors who participated in the Direct-Write Symposium the following day. Meals were provided by Stanford University and the vendors.



First Photolithography Working Group Meeting at Stanford University, July 12, 2018.

Members: Pat Watson (Penn), Emily Beeman (UCB), Shivakumar Bhaskaran (Stanford), Garry Bordonaro (Cornell), Allison Dove (UCB), Mark Fisher (Minn), Phil Himmer (MSU), Jiong Hua (Neb), Duane Irish (UWash), David Jones (Penn), Gyosok Kim (Penn), Swaroop

Kommera (Stanford), Xuekun Lu (UCSD), Curt McKenna (UofL), Vinh Nguyen (GT), Laura Palmer (Minn), John Tamelier (UCSD), Mary Tang (Stanford), Rich Tiberio (Stanford), Shu Xiang (UCSD)

6.9 K-12 and Community Outreach

Activities since 10/1/2017

A. In October 2017 a group of four NNCI sites submitted a proposal to NSF for a multi-site RET program.

1. Objective: Develop a program with some network interaction
2. Working group was SW-NNI (Arizona State University, lead), NNF (University of Nebraska Lincoln), KY-MMNIN (University of Louisville), and MINIC (University of Minnesota).
3. While the proposal was rated as fundable, it did not make the cut for available funds for FY 2018.
4. There is interest in re-submitting a proposal (next deadline in Sept. 18, 2019). We may go with this group, or with a different subset of NNCI sites.

B. NNCI E&O website planning

1. The group has begun looking at how to populate and expand the NNCI education web pages with new nano educational materials (including that generated by our respective sites).
2. Requirements for the materials on the site include
    a. Materials should be accessible to and usable by the broader K-14 STEM education community
    b. Activities and lessons should be searchable by topic, discipline, and grade level, similar to the way that the NNIN site worked
    c. Lessons, activities, modules, etc. should include built-in assessment tools (after-use surveys, downloadable stats)
3. The K-12 Working group is committed to making recommendations to the NNCI coordinating office. Angela, David, and Jim have met to discuss the topic and have relayed preliminary suggestion to Q. Spadola.

C. Assessing the impact of E&O activities

1. Working group has worked with the NNCI Coordinating Office to implement, improve, and standardize the assessment tools we are using for outreach activities (both K-12 and community/public outreach)
2. NNCI CO arranged a special session on program assessment at the NNCI fall 2018 meeting
3. Several sites have implemented new program assessment surveys based on the CO suggestions

D. Working group meetings

The group held three phone conferences over the year and met in person at the NNCI fall meeting in September 2018.

Members: Jim Marti (University of Minnesota), Maude Cuchiara (NC State University), Terese Janovec (University of Nebraska), Dan Ratner (University of Washington), Angela An-Chi Hwang (Stanford University), David Mogk (Montana State University).

6.10 Workforce Development and Community Colleges

This working group met with the Education and Outreach Coordinators from all the network sites during the NNCI Annual Conference in September 2018. Among the topics discussed were engagement with community colleges (CCs) and industry surveys. For the former, one issue raised was the need to help CC instructors become more aware and knowledgeable about nanotechnology. A number of sites conduct workshops to address this (e.g., NNF, RTNN; see the activities summary at the end of this report for details), and they can serve as examples or guidelines for other sites.

For CCs that already have education programs in nanotechnology, some network sites have provided facilities and equipment to support student lab work and internship (e.g., MINIC, NCI-SW, NNI) and for marketing their programs (NCI-SW). There was agreement that NNCI should work more towards providing site facilities for workforce development. Beyond CCs, nano-focused 4-year degrees are also emerging. Virginia Tech (NanoEarth) has recently added bachelor's degrees in Nanoscience and Nanomedicine, and these will contribute towards development of a workforce at the beginning levels.

As for industry surveys, it was pointed out during the meeting that prior results obtained by Georgia Tech (SENIC) and Arizona State University (NCI-SW) have been uploaded to the WG's shared Dropbox folder. These surveys were geared towards ascertaining industry needs for technicians and engineering assistants (positions typically filled by CC graduates), and they can be used by other sites as templates to adapt for conducting their own regional surveys. Titles for job positions filled by graduates from 2- and 4-year nanotechnology focused education programs have been compiled by the NACK Network (http://nano4me.org/) and shared with the NNCI sites.

Lisa Friedersdorf, Director of the National Nanotechnology Coordination Office, was in attendance at the September meeting and mentioned that industry groups such as SEMI have expressed challenges in finding technicians with the right skillsets. She suggested the working group may want to look into working with industry groups to address workforce development objectives. A follow-up call with Lisa was conducted in December 2018, during which it was decided to better begin engagement with SEMI on a smaller, regional level given only certain network sites have a strong electronics industry presence in their areas. The engagement process, however, could be used as a model for other sites and with other industries that make use of micro- and nanoscale technologies. Action along these lines will be planned for 2019, and progress will be disseminated to all sites.

The following is a summary for NNCI sites that have reported 2018 activities related to workforce development and community college engagement. Additional details can be found in the Excel database for such activities in the shared Dropbox folder. Contact information for obtaining more information from each site is also included.

MINIC	The University of Minnesota (UMN) recruited 4 students from Saint Paul Community and Technical College for research internships in its Bio-Nano Lab. UNM also continued its long relationship with the Nano-Link program at Dakota County Technical College by attending their annual student conference and exhibit at the High Impact Technical Education Conference. (Jim Marti: jmarti@umn.edu)
NanoEarth	Virginia Tech hosted a 2-dayworkshop for students at the Kingsborough Community College of CUNY. It also hosted a workshop on introducing nanoscience into the curriculum for Virginia secondary school science teachers. (Tonya Pruitt: trpruitt@vt.edu)
NCI-SW	ASU is continuing its collaboration with Rio Salado College (RSC) by supporting 8 advanced labs that are part of the curriculum for their AAS degree in Nanotechnology. A total of 17 such labs were conducted during Year 3, and ASU facilities were also used for creating RSC's marketing videos. For its 2018 REU program, NCI-SW selected 4 students from rural CCs in the region. There were also 5 sessions conducted with other CCs around the country to remotely access NCI-SW's SEM for student training. (Ray Tsui: raymond.tsui@asu.edu)
NNF	The University of Nebraska-Lincoln hosted over 10 tours and training events to introduce nano-related facilities and technologies to participants that include high school through post-graduate students, educators and industry representatives. UNL also hosted 3 undergrad students and their faculty mentors from regional colleges that do not have access to nanotechnology equipment to participate in its REU program. (Terese Janovec: tjanovec@unl.edu)
NNI	At the University of Washington there were 22 paid internships for undergraduates, many funded by fees from industry users. The participants include 7 women, 4 URM/EOP students (Pacific Islander, Latino, and 2 Native Americans), plus an additional 7 local college and 2 Women in Science and Engineering (WiSE) Bridge interns. (Dan Ratner: dratner@uw.edu)
RTNN	A 2-day workshop for CC educators was again offered, this time at NCSU. Nine participants learned about nanofabrication, conducted work in the clean room, and discussed ways to incorporate RTNN facilities and nanotechnology into their courses. RTNN also had an information booth at the STEAM Day of Wake Technical Community College, and hosted a lab tour for students from Central Carolina Community College. (Maude Cuchiara: maude_cuchiara@ncsu.edu)

SENIC	The Joint School of Nanoscience and Nanoengineering continues with its internship program for community college students. Meanwhile, Georgia Tech has offered assistance and discussed with Atlanta Technical College the possibility of ATC resubmitting an ATE proposal for teacher training in nanotech and biotech. (Quinn Spadola: qspadola3@gatech.edu)

6.11 Evaluation and Assessment

The working group had a call to discuss ways to direct sites to the Dropbox folder that had been organized. The group decided to email the information to both education coordinators and site directors, the latter in order to highlight the importance of evaluation at the sites. Coordinators and directors were also encouraged to show evaluation data during the annual meeting. Twelve site directors included this information during their presentations.

Based on feedback that many sites need to better assess the impact of their education and outreach efforts, there was an evaluation workshop during the Education and Outreach Coordinators Meeting section at the NNCI Annual Conference. Mary White, a research professional within the College Research & Evaluation Services Team at Arizona State University, ran the workshop and surveyed coordinators in advance to better tailor the content. Coordinators representing 13 sites responded to the survey. The results show that 60% of coordinators heard that their evaluation plan is either weak or missing, and 53% lack assessment data tied to goals. As a result, Dr. White led the group through a Refine and Design activity to help us focus our evaluation efforts and create goals for these efforts. There was also discussion on best practices for the collection of demographic information, methods for collecting information from various audiences, reasonable expectations for different events, and additional resources available.

During a monthly coordinators' call, the group discussed the need to assess impact across the network, set a baseline, and better collect demographic data to help understand the diversity of the groups being reached. Possible survey questions for three groups, K-12 students, teachers, and the general public, were posted on the education coordinators' Slack workspace. After posting feedback, coordinators have agreed to ask these same questions at all the sites. Students will be asked to Strongly Disagree, Disagree, Unsure, Agree, or Strongly Agree with the following statements:

- "This activity was fun and informative."
- "I want to learn more about nanotechnology."
- "This activity increased my interest in studying science and engineering."

Teachers will be asked to respond to the statements:

- "I am interested in teaching a lesson on nanotechnology in my classroom."
- "I have the resources needed to teach a nanotechnology lesson in my classroom."
- "I am confident in my ability to teach a nanotechnology lesson in my classroom."

During activities for the general public, coordinators will ask participants to share their level of agreement with the statements:

- "This activity was fun and informative."
- "I want to learn more about nanotechnology."

- "This activity increased my interest in studying science and engineering."

In addition, adults at general public events will be asked to voluntarily provide demographic data. Teachers will be asked to provide similar information on the classes they teach.

Members: Quinn Spadola (SENIC-GT), Nancy Healy (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 (previously the Online Technical Learning working group) consists of three NNCI sites: RTNN, MANTH (UPenn), and nano@stanford, and over the past year have met on a regular basis. Two sites, RTNN and nano@stanford have implemented online resources to support the education of users as well as growth of the user base. MANTH has developed a survey to learn more about the non-traditional users at NNCI sites to better support the creation of educational materials to ideally be used network-wide. Stanford has iterated on their online course and has implemented feedback for new modules. We hope to see more coordination and collaboration with this group as we learn how to support the user base at the macroscale, as well as share best practices with content development. To date, their activities are summarized below:

UPenn (Eric Johnston) developed a short survey for NNCI sites which was sent to the NNCI mailing list on November 29, 2018. The survey was titled "NNCI Questionnaire: Experiences with Non-Traditional Users". At the time of this report, there have been 11 responses. Although the number of responses will hopefully be much larger eventually, there are two takeaways so far: 1) none of the responses indicated videos as a training source; 2) almost all responses indicated that staff are critical to the training process.

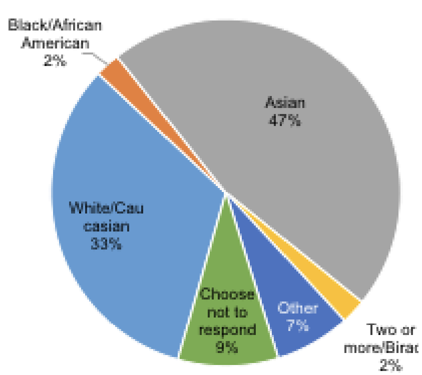
One conclusion that can be drawn is that videos would provide a needed resource for cleanroom training that could take some of the burden off the staff. Although we know there are sites that do have videos for training, videos are certainly not common. And anecdotally, videos are far preferred over written SOPs. Further, videos have the advantage over in-person training as they can be repeatedly accessed. However, videos require a significant amount of production time to make an acceptable product. A repository of videos on the NNCI site (or links to YouTube) could be used by the nanofab community to reduce duplication of effort. Any sites that plan to create videos can benefit the larger community by isolating site-specific videos from those that can be produced for the broader community. For instance, a video describing standard safety protocols when working with flammables can produce the video such that references to emergency phone numbers are put at the beginning or end of the video so they can be easily edited out.

RTNN launched Nanotechnology, A Maker's Course on Coursera in September 2017. The course gives an overview of nanotechnology tools and techniques and shows demonstrations within RTNN facilities by students. The course targets learners/students who have a high school or higher science background and limited exposure to these facilities. The goal of the course is to introduce nanotechnology concepts, give them a better sense of the nanotechnology tools' capabilities, and raise awareness of RTNN facilities and how to access them. Since the course launch, over 22,000 people have visited the course website, over 9,000 have enrolled, and over 1,100 have completed the course. Students hail from more than 130 countries; learners from India (31%) and the United

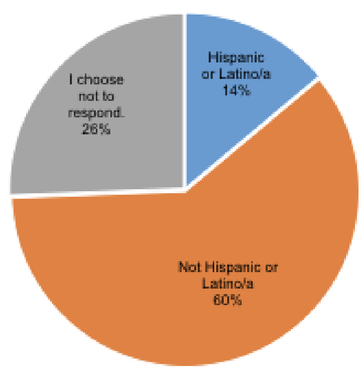
States (17%) account for 48% of total learners. We have continued to see increased growth in enrollment and site visits since the course launch. Additionally, several students have interacted with RTNN outside of the course through the Kickstarter program, facility tours, and subscription to the RTNN newsletter.

Overall the course has been well-received with a rating of 4.8/5 stars on Coursera. Learners can also leave their personal "stories." One student from Botswana noted, "*I just wanted to express my gratitude for the high quality of content delivery in all the course videos by your staff…I learned a lot in terms of the different fabrication techniques that can be employed and in particular the analytical methods. I will be reviewing the course notes for months to come...*" Another student from Mexico stated, "*I really thank all of you for this effort and for sharing freely to the world your knowledge.*"

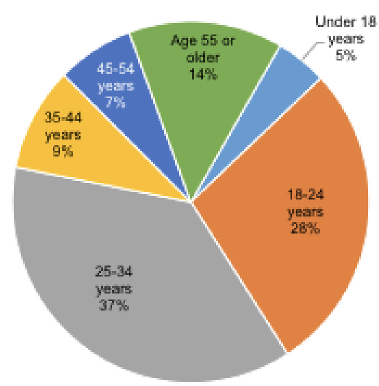
To supplement the data analytics procured from the Coursera platform, RTNN developed a survey instrument that is sent to learners upon completion of the course to understand their demographics. Of 332 surveys sent out, RTNN received 43 completed surveys (response rate: 13%), the data is summarized below. A seven point Likert-type scale was also used for assessment (1=very dissatisfied, 7=very satisfied). Overall, students were very satisfied with the course reporting overall M=6.53 (SD=0.70) for satisfaction measures of the course materials; overall M=6.48 (SD=0.68) for satisfaction measures of the course instruction; and overall M=6.50 (SD=0.75) for multimedia content of the course. 93% of respondents noted that they were Likely or Very Likely to recommend the course to others. 91% of respondents noted that they had a better knowledge of the capabilities of RTNN's facilities.



Race of Coursera learners



Ethnicity of Coursera learners



Age of Coursera learners

nano@stanford has developed an online training course (NanoFab01) that is hosted on an edX based platform supported by Stanford, known as Lagunita. The course is developed on a rolling basis (e.g. modular development) and its primary focus is to support staff in training users or potential users. Since launch of our course in Fall 2016, we have had over 4,000 visitors to the open site (no login needed), and since Fall 2017, we have closed our course to require logins to better understand our user demographics. At the time of this report, we have over 700 users enrolled, of which 42.9% of students are based in US and 18% of students are based in India. The student body is primarily male (80%), and 49% of students are under the age of 25.

Currently the course features the initial modules developed in the first year (“Use and Operation of Plasma-Therm Metal Dry Etcher,” and “Substrates and Wafer Handling”), which have been user-tested by expert staff and facility users in the training process. Initial reception has been positive, however preliminary feedback has shown the content and videos should be more concise. To further accelerate this initiative, we have established nano@stanford fellowships for active Stanford graduate students to: 1) develop and document new and/or unique instrument processes that interests the larger research community; or 2) create educational materials used to support new or non-traditional users obtaining background knowledge on instruments and tools. Over the past year, we have supported four student projects that have incorporated pilot module feedback: scanning electron microscope, Keyence 3D confocal laser scanning microscope, and x-ray photoelectron microscopy educational modules, Optomec aerosol printer instructional videos, documentation of Gatan 4D-STEM software for transmission electron microscopy. We plan to continue supporting this program as it has been useful in expanding the library of educational modules.

Survey data has shown positive reception to the new modules, feedback has highlighted on the videos developed for the Keyence module. Anecdotally, staff reception has also been positive as it has cut down on their time dedicated for training. The staff has been able to deepen the content knowledge during training and shorten sessions as the new users are better prepared. They also view the educational modules as a resource for the users to refresh content knowledge. We plan to continue building the website, aggregating feedback, and survey data to assess the efficacy of the online modules.

Members: Angela Hwang (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. 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.

Marketing Strategies:

1. Engage former users – either internal users moving on to industry or external users that change jobs.
2. Word of mouth advertising.
3. Connect with regional (county) economic development offices – this was seen as something easy to do, but not necessarily very successful.
4. Find start-up companies that have SBIR funding, particularly those outside the university community that may not be aware of resources.
5. Build a good web site. The group noted that typical site websites list equipment, but that potential users would be better served by an applications-focused site.
6. Hold open houses. This approach has been met with mixed success from different sites, but it helps build awareness of capabilities.
7. Exhibit as a vendor at conferences/tradeshows. This approach has also been met with varying degrees of success. Choosing an appropriate conference seems to be a key here to connect with the right audience.
8. Cold calls. Generally seen as ineffective.
9. Produce a single summary slide of your site for faculty to present at meetings and conferences.
10. Print advertisement. One site tried this without success.
11. To increase internal users, work with departments to recruit faculty that will take most advantage of the shared facility infrastructure.
12. Post SOP documents online. These show up in internet searches as people are trying to learn about a technique and provide simultaneous advertisement for your facility.
13. Assemble a database of current/potential users to track contact/usage.
14. Coordinate with other non-NNCI core facilities. This casts a wider net for potential users who are already using facilities in your university.

15. Hold vendor workshops. This helps build relationships with your vendors while leveraging their contacts to help promote your facilities.
16. Work with other research centers on campus. Many research centers may have sponsored research activities with companies and they may also be interested in core facilities access, but aren't aware of what is available.
17. Provide user grants to promote initial usage. Small grants (~$1000 seemed to be a common number) are provided with a simple application to get small companies and startups in the door.
18. Use social media. Many sites seem to recognize the importance of social media, but are just beginning to explore.
19. Develop webinars. This is a good way to fulfill an educational/outreach component while advertising your capabilities.
20. Evening classes/short courses.
21. Interact with less well-equipped universities/colleges in your area and make sure they know they can leverage your site's equipment in grant proposals, etc.
22. Prepare industry-specific marketing materials. Not all of the tools and techniques at your site are applicable for all potential users, so target your capabilities to the potential customer.

Best Practices:

1. Provide excellent customer service.
2. Make a personal connection with users and be sure to follow up.
3. Make usage/access easy. Try to minimize the bureaucratic red tape associated with onboarding a new user.
4. Provide quick turnaround times.
5. Provide users with a single point of contact for your site.

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.* An exhibit booth was hosted at the May *2018 TechConnect* conference in Anaheim, CA. Staffing of the booth was provided by volunteers from NNI, Stanford, SDNI, MONT, and SENIC. Collateral at the booth was provided by sites. In addition, banners and an NNCI flyer were prepared by the Coordinating Office. Suggestions for additional conferences for national attention were solicited from the sites, and many individual sites also host booths at other conferences. A page of the NNCI website is used to highlight participation by NNCI sites at regional and national expos, trade shows, and conferences. However, user survey results (See Section 7.4 below) indicate that effectiveness of conference booth hosting is minimal for user recruitment.

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. Any potential users were referred to NNCI sites for follow-up. More discussion of the website is provided below.

3. *Create an NNCI email list.* During 2017, a listserve 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 85 subscribers to this email list with almost 60 announcements or discussions initiated in this forum during 2017-2018. 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.

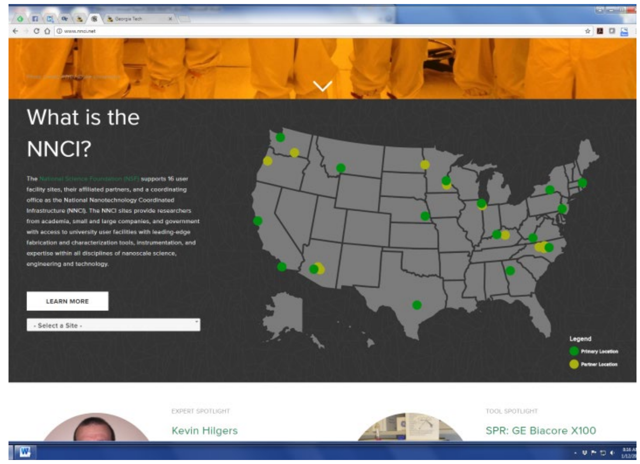
At the suggestion of the NNCI External Advisory Board, an NNCI Infographic (Appendix 13.2) was created. This informational flyer debuted in October 2018 as part of the package of information provided to legislative offices during a Washington DC fly-in visit by a number of NNCI sites.

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 were added during Year 3.

The original launch of the NNCI website (December 2016) included the following basic components:

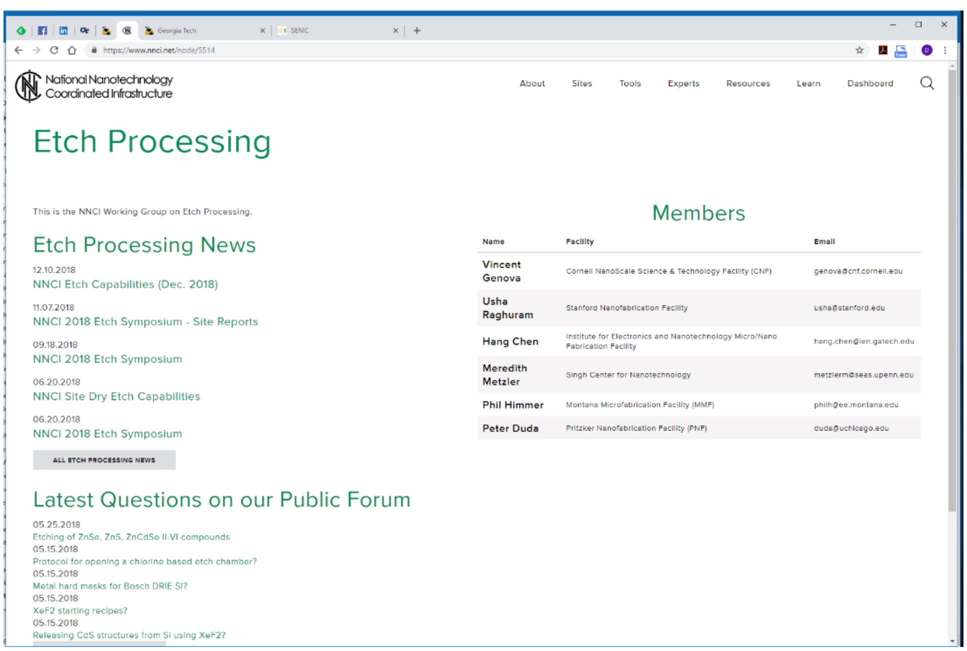
1. Overall design implementation
2. Basic NNCI information
3. Individual site pages
4. Tool database (>2000 tools)
5. Experts database (>200 experts)
6. Contact forms (general information and new user gateway)
7. Education and outreach content (including REU and site-specific information)
8. SEI programs (including site-specific information)
9. Additional resources (other nano infrastructure, link to computation at nanoHub)
10. NNCI news blog



Beginning in March 2017, and with input from site directors, site staff, the External Advisory Board, and our website vendor (Cool Blue Interactive), planning began for the website's Phase 2 development. This plan included changes that improved on existing content and design elements, as well as implemented new features and content. Phase 2 was launched in 2 steps in October 2017 and January 2018 and included the following:

1. Improvements to Home page, including the map of NNCI sites
2. Improvements to contact forms, including addition of a Spanish language version.
3. Improvements and design refinements to the tools and experts database searches
4. Improvements to individual site pages
5. Alternative to 3rd level menus which provides improved navigation of the Learn pages
6. Fixes to and redesign of the Nanooze page
7. Global website search capability

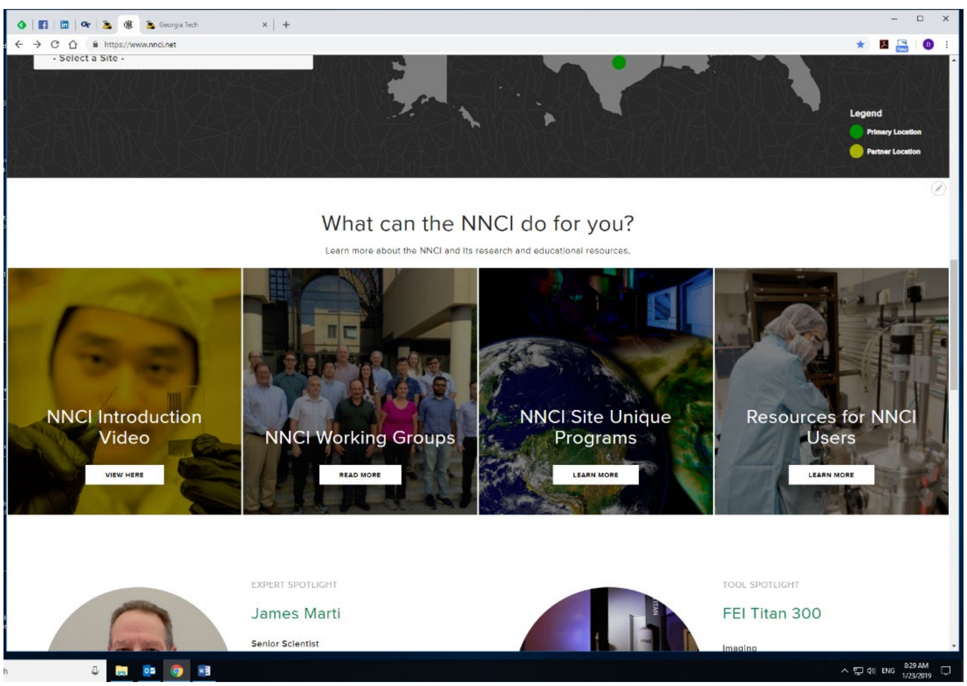
Sites were notified of the revisions in February 2018 with additional content solicited from them to improve the look of the individual site pages. In addition, during 2018 new pages for Technical Working Groups were added which contain (a) list of group members with contact information, (b) a news blog for posting of content by the working group, and (c) a public forum for posting of questions with follow-up discussion. An example of this for the Etch Processing working group page is shown below.



Since the original launch new content has been uploaded 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. Diversity Statement page
6. K-16 Educator Resources
7. Testimonials page
8. Commercialization Resources page
9. Technical Resources, including Remote Work Contractors and Seed Grant Opportunities. The latter two resource lists are summarized in Section 9.3 below.

The most recent mini upgrade finished in January 2019 addressed a need to highlight more ongoing activities and news on the home page by creating a four block section ("What can the NNCI do for you?") in the middle of the page. Items in these blocks are changeable and can include a link the NNCI video, link to an events page, and updatable news or information items. The current single news item at the bottom-right of the home page has been changed to a list of the latest 5 news items. During 2019 an update to the tools and experts databases, to reflect changes since 2016 and based on input from NNCI sites, will also be undertaken.



Since December 2016, the website contact forms have received more than 100 inquiries (1 per week on average). In all cases these were forward 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.

Google analytics for www.nnci.net indicate that in calendar year 2018 there were more than 21,000 visitors to the website, a 61% increase over the previous year. 88% were new visitors with 61% from the United States. There were more than 69,000 page views which is a 13% increase from the prior year. The average session duration was approximately 2 minutes, with an average of 2.4 page views/session, both a decrease compared to 2017. 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 (careers, nature, what is nano).

Table 8: 2018 NNCI Website Page Visits

	Page	Pageviews	% Pageviews
1.	/	13,304	19.25%
2.	/research-experience-undergraduates	4,986	7.21%
3.	/sites/view-all	3,589	5.19%
4.	/careers-nanotechnology	3,114	4.51%
5.	/search/tools	1,766	2.55%
6.	/about-nnci	1,756	2.54%
7.	/nature-helps-nanotechnology	1,306	1.89%
8.	/search/experts	1,170	1.69%
9.	/what-nano	829	1.20%
10.	/resources	818	1.18%

Site acquisition (how visitors get to the website) is primarily through three routes: organic search, direct, and referral from another website (see Figure 3), with less than 1% from social media or email routes. The organic search rate of 56% is a significant increase from 2017 (42%) indicating that the website is gaining traction and appearing more frequently in online search results.

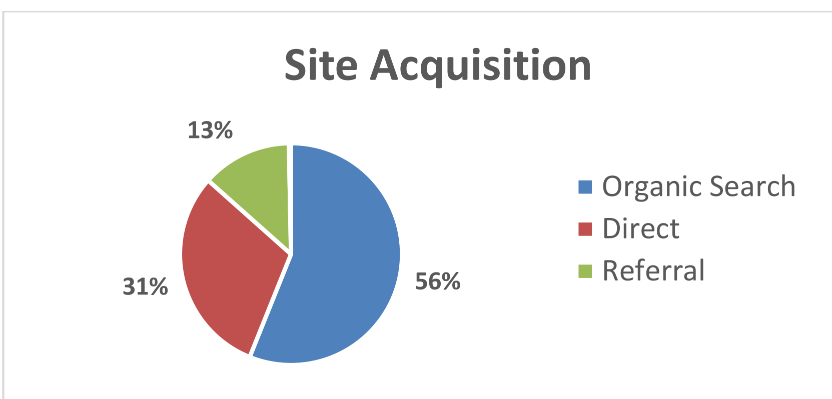


Figure 3: Site acquisition (how visitors get to the website) for www.nnci.net

7.3. NNCI Video

In July 2017, after discussion during the monthly site director's conference call, a decision was made to contract with an external vendor for production of a short video to promote NNCI for general awareness and public relations purposes. Based on her past experience working with NSF programs, Dr. Kirsten Sanford of Broader Impacts Productions was contracted to develop and produce a short (3-4 minutes) video. Initially, a set of points to guide the messaging of the video storyline were developed:

- Nanoscale science and engineering is a research area that can provide significant technical advancement as well as economic growth.
- The infrastructure and expertise for performing this research are intensive and costly, and not available to all those without the financial resources.
- The NNCI network (16 sites and their partners) provides 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.
- The network is geographically distributed for ease of access and is available at a reasonable cost.
- The program aims to make these capabilities broadly available to the nation's researchers in academe, industry, and government to help catalyze new discoveries in science and engineering and to stimulate technological innovation.
- In addition, the NNCI sites are expected to leverage their user facilities and staff to provide innovative education and outreach programs, and activities on social and ethical implications of nanotechnology.

Interviews with some key NNCI figures occurred during the Annual Conference in October 2017 and a set of draft questions were also developed:

1. What is the NNCI?
2. What sorts of capabilities are available at the NNCI sites?
3. What do the NNCI facilities offer beyond access to state-of-the-art tools and expertise (e.g. training, workshops, collaborations, connections to industry)?
4. Outside of the site universities, who else can benefit from this resource?
5. Many of the 16 sites have local/regional partners? What do these partners add to the NNCI network?
6. As a national resource network for nanoscale science and engineering research, why did you choose to participate in this network?
7. All NNCI sites are also required to run programs in education and outreach for the broader public. What do you see as the importance of these activities and what are some examples of these programs?
8. How can the NNCI network achieve the objective of being more than the sum of its parts?

Finally, B-roll video was obtained from several sites (SENIC, RTNN, NNI, Stanford, SDNI, CNF, KY MMNIN, and SHyNE) consisting of both laboratory operations and education activities and this was provided to Broader Impacts. In January 2018, a script was produced, reviewed, and approved with a draft version of the video released in February 2018. After changes and corrections, a final version was posted on the NNCI website, released to all sites for similar posting, and provided to NSF and the NNCO for distribution in April 2018. The YouTube URL is https://youtu.be/72ZXh-ESt3U. As of Feb. 1, 2019 the video had been viewed on YouTube nearly 900 times (including an earlier version that is no longer available).

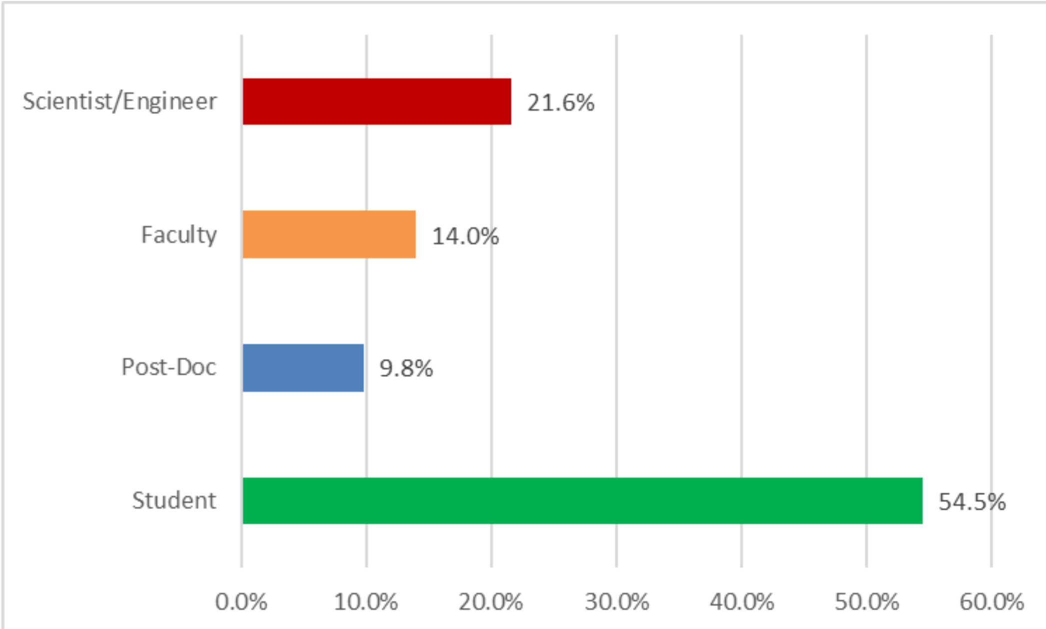
7.4. User Satisfaction Survey

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 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.

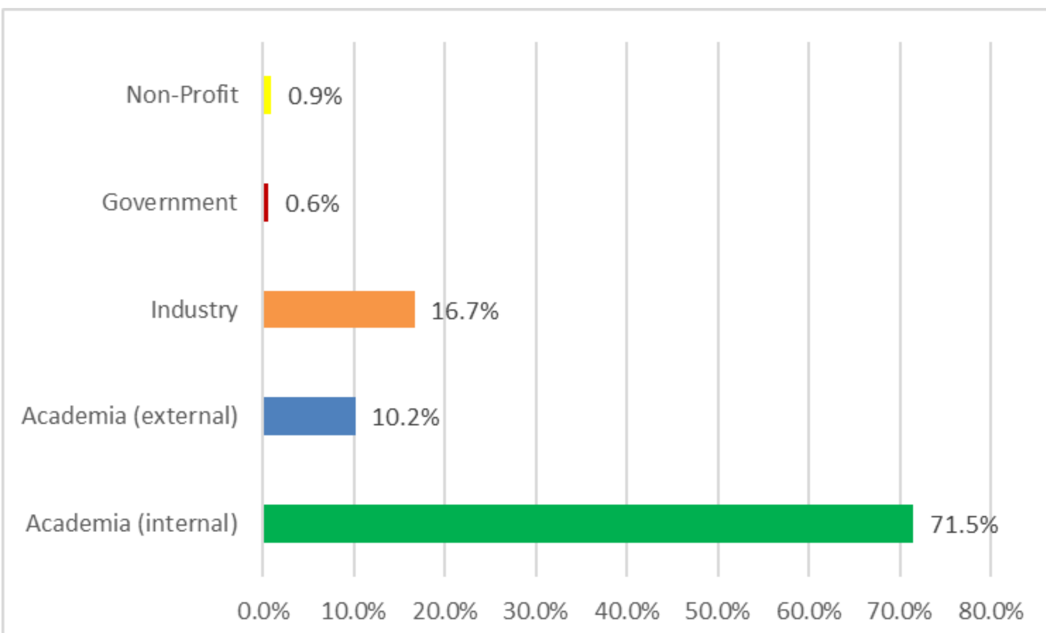
The 2018 NNCI User Survey was opened in July 2018 (earlier this year) and generated 638 responses from 8 sites that participated (as of 1/7/2019). In addition, the remaining 8 sites provided their own survey results for a similar time period. These separate surveys did not all use the same questions as the common version on Survey Monkey, but responses were added to the overall results when possible.

In total, 1385 respondents (more than 10% of users) participated in either the common or individual site surveys. The site-specific filtered results, with comments, were provided to individual sites for identification of action as needed. The results below are from the network aggregate data (all 16 sites) with the number of responses (N) indicated.

User Status (N=979)



User Affiliation (N=991)

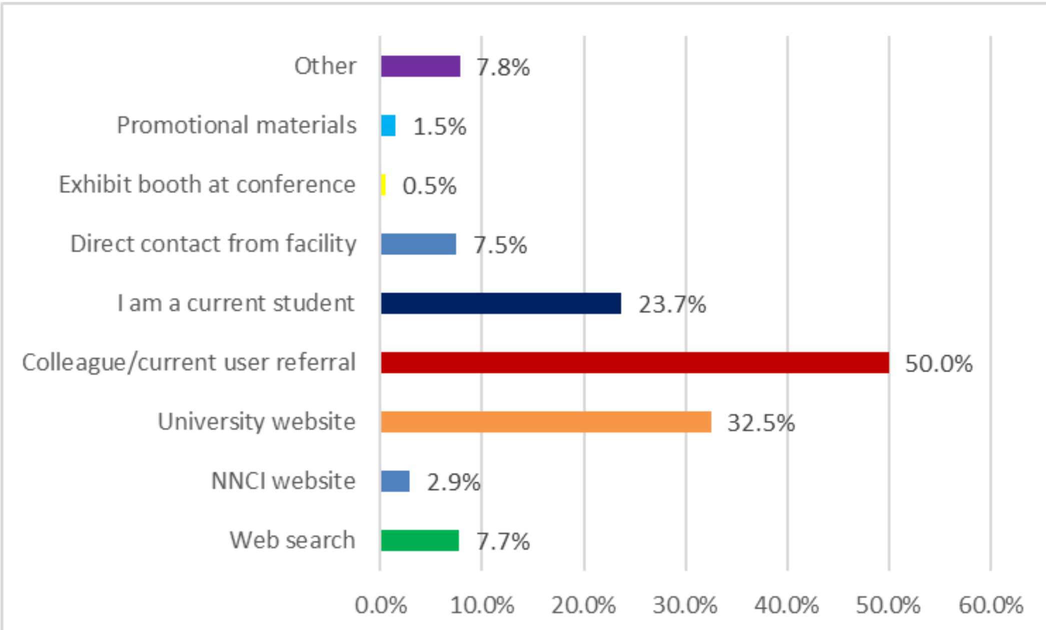


Note that this distribution mirrors very closely the actual user affiliation distribution for the NNCI network as a whole (see Section 10.1, Figure 6).

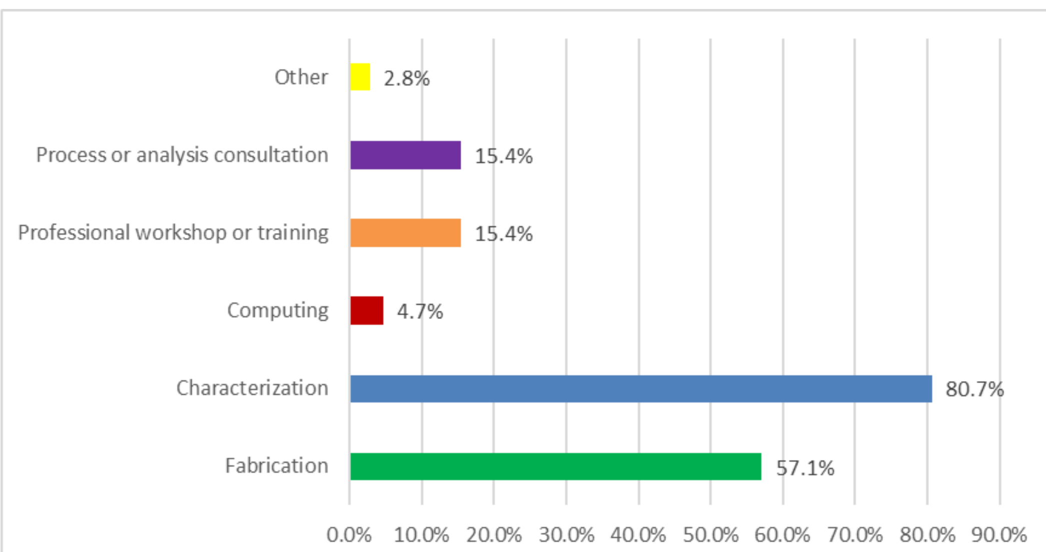
Which NNCI facility were you a user at primarily during the previous 12 months?

The number of responses from each site varies from 17-344. In addition, in a different question, users were asked if they used more than one NNCI facility during the past year. While 7% answered affirmatively that they used more than one site, based on indicated sites there appears to be a misunderstanding by the survey takers and this question will be re-worded for 2019. It is estimated that <5% of users accessed multiple NNCI sites.

How did the user find out about the NNCI facility? (N=1352)



Which services were used at the NNCI facility? (N=1041)



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

More than 100 suggestions were received and provided to the sites. Examples include DUV aligner, more deep Si etching, FIB, improved Mass Spec, think film PZT deposition, pulsed laser deposition, quartz crystal microbalance, ion implantation, X-ray micro CT, and more workshops and seminars.

<u>Were you able to complete your project in a timely manner? (N=883)</u>

Yes: 91.5%

No: 8.5%

Note: These results may be distorted somewhat as many users still had ongoing projects at the time of the survey.

<u>Did you have any concerns about safety while working in this facility? (N=853)</u>

Yes: 3.5%

No: 96.5%

Note: As with all survey components, the individual responses indicating specific concerns were shared with the appropriate site for follow-up action.

<u>Would you recommend this facility to a colleague? (N=1030)</u>

Yes: 97.8% (The range of positive responses by site was 93-100%.)

No: 2.2%

<u>Provide a rating for the facilities at this NNCI site (1=Poor, 2=Fair, 3=Good, 4=Very Good, 5=Excellent). (N=1005)</u>

Network Average: 4.45, with 90.4% responding Very Good or Excellent

<u>Please rate your overall experience with the process of working at this NNCI facility (1=Poor, 2=Fair, 3=Good, 4=Very Good, 5=Excellent). (N=988)</u>

Network Average: 4.46, with 88.6% responding Very Good or Excellent

In addition, more than 100 individual comments were provided, both positive and negative, and a selection of these is provided here:

"This facility is an essential component of our research, and the staff are exceptional. They have been incredibly helpful with equipment and processes, and are very communicative."

"The staff at the … cleanroom are absolutely amazing, extremely helpful, and extremely knowledgeable. They are always willing to go out of their way to help with any equipment or process problems I experience and provide helpful suggestions and advice for my projects."

"I am especially pleased with the communication that comes from the facility to inform users when instrumentation is under repair and to remind users about safety. This is especially important in a university setting in which new users are continually cycling through the facility."

"The new facility is a great improvement; the recent equipment purchases have been very useful. However, if there is not a significant increase in staff levels, I am concerned about the ability to maintain the existing equipment, as well as support the growing user population."

"My company has been able to produce many successful prototypes at this facility."

"Availability of onsite support staff has been critical to my experience at the facility. Several times a prior user has left the instrument in a not usable state but the onsite staff has been able to restore it for me. Please don't reduce staffing levels!"

"The staff at … are excellent at both maintaining the facility, training students, and working with students who do not always get it right the first time. They are also good partners and consultants."

"Staff are responsive and knowledgeable, and the equipment managers are true experts in the operation [of] each device. The service provided by … is vital to our ongoing operations as a small business; access to this analytical equipment (and accompanying scientific expertise of the personnel) have been key to the success of difficult projects numerous times."

"The … nanofabrication facility should put some effort into (statistical) process control, standard process maintenance, and cleanliness. Industrial users in particular have a lot of issues and have to do a lot of extra work to get reasonable device yields."

"I'm very pleased that this site exists. I've managed to do work that I would not otherwise be able to complete thanks to the tools available here. Thank you!"

"Great people; great facility; great experience"

8. NNCI Annual Conference (September 2018)

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."

The third annual NNCI Conference was held September 12-14, 2018 at the University of Washington (NNI site) in Seattle, WA. The 2-day event had an attendance of nearly 130, including senior representation from every site (14 site directors and 2 co-directors), 7 of 9 advisory board members, Dr. Larry Goldberg and Dr. George Janini, NSF program directors, Dr. Lisa Friedersdorf, Director of the NNCO, as well as three invited speakers (see group photo below). The invited lectures were used to highlight an NNCI user, an emerging research area, and a comparison to another shared facility network.

- Dr. Dave Wecker (Quantum Engineering, Microsoft Research): "Achieving Practical Quantum Computing"
- Prof. David Baker (Institute for Protein Design, Univ. of Washington): "De Novo Design of Protein Nanomaterials"
- Dr. Shigeo Tanuma (National Institute for Materials Science, Japan) "Overview of Nanotechnology Platform Japan"

The agenda also featured:

1. 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.
2. Short site reports from each of the 16 NNCI sites. To assist with the organization and flow of these reports, each site was provided a template presentation to follow. The reports were grouped into four panel sessions, each with a different theme. Each site presenting in that panel provided one slide on the topic and participated in the open discussion. These themes were:
    - Future Research Directions

    - Workforce Development
    - Commercialization
    - Resource Allocation and New Equipment
3. Six breakout groups in 2 sessions with subsequent reporting back to all attendees. The breakout group topics were:
    - Education/Outreach
    - Facility Management and Operations
    - Comparing Notes on the NSF Reviews
    - Societal and Ethical Implications
    - Computation
    - User Recruitment and Marketing
4. A separate half-day meeting of the Education and Outreach Coordinators held the day before the main meeting.
5. A meeting of SEI coordinators held the day before the main meeting.
6. Group discussion between the Site Directors and the Coordinating Office.
7. 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.

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

Future NNCI Conferences are scheduled for the following locations:

- 2019 Annual Conference, Harvard University (CNS), October 23-25, 2019
- 2020 Annual Conference, Northwestern University (SHyNE)

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.

<u>Network-Wide Activities</u>

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
5. Participation in National Nanotechnology Day Activities
6. Attending NSF Nano Grantees Conference (December 2017 and 2018)
7. Attending NNCI Annual Conference (October 2017 and September 2018)
8. Sending students to REU Convocation (August 2018)
9. Participation in NNCI site visits with the Coordinating Office
10. Providing content for the NNCI website
11. Discussions between site staff on equipment repair and maintenance issues
12. Promotion of NNCI, network events, and opportunities (workshops, job postings, etc.) through electronic communications and other marketing
13. User referrals to other sites, via NNCI email list or responses to NNCI website contact form

<u>Multi-Site Activities</u>

1. Hosting and participation in NNCI supported workshops and technical events (host site in parentheses)
    a. October 2017: Helium Ion Microscopy (CNF)
    b. January 2018: CryoTEM Webinar (NCI-SW)
    c. March 2018: Chip Bonding Technologies for Heterointegration (CNF)
    d. April 2018: Mid-Atlantic Electron Beam Lithography Workshop (MANTH)
    e. April 2018: Two-Photon 3D Printing (CNF)
    f. May 2018: iNano (SHyNE with Argonne National Lab)

g. May 2018: Optical SPM of 2D Quantum Materials (CNS)
h. July 2018: Direct Write Lithography Symposium (Stanford) – Held in conjunction with a meeting of the NNCI Photolithography Working Group
i. August 2018: Nano+AM Symposium (KY-MMNIN)
j. October 2018: Etch Processing Workshop (Stanford) – Held in conjunction with a meeting of the NNCI Etch Working Group
k. October 2018: Solar Cell 101 (NCI-SW)
l. October 2018: Workshop on Scanning Probe Spectroscopy/Imaging (CNS)
m. December 2018: *in-situ* TEM Workshop (CNS)

2. Participation in SEI Programs:
    a. 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 2018. This year drew upon expertise across the NNCI by bringing in SEI scholars Jan Youtie (Georgia Tech) and Michael Kalichman (UCSD) to work with the students on their projects.
    b. Science Outside the Lab (SOtL): After receiving more applications than any previous year, this event hosted 15 participants from 9 different NNCI institutions including: Stanford, UNC Greensboro, Duke, Harvard, NC State, University of Nebraska-Lincoln, University of Washington, Northwestern, and ASU in June 2018.
3. 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 listserve, 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. Examples include:
    a. A MONT user has incorporated a processing step at Cornell (CNF) into his device development project, travelling two times to perform his work. Multiple MONT users made use of mask writing services at MINIC, while MONT faculty user Wataru Nakagawa is using e-beam lithography capability at SDNI.
    b. MANTH provided LPCVD SiNx deposition and annealing services to NNCI partner NNI at the University of Washington.
    c. CNF and MANTH continue to assist each other on several fronts. CNF has provided anti-stiction coatings to MANTH users for nano-imprinting. CNF has also provided BPSG deposition services and SiNx ALD coatings to MANTH researchers. A MANTH user expressed interest in using a stepper in order to complete a complicated process step, and MANTH staff interacted with CNF staff to arrange a meeting to discuss the problem. After multiple discussions, the CNF made helpful process recommendations that did not require their photolithography equipment.
    d. MONT worked with nano@stanford on ALD samples for a MONT user and aided the microfabrication core director at CNS with an issue they had with their profilometer.

e. SDNI has active interactions with other NNCI who have provided mutual benefits in enabling execution of user projects by leveraging processing capabilities. Examples of such interactions include:
   i. NNI: Enabled fabrication of a microfluidic device for a San Diego start-up; silicon wafer patterning at SDNI and anodic wafer bonding to glass at UW.
   ii. MANTH: Enabled fabrication of an optical grating for a San Diego start-up; grayscale direct-write capabilities were evaluated at SDNI and UPenn.
   iii. Stanford: Enabled measurement of the electric surface potential of polymer coated samples for a UCSD academic project by leveraging Stanford's AIST-NT SPM.
   iv. MONT: Collaborated on fabrication of an optical device structure for a Montana State academic project; Electron-beam lithography, plasma-enhanced vapor deposition at SDNI, other processing steps at Montana State.

4. Equipment/parts backup/exchange:
   a. CNF and MANTH have exchanged spare parts (e.g. turbo pump) and materials (e.g. source gases) in times of exigent needs.
   b. MANTH has assisted CNF with ellipsometry measurements, and with supplying XeF2 for Si etching.
   c. MONT borrowed a valve controller from SDNI, avoiding lengthy downtime for a tool. MONT staff also consulted to share expertise on photoresist lamination with the staff at SDNI.
5. Staff technical interactions:
   a. MANTH has helped MINIC with supplies of the e-beam lithography resist ZEP 520A.
   b. NNI staff scientist Ellen Lavoie engaged CNS, NCI-SW, and PNNL to explore collaborative TEM work.
   c. NNI (Oregon State) co-Director Greg Herman visited NCI-SW to discuss lab management, equipment upgrades, and student educational programs.
   d. SDNI continued ongoing communications with other NNCI sites (e.g. NNI, MONT, NCI-SW, Stanford, SENIC) and non-NNCI sites (UCSB, UCLA, UCI, ORNL) to understand their specific processing capabilities to best serve users in cases where the complementary capabilities of more than one site is needed.
   e. SDNI had multiple communications with MANT, SENIC, and MONT related to equipment repair and maintenance (e.g. DC/RF sputtering discussions with Georgia Tech and UPenn; optical characterization with Montana State).
6. Lab management software support:
   a. MONT is collaborating with Georgia Tech (SENIC) to link their facility to management software (SUMS), leveraging the extensive application development that GT has already done and applying it to the much smaller installation at MSU. Staff members at the two facilities are working together and with their respective university IT departments to define the problems and work out solutions.

b. Greg Cibuzar (MINIC) consults with multiple sites on the suitability of the lab operating software i-Lab for NNCI site operation, and on upgrades to the Badger software.

c. NC State (RTNN) learned about a new laboratory management software from MANTH. As a result, university-wide at NC State, the platform was adopted and a new lab management software was built upon this platform for use by all NC State core facilities including the cleanroom, materials characterization facilities, genomic sciences laboratory, and others.

7. Joint proposals:

   a. NSF AccelNET proposal – led by Karl Bohringer (NNI), with participation by SENIC, CNS, CNF, NanoEarth, RTNN, MINIC, NNF, SHyNE. Letter of Intent was submitted December 2018.

   b. SHyNE SQI Core facilitated connections to the NCI-SW Peptide Array Core for submission of a joint proposal.

   c. NCI-SW led the October 2017 proposal to NSF solicitation 17-575 for a Research Experiences for Teachers site with four other NNCI partners (SENIC, MINIC, KY MMNIN, NNF). Although well-reviewed with three 'Very Goods' the proposal was not recommended for funding. A new proposal is currently being prepared with SHyNE leading the effort.

   d. SENIC (JSNN) and RTNN have collaborated to respond to state-wide (North Carolina) calls for proposals for new research initiatives.

8. RTNN and JSNN (part of SENIC) have had strong collaborations and interactions due to their geographical proximity. RTNN has participated in JSNN's annual Nanomanufacturing Conference and JSNN faculty and students actively participated in RTNN's Carolina Science Symposium (previously called MRS/ASM/AVS joint symposium). RTNN's David Berube served as the keynote speaker at the "Innovate Workshop for Scientific Communication" hosted by JSNN.

9. 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.

10. MANTH hosted and chaired 2018 UGIM Conference (multiple NNCI sites attended)

11. RTNN sharing best practices: TNF is working with Prof. David Berube of the RTNN SEIN team to develop its assessment strategy. RTNN's Kickstarter program has been a model with both SHYNE and SENIC basing their free-use programs after this.

12. Dave Mogk (MONT) and Michael Hochella (NanoEarth) organized the "Nanoscience in the Earth and Environmental Sciences – From Theory to Practice" workshop for the 2018 Goldschmidt Conference (an international conference on geochemistry and related subjects). The workshop included a demonstration session emphasizing "how to" nanoscience with small group interactions with vendors and invited experts. Forty geochemists attended the two-day workshop from around the world, and a permanent public website was created by David Mogk to house our extensive resources in this field of study.

13. Special NSF-funded workshop at NanoEarth. In late 2017, the Director of NanoEarth wrote an NSF proposal entitled "Working Group Activity on Nano-Geo-Enviro Convergent Science and Engineering". The proposal to convene 15 high-level experts in the field of Earth and environmental nanoscience and engineering was funded and the group met at Virginia Tech (April 19-22, 2018) to produce an invited review/perspectives paper for *Science*. Attendees from all over the United States (including the three NNCI nodes at Virginia Tech, Montana State University, and Arizona State University), and two authors from China, created a full, rough draft of the paper during these three days. The paper "Natural, incidental, and engineered nanomaterial impacts on the Earth system" has since been greatly refined, illustrated, submitted, reviewed, and revised. It is currently awaiting final approval, with likely publication in March, 2019.
14. Book collaboration with participation from NanoEarth (Pruitt et al.) and SENIC (Youtie et al.) to include book chapters in the Third Edition of *Nanotechnology Environmental Health and Safety: Risks, Regulation, and Management*, 2018, Elsevier. Eds. M. Hull and D. Bowman. Book Editor, Matthew Hull is the Associate Director for Innovation and Entrepreneurship at NanoEarth. Jan Youtie is SENIC's Coordinator of GT-IEN Social and Ethical Implications and organized the chapter "Lessons from 10 Years of Nanotechnology Bibliometric Analysis". Tonya Pruitt is NanoEarth's Assistant Director and organized the chapter "NanoEarth (National Center for Earth and Environmental Nanotechnology Infrastructure)."
15. USA Science and Engineering Festival: NNCI hosted a booth with multi-site support (SENIC, CNF, RTNN, SHyNE, Stanford), and NanoEarth had its own booth at the biannual USA Science and Engineering Festival in Washington D.C. (April 2018).
16. Joint marketing efforts and representation of NNCI via conference exhibit booths and/or presentations (MRS, AVS, EIPBN, CLEO, TechConnect, SERMACS).
17. NCI-SW, RTNN, NNF and SENIC participate in the Nanotechnology Applications and Career Knowledge Network's Remote Access Instrumentation in Nanotechnology (RAIN) coordinated by Pennsylvania State University.

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

1. Nanooze: CNF publishes Nanooze, and, in addition to direct distribution to classrooms, distributes it to all NNCI sites for use in their outreach activities. CNF also conducted a survey-based evaluation of the magazine. In brief, most (92%) of the survey respondents were school teachers. 91% of teachers used Nanooze as a teaching tool in a teaching environment. Most (93%) teachers used Nanooze in formal classrooms. 43% of students that read Nanooze to learn about STEM or nanotechnology were middle-schoolers (grades 6-8). 3rd to 5th-graders (20%) and high-schoolers (25%) made up the next largest groups. 71% of students demonstrated increased knowledge of STEM topics from reading Nanooze.
2. NNCI Web Site: CNF provided the temporary NNCI.net web site until December 2016, assisted in the transition of content to the new NNCI web site, and maintains archival NNIN information that has not yet been transferred. Georgia Tech (SENIC) maintains the current NNCI website.
3. Disney NSF Science Portal: CNF is restructuring the Nanooze Disney exhibit into the Disney NSF Science Portal to promote NSF research, NNCI, and nanotechnology in general.

4. CNF funds and manages the iREU program that affords a second year research experience abroad from among the highest rated REU interns from the previous summer. During the summer of 2018, five interns worked in the labs of NIMS researchers in Tsukuba, Japan. In a reciprocal arrangement Japanese graduate students are placed at NNCI host sites for the summer (iREG). During summer 2018 this student worked at NNF.
5. CNF and Georgia Tech (Coordinating Office) have conducted longitudinal tracking of NNUN/NNIN/NNCI REU students since 1997.
6. Hosting of NNCI conference by University of Pennsylvania (Oct. 2017) and University of Washington (Sept. 2018)
7. Hosting of REU Convocation by RTNN (NC State, UNC, and Duke) (Aug. 2018)
8. Mark Allen (MANTH) presented on behalf of NNCI at the annual 2017 NSF Nano Grantees Meeting and Bill Wilson (CNS) presented at the 2018 meeting (which was organized by CNS).
9. SHyNE represented NNCI at MRSEC Shared Facilities Workshop
10. SENIC (David Gottfried) presented on behalf of NNCI at UGIM Conference.
11. NanoEarth is a sponsor of the Pulse of the Planet syndicated radio program, helping produce 30 radio shows related to Earth and environmental nanotechnology. Over a million people have been reached via the live national listening audience and podcast streams/downloads.

9.2. Unique Site Programs and Capabilities

All NNCI sites have extensive tool sets and facilities for nanoscale fabrication and characterization. Some sites have unique capabilities and programs in the technical areas as well as in education, outreach, and commercialization. Table 9 below summarizes some of these programs and strengths, while more details can be found in the individual site reports (Section 11).

Table 9: Unique Activity within NNCI

Site	Program	Technical	Education	Outreach/ Societal	Commercialization
CNF	Foundry Tool Mapping	✓			✓
	Focus on Diversity			✓	
	Nanooze		✓		
CNS	REV Interns		✓	✓	
	CNS Scholars	✓		✓	✓
	Incubator Partnerships				✓

KY-MMNIN	3D Printing and Additive Manufacturing	✓			✓
MANTH	Seed Grant Program for Startups				✓
	Graduate Fellowship Program		✓		
	Technician Training Program		✓		
	Scholarly Commons Database	✓	✓		
MINIC	NDSU Advanced Packaging Capabilities	✓			
MONT	Center for Biofilm Engineering	✓			
	Carleton College Science Education Resource Center	✓	✓		
NanoEarth	Earth and Environmental Focus	✓			
	Emphasis on Diversity			✓	
	Focus on Entrepreneurship				✓
NCI-SW	SEI User Facility and Programs		✓	✓	
NNF	Traveling Nano Exhibit		✓	✓	
NNI	Outreach to First Nation K-12 Students		✓	✓	
RTNN	Textile Capabilities	✓			
	MOOC (Nanotechnology: A Makers Course)	✓	✓		
	Assessment Programs			✓	
SENIC	Broad Education Programs		✓	✓	
	I-Corps+ Training			✓	✓
SHyNE	Nano Journalism Program		✓	✓	
Stanford	Unique Tools (MOCVD, NanoSIMS, Scanning SQUID Microscope)	✓			

	Online Learning	✓	✓		
	Summer Institute for Middle School Teachers		✓		
TNF	SEI Activities			✓	
SDNI	Chipscale Photonics Test Facility	✓			
	Remote Nanolab for K-12 and 2-Year Colleges		✓		

9.3. Site Resources for Users

The information in this section was solicited from NNCI sites in 2018 and is subject to change.

Most NNCI sites desire users to access the facilities on-site, where the user is trained and performs the work themselves, under the guidance of expert staff. However, many sites also offer opportunities for remote (off-site) work, where the site staff performs the work for the user and only materials are exchanged. The guidelines for what remote work is accepted is determined solely by the site itself.

For those occasions where site staff are unable to perform the remote work, some sites have local, independent contractors/consultants who can perform the work on a fee-for-service basis. These contractors are not formally affiliated with the site but are trained facility users and have expertise in fabrication and/or characterization methods. NNCI provides the list in Table 10 for information purposes only, and does not endorse nor guarantee the services of these contractors. Potential users of these contractors must do their own due diligence and negotiate terms and conditions of service directly with the contractor.

Table 10: NNCI Contractors/Consultants

NNCI Site	Contractor (Company) Name	Fabrication or Characterization	Local or Travel
CNF	See CNF listing at http://www.cnf.cornell.edu/cnf_remotework.html		
MANTH	Stephen Jones (Jones Nanofabrication)	Fabrication and Characterization	Travel
MINIC	John Snyder (JCap, LLC)	Fabrication and Characterization	Travel
MONT	Chris Arrasmith	Fabrication and Characterization	Travel
MONT	Clay Hunt	Characterization	Travel

nano@Stanford	See Stanford listing at http://snf.stanford.edu/contact/consultants.htm		
NNI	Frank Garcia, Senior Microfabrication Engineer (RJC Enterprises, LLC)	Mainly Fabrication	Local at UW WNF
RTNN	Brenda Prenitzer (Nanospective)	Characterization	Travel
RTNN	Hessam Ghassemi	Characterization	Travel
SHyNE Resource	Yoshi Mizobuchi (YM Consultants, LLC)	Fabrication and Characterization	Travel
SHyNE Resource	Nicolaie Moldovan (Alcorix Co.)	Fabrication and Characterization	Travel
TNF	Burt Fowler (SymboLight LLC)	Fabrication and Characterization	Primarily Local at UT MRC

Many NNCI sites also offer seed grants for new users, graduate students, or startup companies to help them get started (Table 11). Each of these opportunities is provided by the individual site, with specific proposal and deliverable requirements determined by the site.

Table 11: NNCI Seed Grant Opportunities

NNCI Site	Grant Program	Eligibility	Funding	Period
MANTH	Singh Center Innovation Seed Grant Competition	Students, individuals, or small companies (<50)	Varies from $1k to $4k - total dispersed is $15k this year	1 year
MONT	Research Initiation Grants	Any new facility user or external user	$5,000 ceiling	1 year
NanoEarth	NanoEarth Director's Fund	External (non-VT) earth & environmental nanoscience researchers	Seed funding varies by project	TBD based on research
NanoEarth	Multicultural and Underrepresented Nanoscience Initiative (MUNI) Grant	External (non-VT) from multicultural, underrepresented, and underserved communities	Seed funding varies by project	TBD based on research

NCI-SW	NanoFab and EMC Core Facility Seed Grants	External academic users (full-time PhD students) from the regional southwest (not ASU affiliated)	Up to $5,000 in facility use fees	12 months
NCI-SW	I-Corps Boot Camp Grants	Faculty, student, post-doc and small-business users of NNCI sites; Must **not** have prior SBIR/STTR funding or investment greater than $100K for the technology	Travel and accommodation to attend two-week boot camp training session	12 months
NNI	NIH NESAC/BIO seed grant	New user of UW MAF facility	~$1,000-$2,000 for new users, ~$20,000/year for new collaborators	
NNI	Professional Masters Program Courses / Intensive Short Courses	Any student enrolled in Professional Masters Program or Intensive Short Course	Full coverage of lab access fees, ~$50,000/year	1 quarter / 1 week
RTNN	Kickstarter Program	External researchers/students/educators.	$1000 in facility access	1 year
SENIC	IEN Core Facility Seed Grants	Any 1st or 2nd year graduate student in the southeast US	6 months of free facility access ($6000 value)	6 months
SENIC	Catalyst Program	Any external academic/non-profit researcher whose PI is a first-time SENIC user	$1000 in services	6 months
SHyNE	SEED (SHyNE External Experiment Development)	Any new, external user	Up to $2500	1 Year

9.4. NNCI Outstanding Staff Awards

During 2018 the NNCI Coordinating Office created 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 2018, 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 presented at the NNCI Annual Conference and travel support to attend the Conference if desired.

<u>Education and Outreach</u>

- Matt Hull: Associate Director of Innovation and Entrepreneurship, NanoEarth
- Ben Myers: Director of Operations, SHyNE

<u>Technical Staff</u>

- Chris Alpha: User Program Manager, CNF
- Tonya Pruitt: Assistant Director, NanoEarth

<u>User Support</u>

- Carrie Sinclair: Process Technologist - Photolithography, NCI-SW
- Phillip Strader: Project Scientist, RTNN

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 users program. 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, 2017 - Sept. 30, 2018)

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 3)

	NNCI Network	NNCI Sites Mean (Min - Max)
Unique Facility Users	13,110	819 (158 – 1,660)
Unique Internal Users	9,731	608 (107 – 1,444)
Unique External Users	3,379 25.8%	211 (51 – 622) 26.6% (13.0% – 47.0%)
External Academic	1,365	85 (11 – 443)
External Industry	1,870	117 (26 – 277)
External Government	65	4 (0 – 26)
External Foreign	79	5 (0 – 23)
Average Monthly Users	5,001	313 (43 – 797)
New Users Trained	4,981	311 (58 – 695)
Facility Hours*	1,006,764	62,923 (5,420 – 185,288)
Facility Hours – External Users*	228,441 22.7%	14,278 (879 – 58,626) 22.7% (4.5% – 50.5%)
Hours/User*	77	70 (34-140)
User Fees Internal Users External Users	 $23.6M $16.9M	 $1.48M $1.05M

*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. For example, the NanoEarth site has approximately 20% external users (see the data table in Section 11.16). More importantly, however, 54% of the users who identify with the Geology/Earth Science discipline, NanoEarth's focus, are external users. 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 1-3 is shown in Table 13 below. As can be seen, all metrics show increases from Year 2 to Year 3, although the increases are smaller in many cases than the growth from Year 1 to Year 2, as would be expected as the newer NNCI sites become more established and their overall growth begins to plateau.

Table 13: Comparison of Years 1-3 NNCI Aggregate Usage Data

	Year 1	Year 2	Year 3	Year 2-3 Change
Unique Facility Users	10,909	12,452	13,110	+5.3%
Unique Internal Users	8,342	9,276	9,731	+4.9%
Unique External Users	2,567 23.8%	3,176 25.5%	3,379 25.8%	+6.4%
External Industry Users	1,413	1,669	1,870	+12.0%
External Academic Users	1,154	1,295	1,365	+5.4%
Average Monthly Users	4,429	4,911	5,001	+1.8%
New Users Trained	4,116	4,563	4,981	+9.2%
Facility Hours	909, 151	939,230	1,006,764	+7.2%
Facility Hours – External Users	173,511 19.1%	191,494 20.4%	228,441 22.7%	+19.3%
Hours/User	83	75	77	+2.7%
User Fees Internal Users External Users	 $20.6M $13.5M	 $23.0M $14.5M	 $23.6M $16.9M	 +2.6% +16.6%

The nearly 3,400 Year 3 external users come from 1,155 distinct external institutions (full list shown in Appendix 13.3), including 224 academic institutions, 610 small companies, 231 large companies, 24 US local/federal government organizations, 46 international institutions (from Europe, Asia, South America, Africa, and Australia), and 20 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 152 institutions that remain unnamed due to contractual requirements with one of the NNCI sites and may or may not overlap with those listed in the appendix.

As part of an effort to demonstrate and visualize the broad reach of the NNCI network, maps of US-based user institutions (academic and industry) based on zip codes were created using Year 2 data (which was available at the time of the maps creation). These maps are shown in Figures 4 and 5 and illustrate the geographic distribution of these institutions, with some natural clustering observable around the NNCI sites. Because the maps are based on zip code data, locations with multiple companies in the same area cannot be distinguished. It is anticipated that maps generated using Year 3 institutions (Appendix 13.3) would result in similar geographical distributions.

Figure 4: NNCI Year 2 Academic Institutions (222 External)

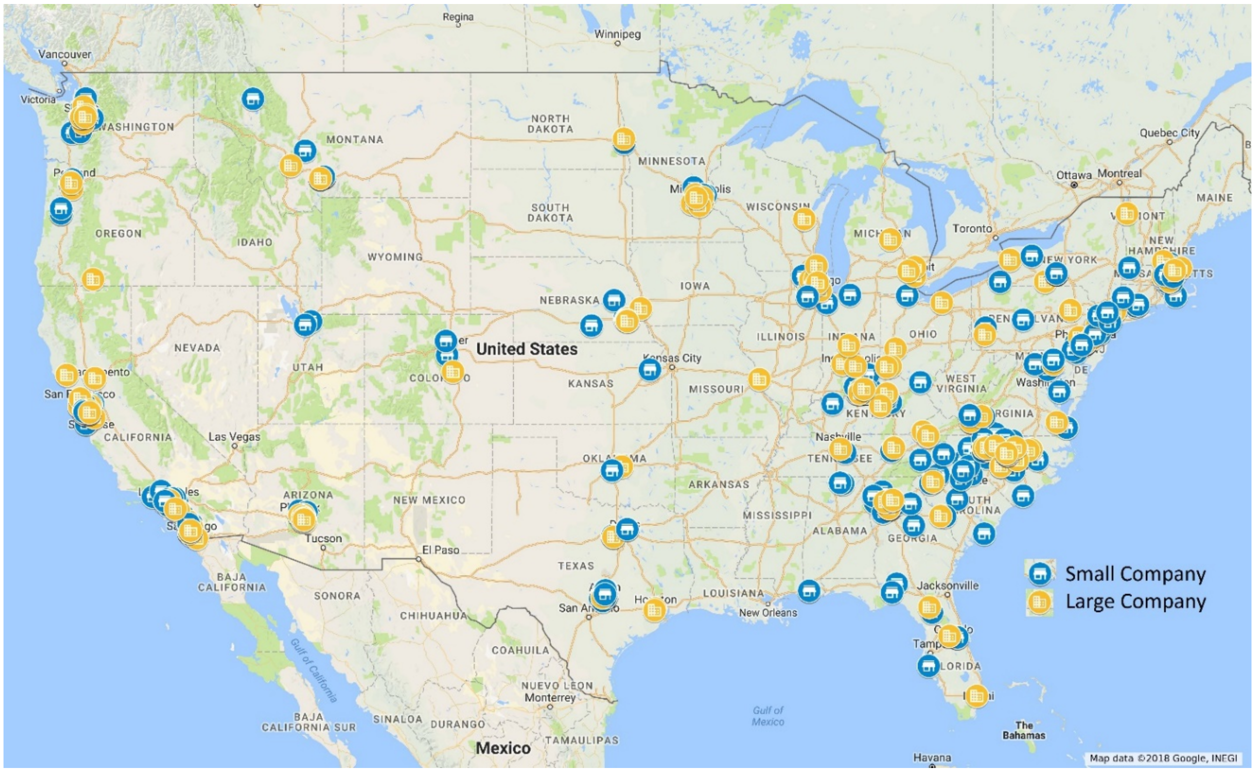


Figure 5: NNCI Year 2 Company Institutions by Zip Code (564 Small, 207 Large)

Figures 6 and 7 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 25.8% of total users, external hours are 22.7% of total hours. As noted in previous reports, this discrepancy 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 with more than a 19% increase in external user hours in Year 3 compared to Year 2.

A comparison of Year 3 cumulative users (by affiliation) by site is provided in Figure 8 for all users and Figure 9 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 have been part of the NNIN program, others have not; some have a large number of tools and staff, others have not. Thus, it can be difficult to draw conclusions from a site-to-site statistical comparison.

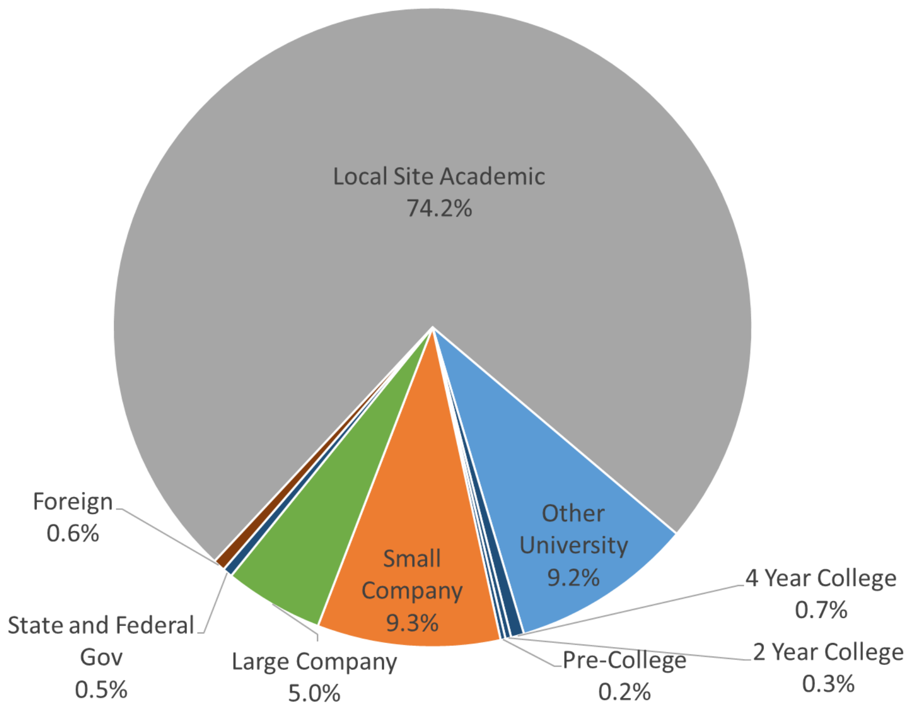


Figure 6: NNCI Users by Affiliation (Year 3)

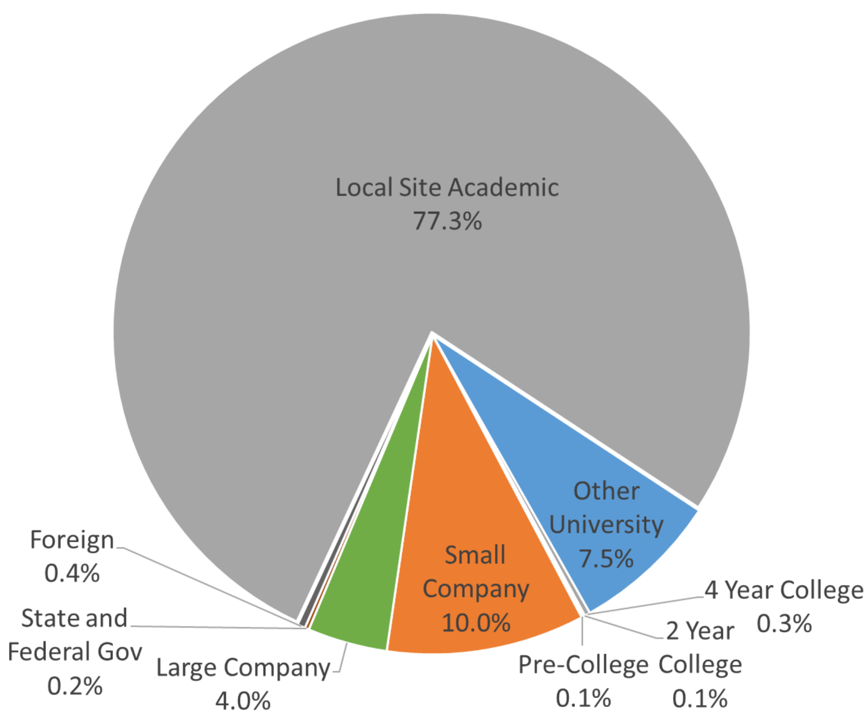


Figure 7: NNCI Usage Hours by Affiliation (Year 3)

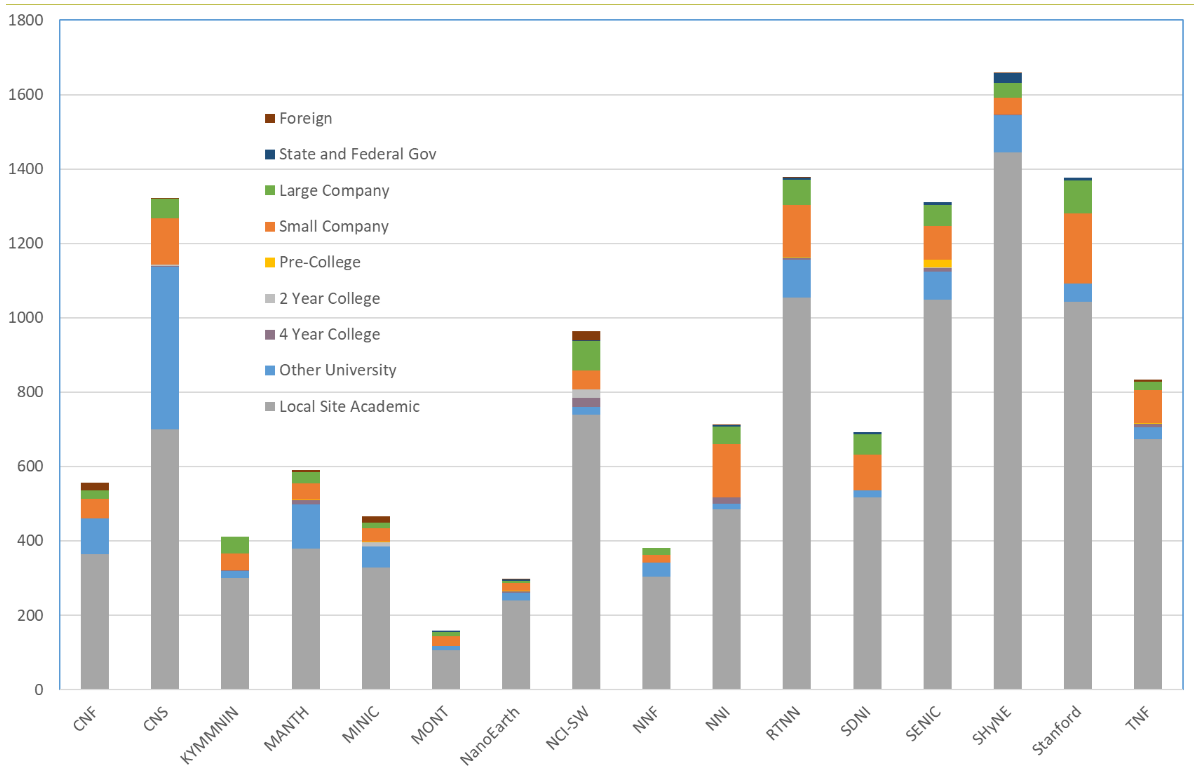


Figure 8: NNCI Cumulative Users by Site (Year 3)

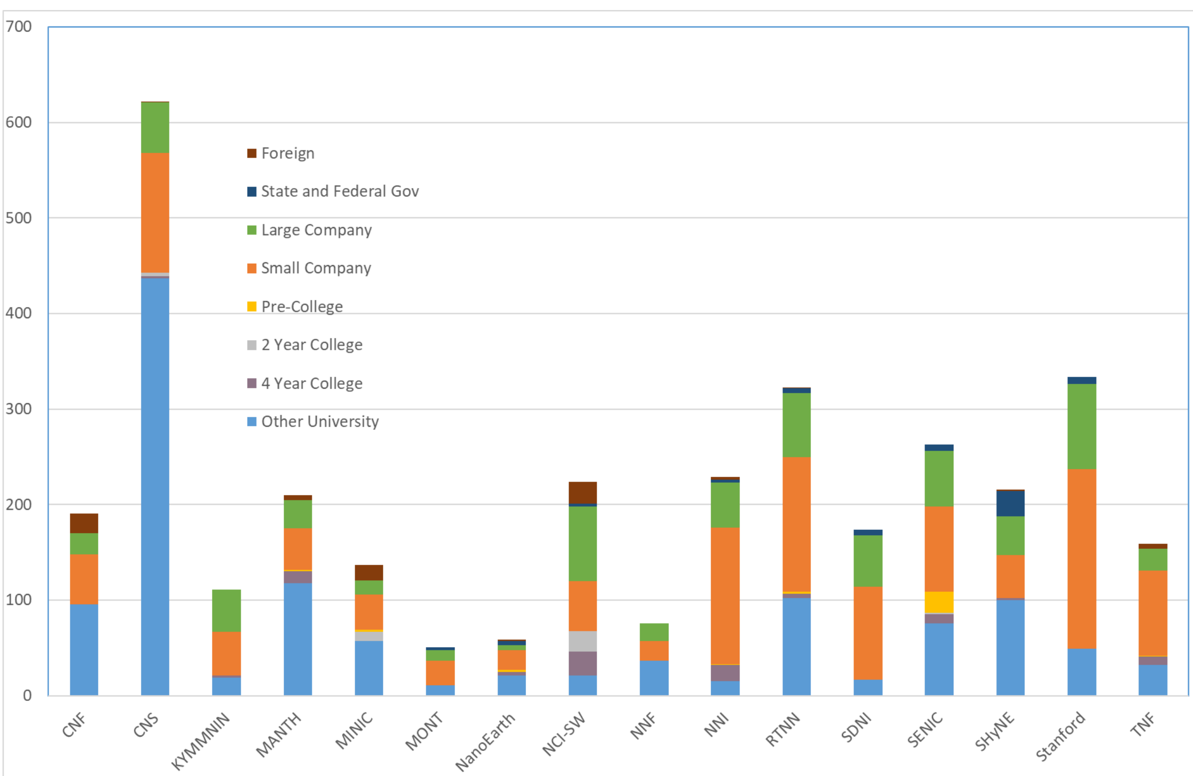


Figure 9: NNCI Cumulative External Users by Site (Year 3)

For academic institutions a network map showing the NNCI nodes and associated US colleges and universities (from 46 states and Puerto Rico) is shown in Figure 10 below. Note that the RTNN site does not show the full set of networked institutions (34) because the names of these are anonymous and thus could not be included with the rest of those in the network.

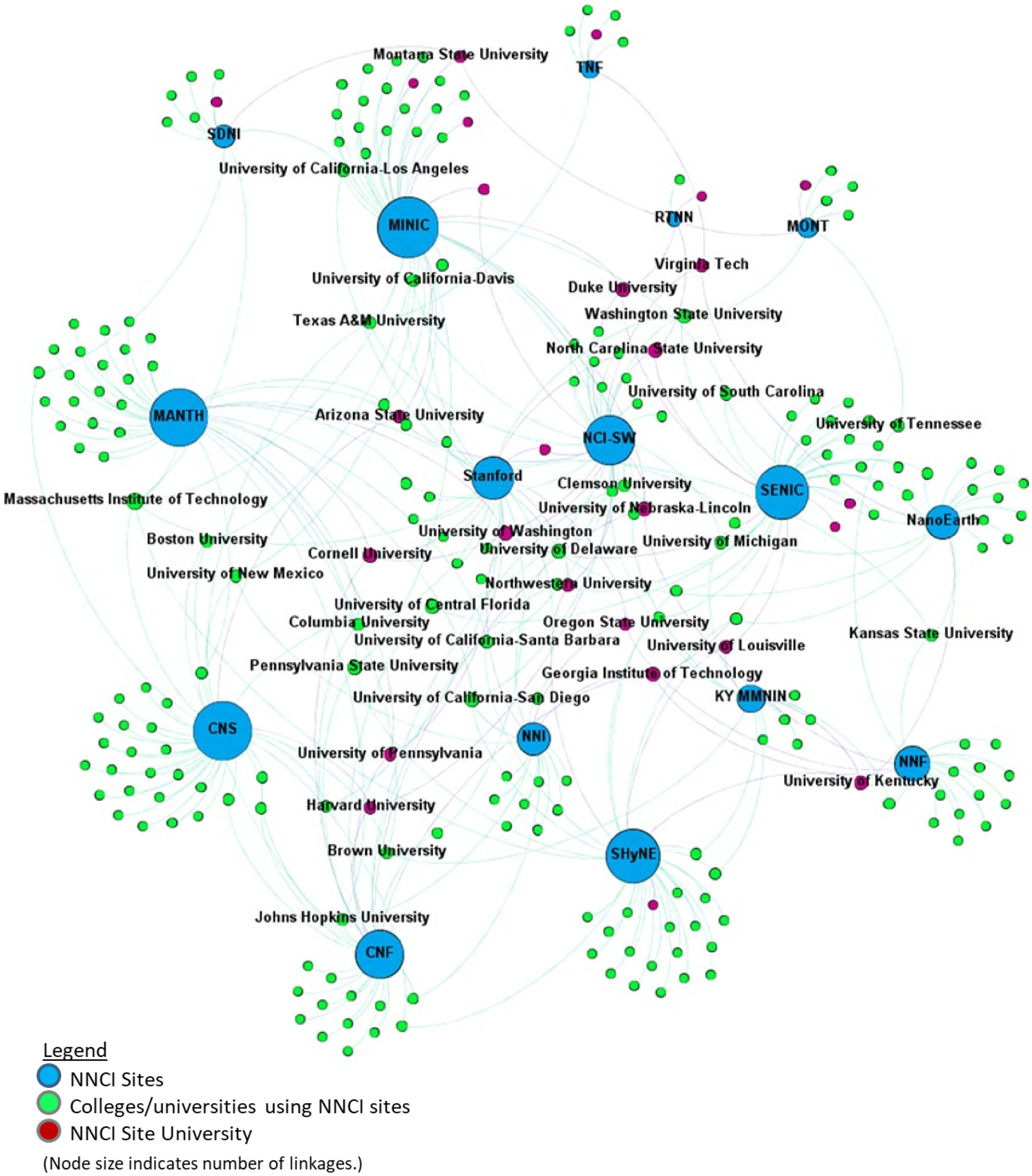


Figure 10: NNCI Academic User Network Map (Year 3)

Universities with projects at three or more NNCI sites (22 in Year 1, 26 in Year 2, and 35 in Year 3) are labeled in Figure 10, including one institution (MIT) working at 6 different NNCI sites and one (Univ. of Kentucky) working at 5 sites. Year 1 had 296 linkages between institutions, while this increased to 343 in Year 2 and 350 in Year 3. In addition to the academic users indicated in the figure, it was also observed that >40 companies or government agencies accessed facilities at multiple NNCI sites, although it cannot be determined if these resulted from the same or unique users or projects.

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 held January, 2017. A summary of that discussion was included as part of the Year 1 NNCI Annual Report (March 2017).

The charts below illustrate the usage of the NNCI network by users in specific disciplines (internal and external). It is worth remembering that in many cases these disciplines are self-selected, and may reflect the user's home department or their specific area of research, and these may be different from each other. Figure 11 illustrates the breakdown by number of users in specific disciplines, while Figure 12 illustrates the usage hours by discipline. Furthermore, Figure 13 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, but with a significant increase in Geology/Earth Sciences users (3.8% in Year 3 compared to 2.4% in Year 2) and usage hours (4.6% in Year 3 compared to 2.4% in Year 2), and this is also reflected in the hours/user for that discipline.

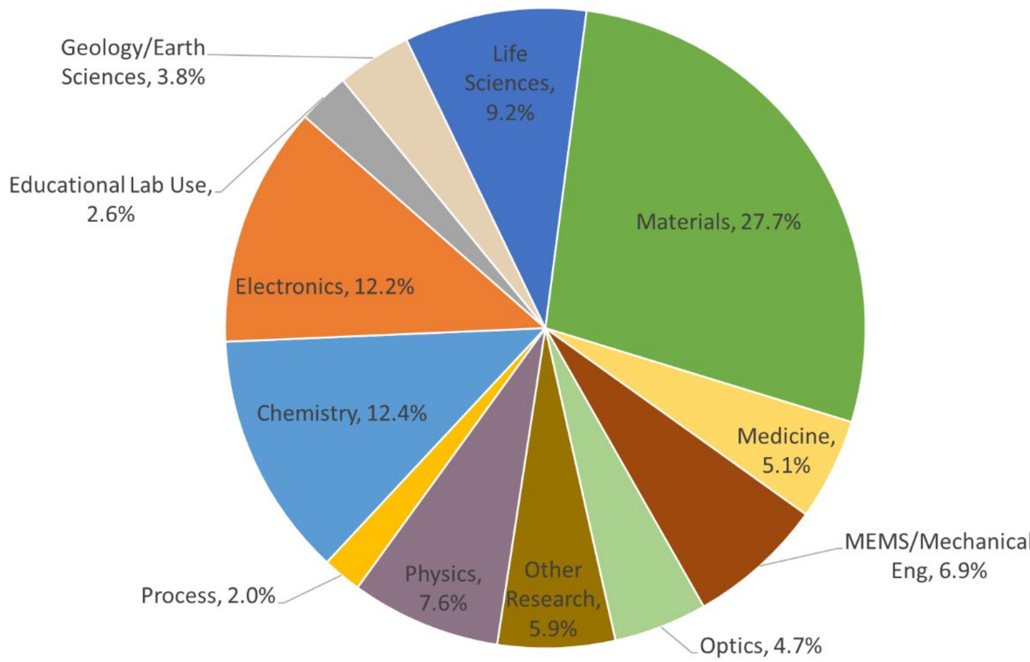


Figure 11: NNCI Users by Discipline (Year 3)

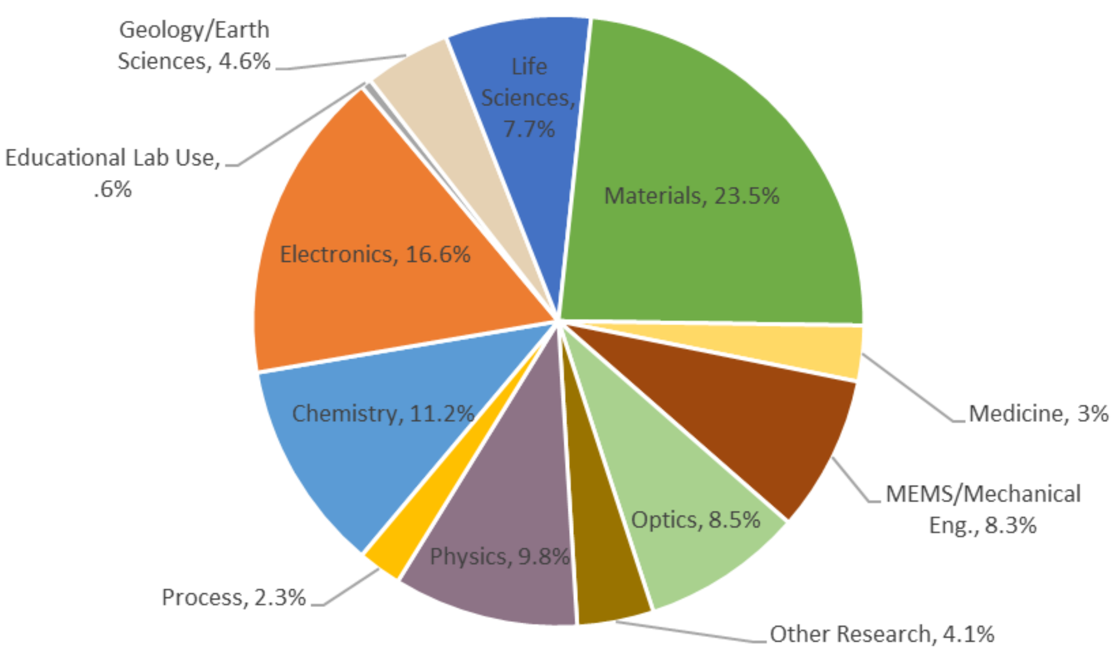


Figure 12: NNCI Usage Hours by Discipline (Year 3)

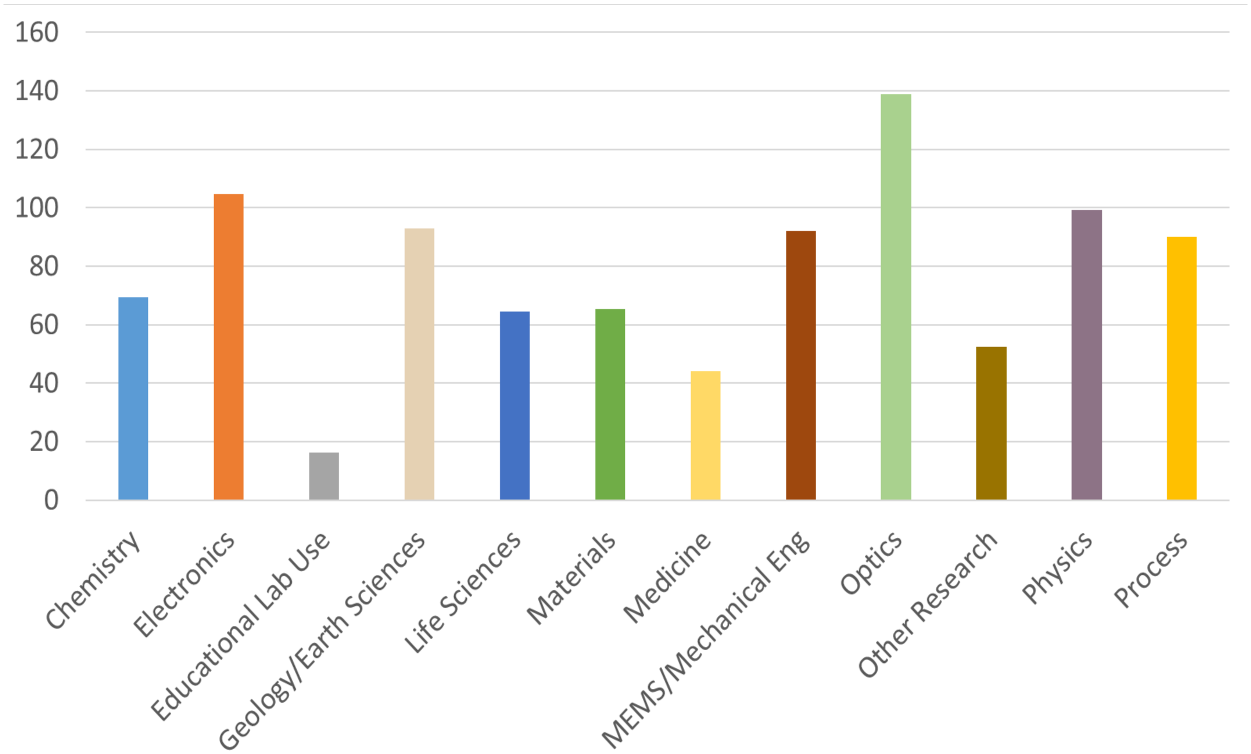


Figure 13: NNCI Hours/User by Discipline (Year 3)

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 has been an even split between traditional and non-traditional over the past three years, however there has been a measurable shift in the usage hours from traditional to non-traditional during that same time period.

Table 14: Usage by Traditional and Non-Traditional Disciplines

	Year 1	Year 2	Year 3
# of Users			
Traditional Users*	5386 (51%)	6063 (50%)	6384 (50%)
Non-Traditional Users**	5262 (49%)	6044 (50%)	6383 (50%)
Hours of Usage			
Traditional Users*	495,215 (55%)	506,393 (54%)	510,180 (51%)
Non-Traditional Users**	409,935 (45%)	424,855 (46%)	490,992 (49%)

* Electronics, Materials, MEMS/ME, Process
** Chemistry, Physics, Optics, Medicine, Life Sciences, Geo/Earth Sciences, Other

10.3. Publications Information

The publications data shown below (Table 15) was collected by sites for the calendar year 2017. 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 nearly 10% increase in total publications compared to Year 2 (2016 publication), with increases in all categories except External User Papers. Publications reported by each site range from 81 to 723. In addition, see the report of the Metrics subcommittee (Section 5.2) which provides guidance to sites for increasing the percentage of publication acknowledgements which include mention of NNCI and the NSF grant number.

Table 15: NNCI 2017 Publications

Publication Type (CY 2017)	
Internal User (Site) Papers	2743
External User Papers	222
Internal User Conference Presentations	1247
External User Conference Presentations	151
Books/Book Chapters	38
Patents/Applications/Invention Disclosures	486
Total	**4887**

11. NNCI Site Reports

NNCI sites were asked to provide summary information as part of this Year 3 report. Specific information requested included:

1. A brief narrative corresponding to the NNCI Year 3 (Oct. 1, 2017 - Sept. 30, 2018).
    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 highlights 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 3, 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 2017. The list of publications may have been part of each site's Year 3 report to NSF, but the data presented here (Table 13 above) is 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.

In addition, the user statistics for NNCI Year 3 (Oct. 2017-Sept. 2018) 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 productive third year for the Center for Nanoscale Systems. 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. The specific new tools and techniques added this year will be outlined below. CNS has begun a program 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 this fiscal year. PI Westervelt and co-PI Wilson have also continued cultivating a cooperative, synergetic relationship with the Center for Integrated Quantum Materials (an NSF STC).

This year we enlisted several new participants in the CNS scholars' program. This activity is focused on enabling young researchers access to CNS expertise and instrumentation, particularly researchers from underrepresented groups and researchers from minority serving institutions. The new participants were mostly Howard University, Smith College, among others and we have supported a few international users. Most of these users are engaged in activities in Quantum Engineering and translational bioscience. In addition to the programs mentioned, we have continued our partnership with Harvard Catalyst, a federally sponsored translational Biosciences initiative to train non-traditional life science researchers in an array of techniques available at CNS. Catalyst Reactor sponsors pilot grants of ~$50,000 for researchers to enabling access nanoscience technologies in the pursuit of life science. The funding is designed to support the innovative application of light and electron microscopy, nanoscale fabrication, and nanoscale analysis technologies for big ideas that will advance clinical healthcare. Again, as last year, these projects have helped greatly increase the number of *"non-traditional"* users at CNS particularly in the life sciences and in several new emerging biomedical areas.

Facility, Tools and Staff Updates

This year we have not added any new permanent staff; but have expanded our instrumental research capabilities. A list of new instruments is below. We have expanded the capabilities available to the userbase, both in the nanofab and the other core instrumentation focused areas of the lab. The new tools and instrumentation include:

Imaging and Analysis additions

- Leicia NonLinear Microscope/FLIM System
- Hitachi 7800 120 keV TEM
- JEOL 7900 Analytical SEM
- NEXSA XPS/UPS System
- VitraBot Cryoplunge System

Nanofabrication additions:

- Oxford PECVD System
- Allwin RTP Furnace System
- PVD E-beam evaporator
- Film-Sense Wafer scan Ellipsometer

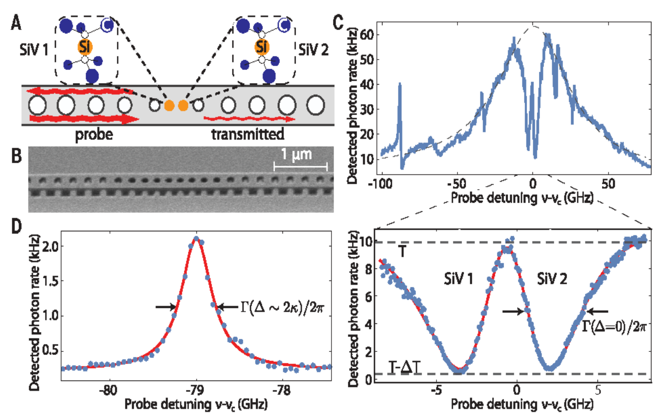
These new tools expand our analysis and processing capabilities. The FLIM system for example has been instrumental in our rapidly expanding efforts in the characterization of "2D Quantum Materials". (The system allows 2nd Harmonic imaging-based characterization of TMDC.)

User Base:

Once again, our accumulated user base topped 1650 active users (as of 12/10/2018). Moreover, again ~48% of our user base is external, 34% being external academic users and ~14% industrial users, (~70% of which are from small companies).

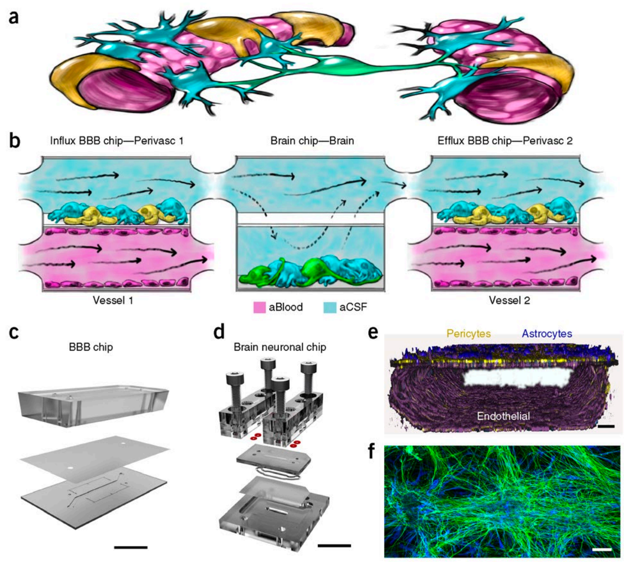
Research Highlights and Impact:

Quantum Engineering: *Photon-mediated interactions between quantum emitters in a diamond nanocavity.; R.E. Evans, R. E.; Bhaskar, M. K.; Sukachev, D. D.; Nguyen, C. T.; Sipahigil, A.; Burek, M. J.; Machielse, B.; Zhang, G. H.; Zibrov, A. S.; Bielejec, E.; Park, H.; Loncar, M.; Lukin, M. D.; Department of Physics, Harvard University, Institute for Quantum Information and Matter and Thomas J. Watson, Sr., Laboratory of Applied Physics, California Institute of Technology, John A. Paulson School of Engineering and Applied Sciences, Harvard University, Sandia National Laboratories, Department of Chemistry and Chemical Biology, Harvard University.* Photon-mediated interactions between quantum systems are essential for realizing quantum networks and scalable quantum information processing. The Loncar and Lukin groups have demonstrated such interactions between pairs of silicon-vacancy (SiV) color centers coupled to a diamond nanophotonic cavity. When the optical transitions of the two-color centers are tuned into resonance, the coupling to the common cavity mode results in a coherent interaction between them, leading to spectrally resolved superradiant and subradiant states. They use the electronic spin degrees of freedom of the SiV centers to control these optically mediated interactions. Such controlled interactions will be crucial in developing cavity-mediated quantum gates between spin qubits and for realizing scalable quantum network nodes. (*Reference: Science* ***362****, 662-665, 2018*)



High cooperativity SiV-photon interface. (A) Schematic of a diamond nanocavity containing two SiV centers. (B) Scanning electron micrograph of a nanocavity. (C) Transmission spectrum of the coupled SiV-cavity system (blue). The broad Lorentzian response of an empty cavity (dashed) is modulated by cavity-coupled SiVs. Near the cavity resonance (lower panel), two SiVs each result in greater than 95% extinction in transmission and are broadened by the Purcell effect [Γ(Δ = 0) = 2π x 4.6 GHz]. (D) In the dispersive regime (Δ =

Bionanotechnology Research: *A linked organ-on-chip model of the human neurovascular unit reveals the metabolic coupling of endothelial and neuronal cells; Ben M Maoz, Anna Herland, Edward A FitzGerald, Thomas Grevesse, Charles Vidoudez, Alan R Pacheco, Sean P Sheehy, Tae-Eun Park, Stephanie Dauth, Robert Mannix, Nikita Budnik, Kevin Shores, Alexander Cho, Janna C Nawroth, Daniel Segrè, Bogdan Budnik, Donald E Ingber and Kevin Kit Parker, Disease Biophysics Group, Harvard John A. Paulson School of Engineering and Applied Sciences, Harvard University, Wyss Institute for Biologically Inspired Engineering at Harvard University, Department of Biomedical Engineering, Faculty of Engineering, Tel Aviv University, Sagol School of Neuroscience, Tel Aviv University, The Center for Nanoscience and Nanotechnology, Tel Aviv*

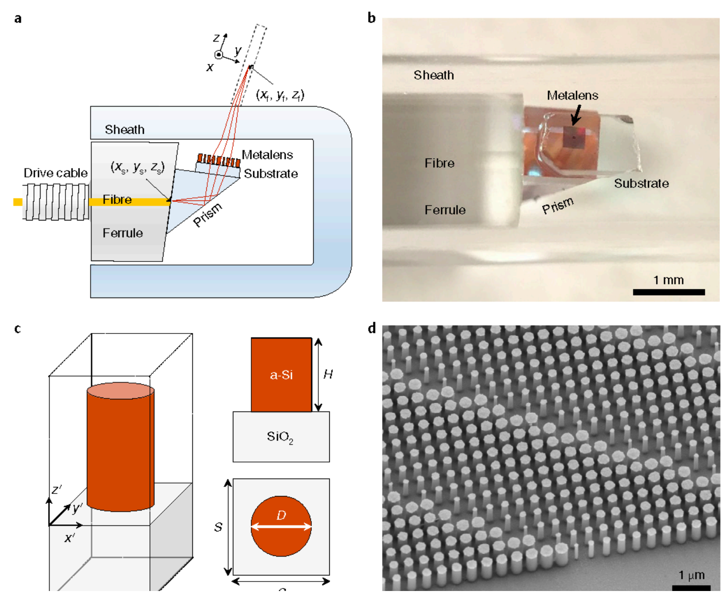


Decoupling the NVU. (a) Simplified anatomical illustration of the NVU, highlighting positions and cell–cell interactions between vascular endothelial cells (pink) that line brain blood microvessels (left, right) and surrounding perivascular pericytes (yellow) and astrocytes (blue) that form the (Brain Blood Barrier) BBB, as well as neighboring neurons (green) in the brain parenchyma. (b) Schematic of the experimental setup of NVU system. hBMVECs (magenta) are cultured on all four walls of the lower vascular compartment and a mixture of brain astrocytes (blue) and pericytes (yellow) in the top compartment of both BBB chips; human brain neuronal cells (green) and astrocytes (blue) are cultured in the lower compartment of the brain chip. Cell culture medium is flowed into the upper perivascular compartment of BBB chip as an artificial cerebral spinal fluid (aCSF, blue), and cell culture medium mimicking blood is flowed separately through the lower vascular compartment. Components that pass through the BBB perfuse into the perivascular fluid in the upper compartment and are transferred to the upper compartment of the brain chip. They pass by diffusion in and out of the lower neuronal cell compartment, and from there into the upper perivascular compartment of the BBBefflux chip, where some components pass back out into the vascular compartment. CAD illustration of the in vitro human NVU. (c) The BBB chip is composed of optically clear polydimethylsiloxane (PDMS) polymer containing two parallel hollow microchannels (compartments, 2 cm long x 1 mm wide); the top and bottom channels (1 and 0.2 mm high, respectively) were separated by a porous (0.4 µm diameter; 4 x 10^6 pores/cm^2) polyethylene terephthalate (PET) membrane coated with fibronectin and collagen IV (d) The brain chip is a polycarbonate microfluidic device containing two parallel channels (compartments, 2.5 cm long x 2.5 mm wide); the top and bottom channels (compartments, 0.2 and 1 mm high, respectively) were separated by a porous (5 µm diameter; 4 x 10^6 pores/cm^2) polycarbonate membrane (Fig. 1d). (e) Three-dimensional reconstruction of the human BBB chip from confocal fluorescence microscopic images showing the lower compartment covered by a continuous endothelial monolayer stained for VE-Cadherin (purple), and a mixture of pericytes (F-actin, yellow) and astrocytes (GFAP, blue) on

University, Department of Micro and Nanosystems, KTH Royal Institute of Technology, Swedish Medical Nanoscience Center, Department of Neuroscience, Karolinska Institute, Small Molecule Mass Spectrometry Facility, Harvard University, Graduate Program in Bioinformatics and Biological Design Center, Boston University, Vascular Biology Program and Department of Surgery, Boston Children's Hospital and Harvard Medical School, Department of Biology, Department of Biomedical Engineering, Department of Physics, Boston University, Mass Spectrometry and Proteomics Resource Laboratory, Harvard University, Harvard John A. Paulson School of Engineering and Applied Sciences, Harvard University. The neurovascular unit (NVU) regulates metabolic homeostasis as well as drug pharmacokinetics and pharmacodynamics in the central nervous system. Metabolic fluxes and conversions over the NVU rely on interactions between brain microvascular endothelium, perivascular pericytes, astrocytes and neurons, making it difficult to identify the contributions of each cell type. Here the Parker group has modeled the human NVU using microfluidic organ chips, allowing analysis of the roles of individual cell types in NVU functions. Three coupled chips model influx across the blood–brain barrier (BBB), the brain parenchymal compartment and efflux across the BBB. They used this linked system to mimic the effect of intravascular administration of the psychoactive drug methamphetamine and to identify previously unknown metabolic coupling between the BBB and neurons. Thus, the NVU system offers an in vitro approach for probing transport, efficacy, mechanism of action and toxicity of neuroactive drugs. (*Reference: Nature Biotechnology Vol 36, 9, 2018*).

NanoPhotonics: *Nano-optic endoscope for high-resolution optical coherence tomography in vivo;Hamid Pahlevaninezhad, Mohammadreza Khorasaninejad, Yao-Wei Huang, Zhujun Shi, Lida P. Hariri, David C. Adams, Vivien Ding, Alexander Zhu, Cheng-Wei Qiu, Federico Capasso and Melissa J. Suter Department of Medicine, Pulmonary and Critical Care Division, Massachusetts General Hospital and Harvard Medical School, Harvard John A. Paulson School of Engineering and Applied Sciences, Harvard University, Department of Electrical and Computer Engineering, National University of Singapore, Department of Physics, Harvard University, University of Waterloo.* Acquisition of high-resolution images from within internal organs using endoscopic optical imaging has numerous clinical applications. However, difficulties associated with optical aberrations and the trade-off between transverse resolution and depth of focus significantly limit the scope of applications. Here, the Capasso Group integrates a metalens, with the ability to modify the phase of incident light at subwavelength level, into the design of an endoscopic optical coherence tomography catheter (termed nanooptics endoscope) to achieve near diffraction-limited imaging through negating non-chromatic aberrations. Remarkably, the tailored chromatic dispersion of the metalens in the context of spectral interferometry is utilized to maintain high-resolution imaging beyond the input field Rayleigh range, easing the trade-off between transverse resolution and depth of focus. They demonstrate endoscopic imaging in resected human lung specimens and in sheep airways in vivo. The combination of the superior resolution and higher imaging depth of focus of the nano-optic endoscope is likely to increase the clinical utility of endoscopic optical imaging. (*Reference: Nature Photonics Vol 1, 540-547,* 2018)

Nano-optic endoscope design and fabrication. **a**, Schematic of the nano-optic endoscope. The metalens was designed to image a point source at (x_s, y_s, z_s) to a diffraction-limited spot at (x_f, y_f, z_f) with working distance WD = 0.5 mm. **b**, Photographic image of the distal end of the nano-optic endoscope. **c**, Schematic of an individual metalens building block consisting of an amorphous silicon (a-Si) nanopillar on a glass substrate. The nanopillars have height H = 750 nm and are arranged in a square lattice with unit cell size S = 400 nm. Phase imparted by a nanopillar is controlled by its diameter (D). **d**, Scanning electron micrograph image of a portion of a fabricated metalens.



Education & Outreach Activities

This year's REU and REV students were again chosen using a joint Harvard website hosting potential research projects campus wide. The students selected, their institution, and their summer project and Mentor/Mentors are listed in the table below. *Note the Vet participants are* ***bolded*** *in the table.* PI Westervelt and co-PI Wilson again used 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 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 BunkerHill Community College. BHCC has a very vibrant STEM focused directed at VETs. As part of our traditional REU program, this year we again solicited summer research projects from the entire CNS user base, (both internal and external). The goal, to foster new strong interactions between staff and research groups. The selected projects are also listed below.

Student Interns and Projects for FY18

Last	First	Home Institution	Major	Project
Baublis	Andrew	University of Notre Dame	Chemistry	Using Large Footprint Area Organic Ligands to Build Nanocluster Architectures
Davis	**Ethan**	**Dartmouth College**	**Biomedical Engineering**	**Liquid metal infused slippery surfaces with switchable wettability**
Draper	Chelsea	University of New Mexico	Chemical Engineering	Nanoelectrodes for redox flow batteries
Feeney	Stanley	University of Massachusetts - Lowell	Chemical Engineering - Nanomaterials Option	Photonic Wire Bonding using 3D laser lithography
Maldonado Luna	Nadja	Universidad üe Puerto Rico - Recinto de Mayagüez	Mechanical Engineering	Application of temperature sensitive tough adhesive biomaterials to improve tendon repair
Quiros Cordero	Victoria	Universidad de Costa Rica	Physics	A Molecular Diode Switched by Supramolecular Chemistry
Villareal	**Daniel**	**Bunker Hill Community College**	**Biology**	**Fabrication and metrology for laser-activated gene therapy devices**
Vu	Dylan	Cornell University	Chemical Engineering	Electrochemical Detection of Important Health Biomarkers at the Point-of-Care

Morales	Javier	Inter American University of PR - Bayamon campus	Mechanical Engineering	3D Printing of Dielectric Elastomer Actuators
McDaniel	**Karlie**	**Bunker Hill Community College**	**Radiography**	**Characterization of ALD Gate Oxide Films via electrical measurements, XPS, and other techniques**
Brooke	**Aaron**	**Bunker Hill Community College**		**Building a time resolved Photoluminescence Microscope**
Kuhn	**Ethan**	**Bunker Hill Community College**		**TBD**

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 and their institutions are listed in the table below. 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 possibly inclusion of some of these bioscience teams in CNS Scholars.

CNS Scholars

First Name	Last Name	Current Institution
Atefeh	Rahmani	Umass - Dartmouth
Ryotaro	Aso	Osaka University
Kristen	Dorsey	Smith
Stanley	Feeney	Umass - Lowell
Daniel	Getega	Harvard
Katie	Hills-Kimball	Brown
Renita	Horton	Mississippi State
Aaron	Jackson	Howard
Ethan	Kuhn	Bunker Hill CC
Karlie	McDaniel	Regis College
Stefano Luigi	Oscurato	University of Naples
Cigdem	Ozsoy Keskinbora	CQIM

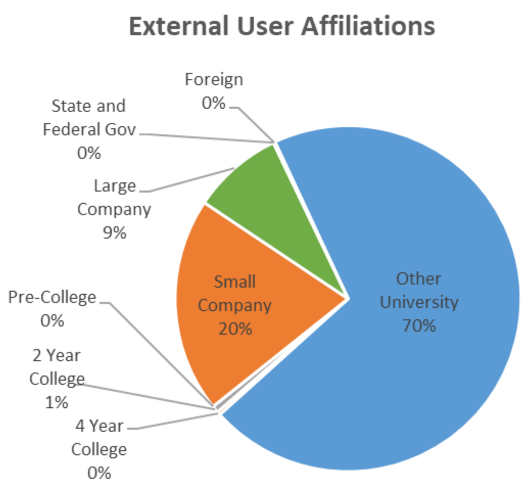
Yi Ming	Qin	Harvard
Mehdi	Rezaee	Howard
Maurizio	Ritzer	U of Jena
Thomas	Searles	Howard
Amirhassan	Shams Ansari	Howard
Guillermo	Solorzano	PCU of Rio de Janeiro
Christina	Viray	U of Sydney
Pheona	Williams	Howard
Amber	Wingfield	Howard
Maximilian	Zapf	U of Jena

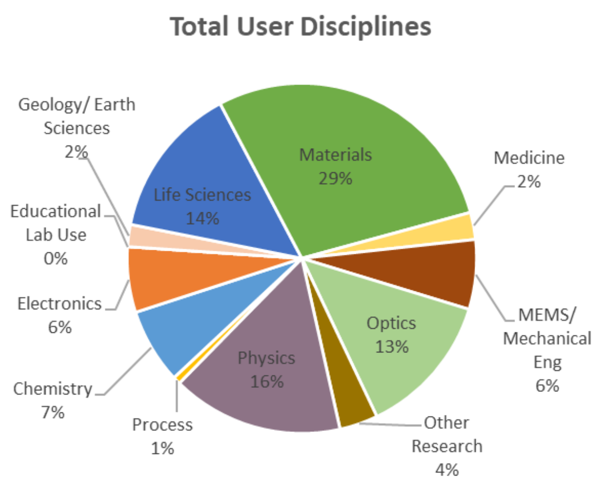
The senior leadership team has also continued visiting current and potential users throughout Northeast and the within the Cambridge area to assess overall user needs community-wide. *One new initiative this year has been expansion of our support to the New England start-up community.* Here in particular, 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. 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. We plan a start-up *"Boot Camp"* this spring as a vehicle to teach the userbase the promise and pitfall of Start-ups. We have 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 will be open to the entire NNCI network.

CNS Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	1,023	1,251	1,322
Internal Cumulative Users	562	678	700
External Cumulative Users	461 (45%)	573 (46%)	622 (47%)
Total Hours	174,710	181,826	185,288
Internal Hours	124,256	133,020	126,662
External Hours	50,454 (29%)	48,806 (27%)	58,626 (32%)
Average Monthly Users	511	514	538
Average External Monthly Users	201 (39%)	196 (38%)	218 (40%)
New Users	415	404	452
New External Users	196 (47%)	200 (50%)	233 (52%)
Hours/User (Internal)	221	196	181
Hours/User (External)	109	85	94

Year 3 User Distribution





11.2. Cornell Nanoscale Science and Technology Facility (CNF)

Facility, Tools, and Staff Updates

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. The following tools, processes, facilities and software have been acquired or developed over the past year.

New Tools	New Processes
OEM Piezoelectric Split Cathode Sputter Deposition System (installed)	Block Copolymer Lithography
AJA Orion 8 load locked sputter deposition (delivered)	Improved Photocurable NanoImprint Lithography
YES Image Reversal System (installed)	Etching processes for Expanded Metals and Transition metal di-chalcogenides
Filmetrics F40UV ultra-thin film measurement system (installed)	Deep Etch (modified Bosch Process) for Germanium
Malvern ZS ZetaSizer (installed)	
Malvern NS300 Nanosight (installed)	

User Base

CNF established a set of specific milestones to measure our success in serving users, particularly external users, and measuring our other proposed goals. We were successful in meeting our benchmarks. Over the prior 12 months CNF hosted 556 unique users, among them 191 (34%) external users who alone clocked over 33,000 hours of cleanroom plus equipment hours. External user fees were $2.07M out of a total of about $3.12 M (66%), and our median Likert scale score for user satisfaction was 4.67/5 with 99% stating they would recommend CNF to their colleagues. Overall cleanroom hours were over 45,000 and our monthly average number of users was 225 (up 5% over last year). Using the NNCI categories 54% of users and 44% of CNF usage is from non-traditional fields. Remote usage serves as a way to engage future users, achieve higher tool utilization, and enhance the NNCI network value to users. This year 42 remote jobs were completed by staff. All other user stats have been collected by the NNCI coordinating site and are presented elsewhere in this report.

Research Highlights and Impact

Research reports are provided annually for many projects and are published as *CNF Research Accomplishments* and online at http://www.cnf.cornell.edu/cnf_2017ra.html. For calendar year 2017, users reported 450 different publications (201), conference proceedings (136), and patents (113 disclosures + applications + issued). Here we highlight five of the many significant research projects enabled by CNF in the past year.

- In ***Nature Nanotechnology***, the Wanunu team (Northeastern) and scientists from Pacific BioSciences use the CNF to show that the efficiency of voltage-induced DNA loading into nanopores in waveguides is five orders of magnitude greater than existing methods. Compared to conventional methods, single molecule, real-time (SMRT) DNA sequencing exhibits longer read lengths than conventional methods. They here find that DNA loading is nearly length-independent. The authors demonstrate loading and proof-of-principle four-colour sequence readout of a polymerase-bound 20,000 base-pair long DNA template within seconds from a sub-ng input quantity, a step towards low-input DNA sequencing and mammalian epigenomic mapping of native DNA samples. (supported by NIH)
- In ***Science***, McEuen et al. (Cornell) use CNF to show that excitons, the bound states of an electron and a hole in a solid material, play a key role in the optical properties of insulators and semiconductors. They observed excitons in bilayer graphene using photocurrent spectroscopy of high-quality BLG encapsulated in hexagonal boron nitride. They observed two prominent excitonic resonances with narrow line widths that are tunable from the mid-infrared to the terahertz range. These excitons obey optical selection rules distinct from those in conventional semiconductors and feature an electron pseudospin winding number of 2. An external magnetic field induces a large splitting of the valley excitons, corresponding to a g-factor of about 20. These findings open up opportunities to explore exciton physics with pseudospin texture in electrically tunable graphene systems. (supported by NSF, AFOSR)
- In ***Science***, Khodagholy et al. (NYU) and colleagues at Columbia used the CNF to produce a conducting polymer-based conformable microelectrode array (NeuroGrid) and used it to record local field potentials and neural spiking across the surface of a rat brain, and combined with silicon probe recordings in the hippocampus, to identify candidate physiological patterns. Although experimental evidence supports the role of sharp-wave ripples in transferring hippocampal information to the neocortex, the exact destinations and the mechanisms of such transfer are unknown. Parietal, midline, and prefrontal, but not primary cortical areas, displayed localized ripple (100 to 150 Hz) oscillations during sleep, concurrent with hippocampal ripples. Coupling between hippocampal and neocortical ripples strengthened during sleep following learning, suggesting ripple-ripple coupling supports memory transfer. (supported by NIH and DARPA)
- In ***Nature***, Park et al. (Chicago) use the CNF to assemble multilayer stacks of graphene and transition-metal dichalcogenides—which represent one- and three-atom-thick two- dimensional building blocks, respectively—and to realize previously inaccessible heterostructures. Here Park et al. report the generation of wafer-scale semiconductor films with a very high level of spatial uniformity and pristine interfaces designed at the atomic scale using layer-by-layer assembly of two-dimensional building blocks under vacuum. They fabricate superlattice films with vertical compositions designed layer-by-layer, batch-fabricated tunnel device arrays with resistances that can be tuned over four orders of magnitude, band-engineered heterostructure tunnel diodes, and millimeter-scale ultrathin membranes and windows. The stacked films are detachable, suspendable and compatible with water or plastic surfaces, to enable their integration with advanced optical and mechanical systems. (supported by NSF, AFOSR)
- In ***Nature Communications*****,** Fuchs (Cornell) and colleagues at Argonne National Labs used the CNF to experimentally demonstrate that the spin–strain coupling in the excited state is 13.5±0.5 times stronger than the ground state spin–strain coupling. Cooling a mechanical resonator mode

to a sub-thermal state has been a long-standing challenge in physics. An alternate method is to couple the resonator to a well-controlled two-level system. Here they propose a protocol to dissipatively cool a room temperature mechanical resonator using a nitrogen-vacancy center ensemble. The spin ensemble is coupled to the resonator through its orbitally-averaged excited state, which has a spin–strain interaction that has not been previously studied. They then theoretically show that this interaction, combined with a high-density spin ensemble, enables the cooling of a mechanical resonator from room temperature to a fraction of its thermal phonon occupancy. (supported by ONR and NSF)

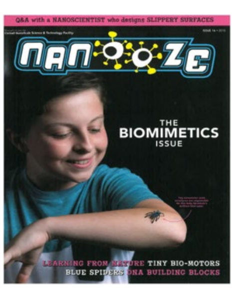
CNF continue to serve as an engine for economic development for small businesses. We supported projects from 51 companies and recorded two more startups this year. We established a partnership with the Fraunhofer Institute in Dresden for providing foundry services for manufacturing chip-based products for small companies. We also learned that Pacific Biosciences, a former CNF startup, was acquired for $1.2B this year.

Education and Outreach Activities

CNF supports a broad range of educational and outreach activities. In 2017-18 CNF hosted 164 individual events with over 3100 direct participants.

Research Experience for Undergraduates (REU): In 2018, CNF hosted five students including 1 woman, 1 underrepresented minority student and 3 from non-R1 institutions. We included an additional 16 interns from other REU funding sources into our cohort for the summer. Research reports are available at http://www.cnf.cornell.edu/cnf_2018reu.html

International Research Experience for Undergraduates: CNF coordinated an NNCI signature international research program for undergraduates selected from the prior year REU program and given an opportunity for a 2nd summer advanced research experience with the National Institute of Materials Science in Tsukuba, Japan. Six students from across the 2017 NNCI REU programs were selected for this program in 2018 performed projects in Japan and returned to join in the REU convocation. As a reciprocal program to the IRES funded iREU program, Cornell placed one Japanese graduate student at the Nebraska NNCI site for this summer. Twenty-three projects were volunteered by NNCI sites for 2019. So we expect significant growth in this program next year.



Nanooze: CNF produces and distributes Nanooze, a children's science magazine relating to nanotechnology. Nanooze (http://www.nanooze.org/) is both a web-based and printed magazine, with kid-friendly text, topics, and navigation. Nanooze is edited by Cornell Professor Carl Batt; it is distributed to ~1300 classrooms and through many other channels throughout the US. We print 100,000 copies per issue as requests from classroom teachers continue to grow. The newest issue is on Biomimetics is shown at left.

NSF Disney Science Portal: Working with Prof. Carl Batt, CNF has updated the existing "Take a Nanooze Break" exhibit at Disney EPCOT into a more universal and maintainable "NSF Disney Science Portal" to highlight a range of current NSF nanotechnology research. The interactive exhibit was completed this year and is open to the public! It is expected to receive hundreds of thousands of visitors each year.

TCN – Technology and Characterization at the Nanoscale: CNF offered an introductory short course on nanotechnology (TCN – Technology and Characterization at the Nanoscale) semi-annually during the summer and winter recess, so that interested students from universities and industry can easily participate. Under NNCI we are offering TCN free to grad students from external US colleges and universities. Over forty students and scientists registered for the two courses offered this year. The course includes lectures and laboratory demonstrations as well as hands-on equipment sessions. Participants uniformly recommend the course to others.

4-H: CNF is teaming with 4-H to host STEM activities and to use 4-H as a distribution network for demonstration materials and Nanooze science magazines. We hosted a large campus visit of 4-H members for their “Career Explorations” featuring hands-on STEM nanotechnology activities.

CNF Annual Users Meeting was held this fall featuring keynote speaker Cyrus Mody, author of “The Long Arm of Moore’s Law,” 14 Invited Talks, 60 Student Posters, 24 Company Sponsors, and nearly 200 attendees.

Whetton 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, was awarded by CNF to Ph.D. student, Samantha Norris.

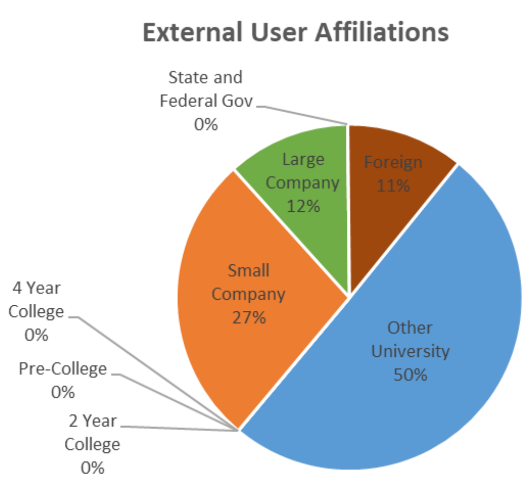
Junior FIRST Lego Expo (~300 attendees) featuring 23 teams of 6-10 year olds presenting their displays on an “Aqua Adventure” theme. CNF sponsored the event and staff and users served as reviewers.

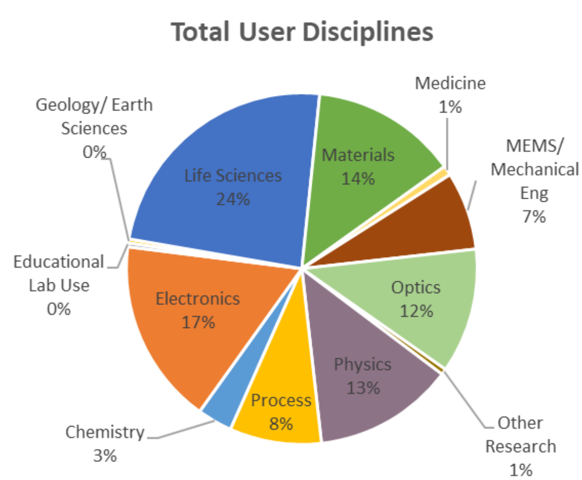
Publications: CNF published two *Nanometer* newsletters (latest at http://www.cnf.cornell.edu/doc/2018cnfNM_v27n2.pdf), an annual *Research Accomplishments*, an REU Research Reports compendium, and several promotional brochures. These periodic publications are all available in pdf format on our website.

CNF Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	548	538	556
Internal Cumulative Users	325	330	365
External Cumulative Users	223 (41%)	208 (39%)	191 (34%)
Total Hours	40,544	45,340	53,680
Internal Hours	22,965	25,201	31,143
External Hours	17,579 (43%)	20,139 (44%)	22,537 (42%)
Average Monthly Users	210	204	225
Average External Monthly Users	67 (32%)	66 (32%)	68 (30%)
New Users Trained	131	161	174
New External Users	46 (35%)	51 (32%)	42 (24%)
Hours/User (Internal)	71	76	85
Hours/User (External)	79	97	118

Year 3 User Distribution





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

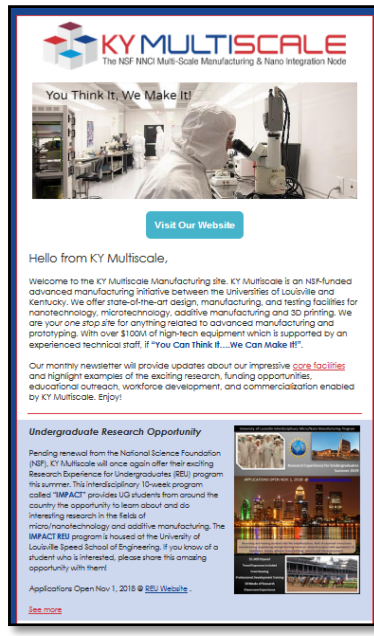
Facility, Tools, and Staff Updates

Year 3 continued to be a busy and productive period for the new KY MMNIN NNCI site (i.e. KY Multiscale). One of the major highlights for KY Multiscale was exceeding $1M in revenues for the first time, ***up an impressive 52% from year 1***. This demonstrates the large impact that being a part of the NNCI has on our regional site. Other activities include the following. The University of Louisville acquired an adjacent building and set up metals additive manufacturing training facility called the Additive Manufacturing Competency Center (AMCC). Together with the UofL Rapid Prototyping Center, they offer all types of 3D printing and additive manufacturing services to our clients. A new state-of-the-art Nanoscribe two-photon lithography system was purchased for printing three-dimensional structures with nano-meter resolution. This major addition is housed at the University of Kentucky's CeNSE core facility. An important repair was made to UofL MNTC's 20-year old Deep Reactive Ion Etching (DRIE) System, which had been down for several months. This included the purchase of a new turbo pump and controller. The UofL CCRER core facility acquired two new pieces of equipment, a Water Vapor Permeability Analyzer and a Gas Permeability Analyzer. These tools are used by the food, pharmaceutical, personal care, household, and electronics industries to test the (vapor and gas) transmission rate of various packaging materials, such as plastic film, composite film, coextrusion film, aluminum foil, paper, cellophane, ceramic and porcelain. The UofL RPC core facility acquired an EOS M290 Direct Metal Laser Sintering tool that uses a 400W laser to selectively melt metal powders layer by layer driven from a CAD file. It can create complex shapes and lattice structures difficult or impossible to create via traditional manufacturing processes. It is capable of fabricating with any alloy that is available in powder form, including stainless steels, titanium, nickel alloys, CoCr and aluminum. The maximum size is approximately 10x10x10 inches. The UofL Huson Metrology core facility acquired a Bruker Energy Dispersive X- ray Spectrometer Quantax Compact to replace its old/broken EDAX EDS detector on their Zeiss Supra SEM. The Quantax Compact is an easy-to-use EDS system for qualitative and quantitative microanalysis in industry, research and education. The system's standardless quantification software enables manual, automatic or interactive spectra evaluation and provides reliable results for specimens with polished or rough surfaces. The Quantax Compact features a powerful scanning system for the acquisition of images, line scans with PTS functionality and HyperMaps (hyper-spectral mapping) including online deconvolution. The UK EMC node acquired a new state-of-the-art transmission electron microscope (FEI Talos F200X), and in July the EMC also installed a new high temperature stage and transmission electron detector for wet samples for its FEI Quanta 250 environmental SEM, opening up many research opportunities with the life science community.

Finally, a major equipment proposal to the NSF MRI program was funded which will directly benefit KY Multiscale. UofL Endowed Prof. Dan Popa received $1.5M for the development of a Multiscale Additive Manufacturing Instrument with an Integrated 3D Printing and Robotic Assembly. This "NEXUS" system will strategically combine fused deposition modeling (FDM), aerosol jet printing, ultrasonic metal additive manufacturing, fiber weaving, pick and place, intense pulsed laser (IPL) annealing, and optical/electrical inspection in a single robotic autonomous system. The Nexus system will be used for the automated fabrication of smart AM components, microsystems, microrobots, distributed sensors/actuators, soft robots, and wearables. This tool will be housed in KY Multiscale.

<u>User Base</u>

KY Multiscale organized and hosted an annual symposium focused on the intersection of Nanotechnology and Advanced Manufacturing (KY Nano+AM Symposium). This annual conference included an Industry Outreach Day where potential industrial users toured our core facilities. The goal of the 2018 KY Nano+AM Symposium was 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 venue for the 2018 KY Nano+AM Symposium was the newly-renovated Speed Art Museum on the UofL campus. It was held on August 1-2, 2018. The symposium brought together 140 participants from industry and academia. The 2-day agenda consisted of parallel technical and business sessions, several joint keynote presentations by national renown speakers, poster presentations, sponsorship opportunities, food and refreshments, core facility tours, and a valuable evening networking reception. Local dignitaries included the Mayor of Louisville and the President of UofL.

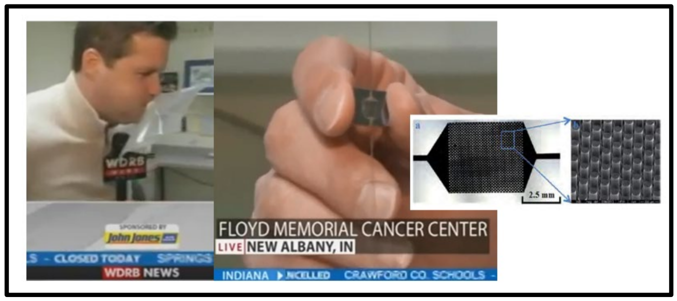


In year 3 we expanded the marketing effort of our NNCI site by engaging an outside professional service to develop a KY Multiscale Nano+AM monthly newsletter. Our first issue was released this fall (right) and included important information about our site's activities and initiatives (new capabilities, new research results, upcoming conference and seminar opportunities, undergraduate research opportunities, etc). Our newsletter is distributed to over 900 recipients nationally. Our consulting service keeps valuable statistics so we can continually improve our content and distribution.

In addition to the newsletter, we initiated a focused email campaign to advertise our core facilities to local and regional industries. We designed electronic color-coordinated 2-sided brochures for each of our core facilities with descriptions of each, lists of available resources, example projects, and contact information. Industries targeted were national recipients of SBIR/STTR Phase I and II funding in energy, technology development, advanced manufacturing, and additive manufacturing as well as American universities with specific programs in these areas.

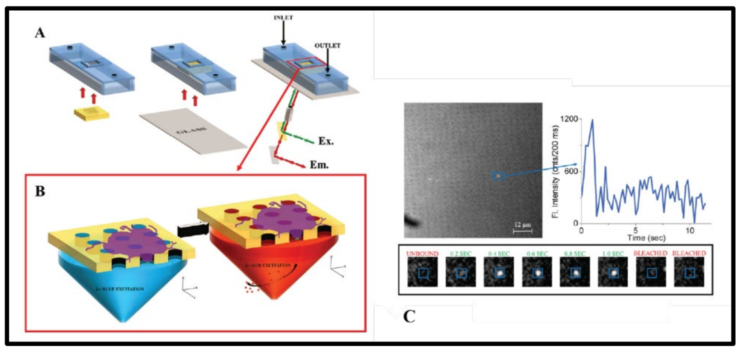
<u>Research Highlights and Impact</u>

Breathalyzer Diagnostic Device for Cancer Detection: Breath Diagnostics Inc is a new company started by Professors Sean Fu (UofL ChE) and Michael Nanz (UofL Chemistry) with the mission to globally implement breath analysis technology to provide early detection for cancers and reduce patient exposure to costly, high risk medical procedures (www.breathdiagnosticsinc.com). They have developed a patented technology that will determine if a patient has lung cancer by analyzing cancer metabolites in a patient's breath with parts-per-billion (ppb) concentrations, allowing very early detection. The company received NSF SBIR Phase I funding in 2017 and subsequent funding from a number of Angel investors. It has two full time PhD scientists and two part-time employees. The short-term goal of the company is to bring the breath analysis technology to market as a lab-developed-test (LDT) for clinical applications. To date, they have studied over 700 patients. This technology has the potential to save a significant number of lives and save the healthcare industry significant dollars. Their device was developed using the core facilities of KY Multiscale and the faculty expertise at UofL. A patient's breath is captured in a specimen bag. The contents of the bag are then drawn through a specially developed MEMS/nano chip containing thousands of coated micro-pillars at a specific rate to optimize the interaction with the chip. The chip can then be further processed to detect if a patient has lung cancer. The custom microchip, bag assembly, and device enclosure were fabricated using three of KY Multiscale's core facilities (UofL MNTC, Huson and RPC).



Custom microchip developed by Breath Diagnostics Inc for detecting cancer.

Nano-aperture Optical Sensor for Ligand Detection: Professors Christine Trinkle (UK ME) and Christopher Richards (UK Chemistry) developed nano-aperture optical sensors for detecting single ligand binding on cell surfaces. The sensors were fabricated partly at KY Multiscale's CeNSE core facility and partly at Oak Ridge National Laboratory. The sensors consist of gold nano-apertures on a silicon nitride membrane incorporated into a glass and PDMS flow cell. Mouse neuroblastoma cells were cultured on the arrays and singled molecules of labeled epidermal growth factor were detected. Such sensors will enable the study of receptor-ligand binding on the surface of live cells while maintaining the cells in a more natural environment. This work was recently published in *ACS Omega.*



Nanoaperature microfluidic device for optical detection of single-ligand interactions with cells. (a) Microfluidic cell. (b) Gold nanoaperature array on a silicon nitride membrane with cultured cells. (c) Demonstration of fluorescence detection of single-ligand binding.

<u>Education and Outreach Activities</u>

KY Multiscale continued to promote and engage the public in Nanotechnology by organizing and participating in numerous outreach events locally. In addition to National Nanotechnology Day, KY Multiscale celebrated National Advanced Manufacturing Day at our state science museum, the Kentucky Science Center located in Louisville. This year approximately 1,500 visited the museum for the coordinated festivities.

National Nanotechnology and Advanced Manufacturing Days at the Kentucky Science Center

KY Multiscale completed the third year of its NNCI-complementary NSF REU program called IMPACT. The IMPACT program hosted 9 students (half from under-represented populations and locations in the state). The goal of our IMPACT REU program was to demonstrate how micro/nano-technology can be used to create new devices and systems capable of "impacting" the grand challenges of today in energy, healthcare, advanced manufacturing, security and the environment. All of our REU students received a unique NNCI-related hands-on cleanroom experience where they each fabricated and tested a photovoltaic device. In addition to that, they were assigned to individual faculty-mentored research projects involving some aspect of micro/nanotechnology. During the ten weeks of the program, the students attended numerous research related talks, workshops, and coordinated social activities. All of our 9 students participated in the national NNCI REU Convocation hosted by North Carolina State University, Duke University, and University of North Carolina in Chapel Hill.

The University of Kentucky also offered a NNCI-related REU program in Engineered Bioactive Interfaces and Devices directed by Prof. Kim Anderson. During the first week of the program, all of their students were introduced to the UK CeNSE and EMC core capabilities and associated research activities. A number of their students used the KY Mutliscale core facilities' instrumentation for their summer research projects.

Girl scouts visit to the NGS Group Robotics Lab

During year 3, we continued to expand our offerings of education and outreach activities for our site. The KY Multiscale conducted events with other laboratories within the engineering school to show how nanotechnology interacts with our daily lives from cell phones to robotics to cosmetics, including a group of Girl Scouts who visited the Next Generation Robotics lab at UofL.

The KY Multiscale UofL CCRER core facility continued to run summer camps, as well as the *2018 High School Science Fair Summer Camp,* which included 30 Eastern Kentucky rural Promise Zone students. The KY Multiscale UofL CCRER staff also participated in the ACC Inventure, which is a provost-supported entrepreneurial competition based upon a model at Georgia Tech. This year a team of mechanical engineers were mentored by the CCRER staff and competed against other ACC teams at Georgia Tech on April 4-5.

Additive Manufacturing Workshop for Community College and High School Teachers

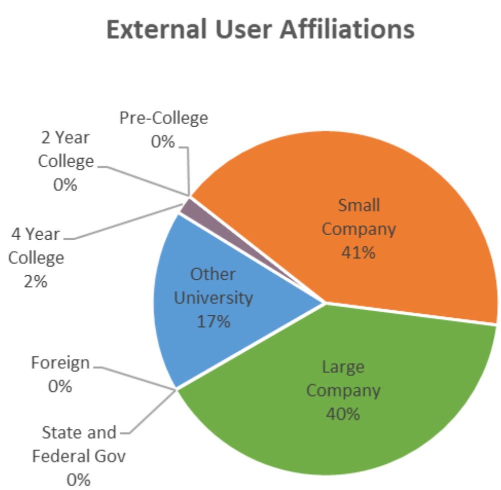
The KY Multiscale UofL RPC core facility hosted a one-day additive manufacturing workshop at the Speed School's Engineering Garage on December 8th (left). Supported by an NSF sponsored project called AM-WATCH, and in collaboration with Tennessee Tech University, this program provided AM (additive manufacturing) curriculum and educational materials for community college and high school instructors. Attendees at this workshop received a 3D Printer Classroom Kit for their school, including software, student exercises, curriculum examples and student modules.

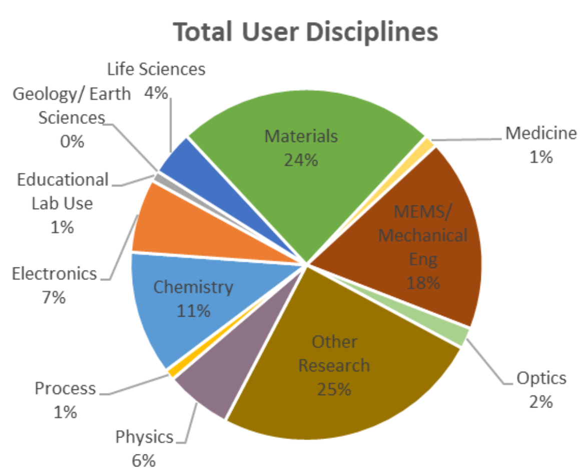
The KY Multiscale UK EMC and CeNSE core facilities participated in the University of Kentucky's engineering day in February. Approximately 3,000 people attended a variety of events including demonstrations of electron microscopy and electron-beam induced material processing.

KY MMNIN Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	278	420	411
Internal Cumulative Users	206	315	300
External Cumulative Users	72 (26%)	105 (25%)	111 (27%)
Total Hours	14,629	17,151	17,301
Internal Hours	9,726	12,166	10,960
External Hours	4,903 (34%)	4,986 (29%)	6,341 (37%)
Average Monthly Users	104	141	120
Average External Monthly Users	22 (21%)	25 (18%)	25 (21%)
New Users	111	251	164
New External Users	26 (23%)	43 (17%)	28 (17%)
Hours/User (Internal)	47	39	37
Hours/User (External)	68	47	57

Year 3 User Distribution





11.4. Mid-Atlantic Nanotechnology Hub (MANTH)

The Mid-Atlantic Nanotechnology Hub (MANTH) at the University of Pennsylvania Singh Center for Nanotechnology provides open access to leading-edge R&D facilities and expertise for academic, government, and industry researchers conducting activities within all disciplines of nanoscale science, engineering, and technology. Users from 35 states and territories, and 5 foreign countries have taken advantage of full access to state-of-the-art instrumentation for the fabrication and characterization of nanoscale structures, devices, and materials. Further, MANTH provides a portal for users to access the intellectual expertise of the Penn faculty and staff in the nano-arena and to other relevant facilities at Penn. Our hub includes a partnership with the Community College of Philadelphia; we collaborate on workforce development activities aimed at training technicians for the nanotechnology industry. After extensive interactions with industry and polling their needs, a prototype curriculum was developed. The first students are expected to be taught in 2019.

MANTH staff continues to take on leading roles in the NNCI community by overseeing Working Groups in Photolithography and in Equipment, Maintenance, and Training. Recently, a MANTH staff member assumed leadership of the Vendor Relations Working Group. The Director of our site heads the NNCI Commercialization Committee.

MANTH plays a leadership role in the larger Nanotech community as well. Noah Clay, Director of the Quattrone Nanofabrication Facility, was the Conference Chair of the UGIM Symposium, hosted by the University of Pennsylvania in June 2018. The conference consisted of 41 presentations on nanotechnology laboratory management, safety, and training; it attracted over 290 experts in the operation of research and low volume manufacturing cleanrooms, hailing from 21 nations.

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

In 2017-2018, MANTH added several new pieces of equipment to our fabrication and characterization facilities. These capital investments totaled \$5.4M and include 2 new electron microscopes, scanning probe improvements, and 4 process furnaces.

An image of the JEOL NEOARM transmission electron microscope currently being installed at MANTH.

1) The JEOL NEOARM is a scanning / transmission electron microscope, equipped with a spherical aberration corrector for the probe-forming optics. This corrector has improved stability and optimizes 5th order aberrations, leading to <0.7Å imaging at 200kV.
2) The JEOL F200 is a 200kV scanning / transmission electron microscope with a cold field emission source, two large area energy dispersive x-ray spectrometers, and Gatan OneView IS camera for in-situ/operando imaging at 30 frames per second.
3) A 3rd laser (491 nm) for the Raman-NSOM system was installed to complement the wavelengths of the existing lasers. The 491 nm laser provides higher spatial resolution and improved Raman yield.
4) A DISCO-TIRF illumination attachment was installed to improve MANTH's fluorescence microscopy capabilities. Disco TIRF is a special implementation of Total Internal

Reflection Fluorescence microscopy that introduces a pivoting mirror to rotate the source of the laser illumination, forming sharper fluorescence images.

5) A 4-stack MRL Cyclone furnace from Sandvik Thermal Process Inc. has been installed. The system is designed to accommodate sample sizes ranging from pieces to full 150 mm wafers and up to a load of 50 wafers and consists of a SiNx deposition tube, a Si oxidation tube and 2 annealing tubes.

User Base

Nearly 600 researchers made use of the MANTH facility in 2017-18. Approximately one third of our users are external, nearly equally split between academic and industry. Approximately 20% of the research conducted here is in the life sciences and medicine.

MANTH has seen an increase in the cumulative number of remote users, in part due to the concerted efforts to attract remote users from outside academia and industry and to offer staff expertise to facilitate their work. Forty-nine remote users conducted research at MANTH through the staff, a 20% increase over last year.

Research Highlights and Impact

MANTH researchers published over 240 papers and presented work at over 50 conferences in calendar year 2017. Twenty-four papers were published in the nanotechnology-centric journals *Nature Nanotechnology*, *ACS Nano*, *Nano Letters*, *Nanoscale*, *Small*, *Nanotechnology Advances*, and *Nano Today*.

MANTH has collected information on the progress of small companies who were winners of the 3 rounds of the NNCI-funded MANTH Seed Grant Competitions. The Seed Grants consist of a few-thousand-dollar-each allowances to be used for MANTH facility access. One way to quantify the economic impact of these grants is to look at how the grantees leveraged the lab use to get additional funding. Folia Water, a 2017 grantee, has received $400k DFID transformation grant to further develop their inexpensive way to purify water. Other grantees, Graphwear and Group K Diagnostics, each received $2M in Series A venture capital. Almost $5M in external funds has been awarded to Seed Grant winners since the start of the program.

Education and Outreach Activities

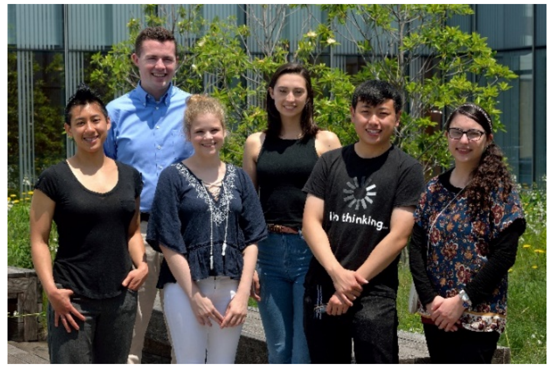
Over 100 researchers participated in the popular MANTH microfluidics workshops, where attendees fabricate and test prototype devices. In the past year, 2 advanced workshops were added to complement the core program. Below are their titles and descriptions:

- Solving Problems in Microfluidics - “It's one thing to make a microfluidic chip. It's another to get it working in the lab. Try setting up sample devices in the Soft Lithography lab at the Singh Center. Learn how to assemble devices, fill them, and avoid bubbles.”
- Two-Level Microfluidic Fabrication - “Learn to the alignment process to fabricate more complex two-layer devices that allow you to generate mixing and control flow.”

MANTH also hosted in-cleanroom hands-on fabrication events for over 40 STEM students from the local colleges Swarthmore, Villanova, and Bryn Mawr.

Last year, MANTH hosted a group of 155 high school students from around the greater Philadelphia region for a day of STEM related fun and learning. These students were treated to a whole host of “nano-related” activities, including: microscopy demonstrations, a window tour of the Singh Center’s Cleanroom and a hands-on microfluidics activity. Among the most popular activities for both the high school students and for the University of Pennsylvania volunteers who support this event were the 10 different nanotechnology demonstration tables.

The Summer 2018 REU cohort consisted of six students who were juniors (N=4, including 1 non-traditional student whose first bachelor's degree was in the humanities) and sophomores (N=2). They came from the mid-Atlantic institutions of Carnegie Mellon University, Georgetown University, Muhlenberg College, Rowan University, St. John's University, Thomas Jefferson University. These four women and two men include one who self-identified as having a disability. Five of the six students participated in the NNCI REU Convocation at Research Triangle NNCI site in Chapel Hill, NC in August.



2018 REU cohort Left to right: D. Wang, P. Mulcahey, H. Kline, L. de Groot, A. Ng, M. Padalino

REU alumni: The Singh Center has hosted 18 REU students for 3 summers since the beginning of the NNCI funded program. We have made an effort to keep in touch with these students; the current status of some of them from the 2016 and 2017 cohorts is listed below.

(2016) K. Miller: 1st year PhD student at Johns Hopkins, Chemical Biology

(2016) M. Pinezich: 1st year PhD student at Columbia, Biomedical Engineering

(2016) B. Murphy: 1st year PhD student at Penn, Bioengineering

(2017) K. DeFrates: will start PhD program at UC-Berkeley/UC-San Francisco's Bioengineering program with an NSF Graduate Research Fellowship

(2016) R. Melkerson: interviewing for jobs

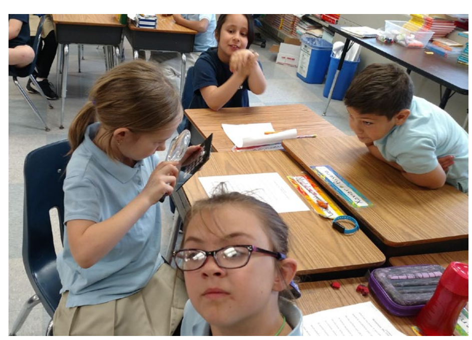
(2016) M. Mudgett: will start PhD program at UC-San Diego, Biosciences

(2017) L. Escobedo: summer 2018 research within a Cornell REU program

(2017) S. Subramaniam: summer 2018 research in her Singh Center REU lab at Penn (she has continued to work in her Singh REU lab [PI: K. Turner] through 2017-2018)

(2017) C. Franco: summer 2018 research with NASA Jet Propulsion Laboratory on the Europa Clipper Mission

MANTH hosted 72 events for 915 participants last year; these events included tours, workshops for students and the general public. MANTH staff participated in career day events at the near-by Alexander Adaire Elementary school last year, where they explained the principles of nanofabrication through presentations with handouts and cleanroom gowning demonstrations throughout the day for 3rd grade to 8th grade students. Many of the 8th graders later visited MANTH for an in-cleanroom demonstration as well.

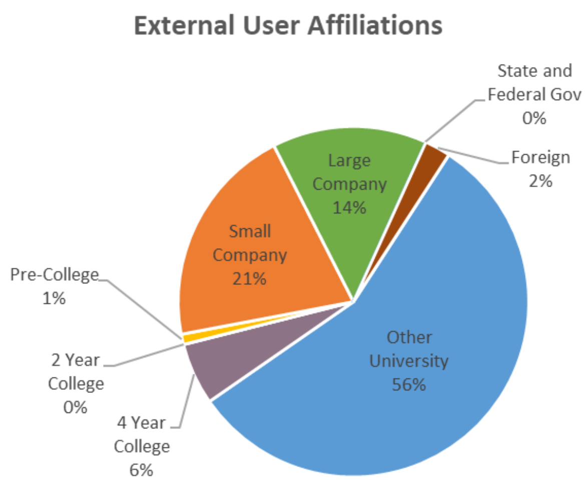


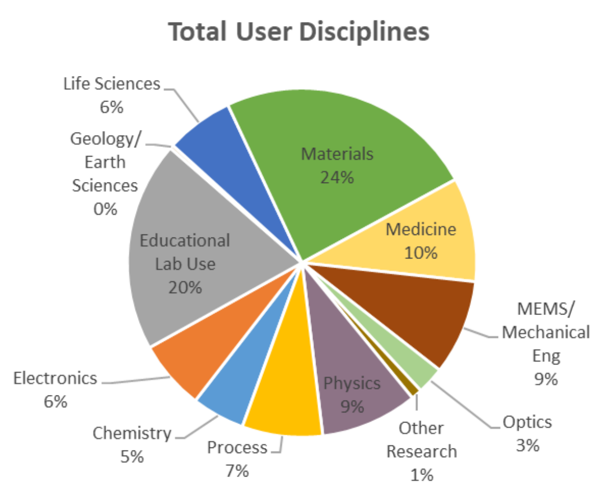
A future nanotechnologist studying a structure on a photomask at Adaire Elementary School.

MANTH Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	482	589	590
Internal Cumulative Users	368	393	380
External Cumulative Users	114 (24%)	196 (33%)	210 (36%)
Total Hours	36,970	37,933	34,796
Internal Hours	34,545	31,542	27,436
External Hours	2,425 (7%)	6,409 (17%)	7,360 (21%)
Average Monthly Users	171	194	186
Average External Monthly Users	29 (17%)	44 (23%)	45 (24%)
New Users	270	339	270
New External Users	73 (27%)	138 (41%)	104 (39%)
Hours/User (Internal)	94	80	72
Hours/User (External)	21	33	35

Year 3 User Distribution





11.5. Midwest Nanotechnology Infrastructure Corridor (MINIC)

Facilities, Tools and Staff Updates

Equipment improvements during the current year include: 1) Installed: new model 2010 Labcoater® 2 Parylene Deposition System from Specialty Coating Systems; 2) Ordered: A new workhorse parallel-plate RIE from Plasmatherm, model Vision 320. This RIE will be used for fluorine-based chemistry etching, primarily of SiO2, SiN_x, silicon and organic materials; 3) Upgraded: The thin film deposition controller and software on one of our workhorse electron beam evaporators from CHA; 4) Installed: A JEOL 6700 SEM with much improved performance over the old Amray SEM to support the e-beam lithography work; and 5) Installed: MINIC has on loan a DWL 2000 laserwriter system. This tool provides write speeds roughly 2x the existing DWL 200. No significant changes were made in facilities or staffing over this period.

Since its inception, MINIC has emphasized growing its user base by cultivating three focused areas of research support: 2D materials, advanced packaging (NDSU), and bionano. In year three, the 2D Materials Focus Area made key progress in establishing standard recipes for transition metal dichalcogendes (TMDs). Now, users have access to stable, reproducible standard operating procedures for growth of both 2D MoS_2 and WSe_2. The current capabilities include monolayer MoS_2 crystal up to 500 and 100 μm on a side, and single-layer film growth up to 1 cm and 2 mm on a side for MoS_2 and WSe_2, respectively. We have also demonstrated controlled p-type doping of WSe_2 using Nb [S. K. Pandey, H. Alsalman, J. G. Azadani, N. Izquierdo, T. Low, and S. A. Campbell, *Nanoscale* 10, 21374 (2018)]. Graphene grown in the MINIC facilities has continued to produce excellent results for users, including the creation of freestanding graphene-based nanocylinders realized by a plasma-triggered self-assembly process, and graphene nanotweezers used to create ultra-sharp traps for nanoparticles and DNA [A. Barik, et al., *Nat. Commun.* 8, 1867 (2017)]. MINIC capabilities for TMD growth have also recently been used to study how electrochemical interactions can be altered by modulating charge transfer kinetics at a monolayer MoS_2 electrode [Wang, et al., *Nano Lett.* 17, 7586 (2017)]. The results have important implications for 2D semiconductor tuning of electrochemistry. MNIC hosted its 3rd annual 2D summer school in June, 2018. Fifteen graduate students from around the country participated in hands-on demos. Finally, the 2D material online database was expanded, enjoying extensive use based on website statistics.

The Device Packaging Focus Area is supporting an increasing effort in biomedical sensor research. Dr. Nawarathna is developing devices for a high-throughput cell isolation technique to support point-of-care diagnostic sensors. Dr. Wang has made breakthroughs with a breath analysis sensor based on a novel nanostructured material to detect diabetes. NDSU recruited Dr. Dali Sun for a new faculty line focused on biosensing research as part of a new center developing test beds to support cancer research on drug therapies and delivery systems. CrossFire Technologies hired a Fargo-based fulltime employee specifically to leverage the device packaging capabilities in the NDSU cleanroom in support of their high density interconnect technology development.

During the third year the bionano labs of MINIC expanded our connection with local industry. MINIC staff played a substantial role in characterizing and refining lipid-based nanocapsules produced by Dynation LLC, a start-up biotech company developing a new dermal drug delivery system for pain relief and cancer medication. The lab also worked with Natureworks LLC on developing a new process to characterize unwanted polymer particles precipitating from solution. We extended our capabilities further in a project with the University's Animal Science Department to develop and refine a method of encapsulating proteins with the biopolymer chitosan to encapsulate animal vaccines.

User Base

MINIC staff pursued several channels to reach new users during the past year, including newsletters, tours, exhibits and presentations at conferences, and working with state agencies to identify start-up companies that might be good candidates to use MINIC's facilities. In addition to sending our quarterly newsletter to all current users, the Nano Center sent a "What's New at the Nano Center" New Year's email update to everyone in our contact list (about 1200 unique names). This annual communication keeps us in front of past and potential users as well as current clients, and helps to keep our contact lists up to date. In November MINIC outreach coordinator Jim Marti presented an invited talk on nanomaterials in medical devices to about 30 industry representatives at the Medical Devices and Materials Conference (MD&M Minneapolis). He staffed an exhibit at the Design of Medical Devices (DMD) Conference in April of 2018, and led tours of the Nano Center facilities for about 20 DMD attendees, most of whom were from the medical device industry. We have found that small businesses and start-ups are good prospects for user recruiting, since these firms are well served by our DIY tool set and fee-for-service offerings. MINC leveraged resources of the University and the state of Minnesota to seek out such companies over the past year. This included presenting a talk on MINIC's capabilities at the MN Dept. of Employment and Economic Development annual "Start-up Week", and participating in discussions at the University's "Resources for Science and Technology Companies" event, both in the fall of 2017. Through these and other contacts, MINIC was able to work with four small companies to help develop and/or support several SBIR proposals to NSF, NIH, and NASA.

Research Highlights and Impact

- Graphene grown in the MINIC facilities has continued to produce excellent results for users, including the creation of freestanding graphene-based nanocylinders realized by a plasma-triggered self-assembly process, and graphene nanotweezers used to create ultra-sharp traps for nanoparticles and DNA [A. Barik, et al., *Nat. Commun.* 8, 1867 (2017)].
- The MINIC capabilities for TMD growth have also recently been utilized by users to study how electrochemical interactions can be altered by modulating charge transfer kinetics at a monolayer MoS_2 electrode [Y. Wang, et al., Nano Lett. 17, 7586 (2017)], and the results have important implications for how 2D semiconductors could be used for tunable electrochemistry.
- MINIC staff scientist Jim Marti conducted lab studies of a solid mercury sorbent for scrubbing combustion gases. This work has resulted in a patent filed by the University and a technology licensing agreement with a start-up company (Mertron Inc).
- MINIC played a substantial role in lab research by Dynation LLC (ST. Paul MN), a start-up biotech company dedicated to developing a new dermal drug delivery system for pain relief and cancer medication. The work was funded by a phase 1 SBIR grant from NIH. The company is presently pursuing phase 2 funding with MINIC's active support.
- MINIC staff worked with Natureworks LLC to develop a process to characterize unwanted polymer particles precipitating from solution. This process, if further developed, will be applicable to many suspensions analyzed by MINIC's Nano Center.

- Working with the University's Animal Science Department, MINC staff developed a method of encapsulating proteins with the biopolymer chitosan and encapsulated vaccines for dairy cattle to prevent Johne's disease, a devastating ruminant infection.
- MINIC staff worked with researchers from the Department of Chemistry to apply nanoparticle tracking analysis to lipid droplets, which play important roles in cellular processes. This work resulted in a paper with Dr. Marti as coauthor.

Education and Outreach Activities

Over the past year, MINIC outreach staff completed 21 educational outreach events, both on campus and at remote sites. Educational outreach highlights include two categories of activities. The first is programs from summer camps and visiting school groups.

- Classes on nanotechnology and photolithography were presented to ten visiting groups, reaching over 300 students in grades 8-12.
- MINIC provided two programs for the Eureka SciGirls summer camp, dedicated to attracting girls in grades 8-10 to STEM fields.

The second focused on programs for undergrads and grad students.

- Undergrads from four regional liberal arts colleges were provided intros to lithography
- MINIC also organized the inaugural Nanomedicine Short Course, a two-day intensive introduction to the use of nanoparticles for drug delivery and medical imaging.

Finally, MINIC delivered several programs for K-12 Teachers:

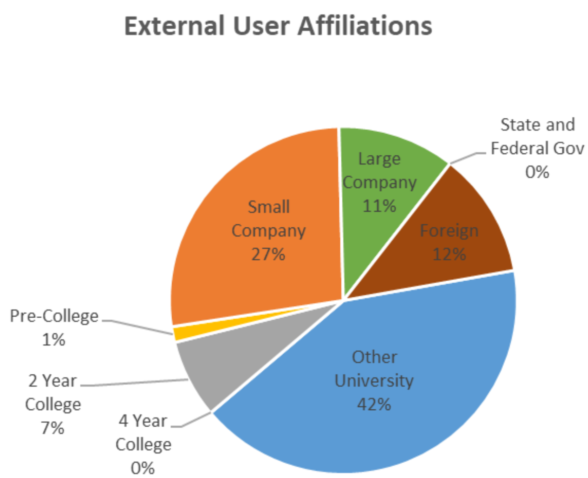
- MINIC staffed an exhibit at the annual convention of the Minnesota Science Teachers Association, meeting with about 30 science teachers at grades 7 and up.
- MINIC staffed an exhibit at the Wisconsin Science and Engineering Festival held in Wausau, WI. Over 5000 middle school students were hosted in this all-day festival.
- MINC staff also traveled to northern Minnesota to present nanotechnology programs to 65 middle school students at the Iron Range Science and Engineering Festival in Chisholm, a town in northern Minnesota close to the Canadian border.

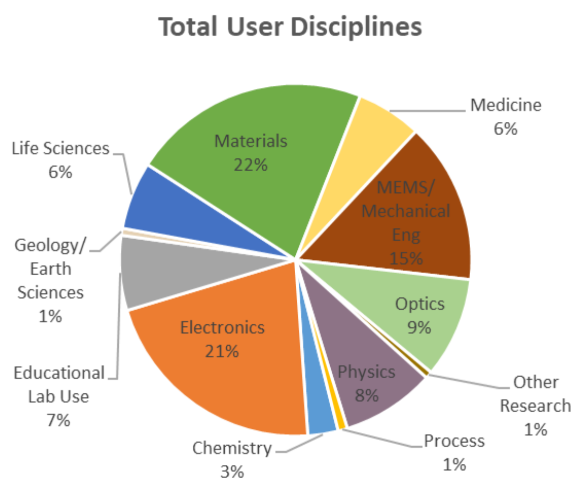
In all, almost 6200 students were impacted by MINC's education and outreach efforts in Year 3.

MINIC Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	384	415	466
Internal Cumulative Users	271	275	329
External Cumulative Users	113 (29%)	140 (34%)	137 (29%)
Total Hours	27,002	26,443	26,851
Internal Hours	20,495	19,733	21,324
External Hours	6,507 (24%)	6,710 (25%)	5,527 (21%)
Average Monthly Users	156	156	161
Average External Monthly Users	26 (17%)	33 (21%)	30 (18%)
New Users	151	150	189
New External Users	57 (38%)	59 (39%)	48 (25%)
Hours/User (Internal)	76	72	65
Hours/User (External)	58	48	40

Year 3 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) and Mass Spectrometry, Metabolomics, Proteomics, Facility (MSMP); Partner site with the Science Education Resource Center (SERC) at Carleton College.

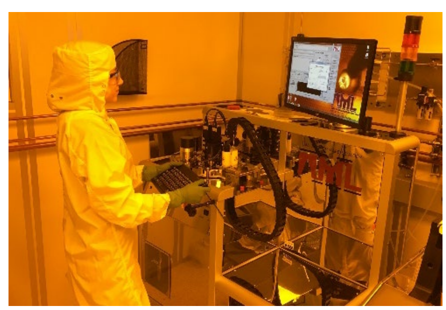
Facility, Tools, and Staff Updates

The **Montana Microfabrication Facility (MMF)** is expanding its Cobleigh Hall cleanroom to support microfluidics and soft lithography activities in support of users developing new tools and techniques to study neural development, disease diagnosis, separation and detection of genetic material and proteins, and propagation of bacteria and viruses at the single cell level. The **Imaging and Chemical Analysis Laboratory (ICAL)** saw increased usage of its new nanoAuger instrument for detailed elemental analysis of surfaces. This tool is attracting several external users and some exotic samples such as interplanetary dust particles. A new cryogenic stage on the SEM is serving users examining biological materials, and also researchers investigating the nanostructure of snow and ice. The **Center for Biofilm Engineering (CBE)** enhanced its own nanocharacterization capabilities with a new Raman microspectrometer and software library for spatially resolved molecular characterization of both biological and geological samples. **MONT** is cooperating with **Georgia Tech of SENIC** to link its SUMS facility management software to MONT facilities, leveraging the extensive application development that Georgia Tech has already done and applying it to our much smaller installation in Bozeman. This effort is ongoing.

New tools that came online in Year 3 of the NNCI project

Major new instruments are now available to users of MONT, funded with grants from the NSF MRI program, the Murdock Charitable Trust, internal MSU funds, and NNCI.

- Gatan Cryo Stage integrated in our Zeiss Field Emission Scanning Electron Microscope. This new capability is used to image biofilms or biological or other fragile soft samples in a frozen natural state (-190 C) with nanoscale spatial resolution. Also, one can image cross-sections of biofilms in 3D or surfaces of bio mineralized microorganisms with nanoscale resolution in their natural frozen state.
- AML Aligner/Bonder This tool was acquired with support from the Murdock Charitable Trust, with matching funds from NNCI; it is now installed and commissioned, and MMF staff and one external user are pioneering bonding processes for SU-8 adhesive bonding
- Horiba LabRam Evolution confocal Raman microspectrometer. NNCI provided some matching funds for this instrument. It is housed in the CBE imaging facility.



MONT continues to successfully leverage strategic expenditures of NNCI funds to help win both external and internal funding for new equipment. MONT has spent about $405,000 of NNCI funds to place tools valued at around $1.93 million.

Staff updates

Lithography specialist, Dr. Joshua Heinemann was hired to replace Benjamin Huang in MMF. Dr. Heinemann earned his PhD at Montana State University and completed is postdoctoral fellowship at the Lawrence Berkeley Laboratory in 2017. This staff position retains its focus on user training and assistance with user process development, especially for lithography and microfluidics processes. Dr. Manjula Nandrasiri was recruited from ICAL to an excellent industry opportunity (a workforce development success!). A national search for the ICAL User Liaison/Lab Manager position is currently underway.

User Base

Marketing, Outreach and Support Activities

MONT held its **annual User's Meeting** on August 20, 2018. The meeting focused on educating users about MONT's emerging capabilities and new equipment, and included user-led listening sessions to identify ways MONT can better serve its user base. Twenty-nine participants attended the half-day meeting and poster session, 5 were from local industry. MONT added monthly **"brown bag" lunch meetings** to visit with users about processes, equipment issues and capabilities users would like in the future. Users from both academia and industry have attended. CBE held its **industrial associates meeting** in July. MONT hosted a demonstration in ICAL for potential external users to see its capabilities. Four companies expressed enthusiastic interest.

MONT awarded three **user grants** in Y3. Visiting Fulbright Scholar, Marketa Hulkova (Masaryk University, Czech Republic) conducted studies to develop and test nanosilver-based antimicrobial coatings; external industrial user, Biomodum LLC, generated data in support of a submitted patent for a signal amplification system; Stephan Warnat, Assistant Professor, Mechanical & Industrial Engineering, is investigating MEMS material reliability in aqueous media - initial results will be used for an NSF application and a publication.

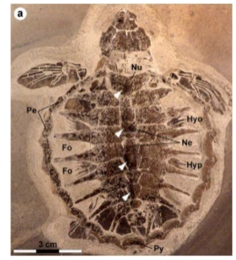
With the aim of recruiting new external users and "getting the word out" about the capabilities of MONT to Montana companies, **MONT entered into a cooperative agreement with the Montana Manufacturing Extension Center (MMEC)**, a NIST supported resource to Montana manufacturers. We are leveraging MMEC's network to identify potential industrial users who may benefit from MONT facilities. An announcement of this cooperation can be found here: http://www.montana.edu/news/17338/msu-nanotech-resources-available-to-montana-manufacturers .

Several MONT users took advantage of **other NNCI facilities**, including **UCSD** and **Cornell**.

Research strengths of MONT users: Nano-systems engineering strengths include **nanophotonics** for optical imaging, environmental sensing and advanced telecommunications, **sensors** for self-healing electronics for spaceflight, and for pathogens, **MEMS active optics** based on shape-changing surfaces are leading to highly miniaturized imaging systems and enhanced microscopy tools for the life sciences. **Energy applications** are enabled by nanostructured ceramic and crystalline materials.

Researchers are using **microfluidics** to explore **life-sciences** questions including neural system development and function, point of care diagnostics, 3D cell culturing and organoids and biofilm formation and mineralization. MONT's imaging and spectroscopy tools are used to address questions in the **geosciences.**

Research Highlights and Impact



Example publications include Lindgren et. al., who used MONT facilities for their ***Nature Scientific Reports*** paper (7(1):13324, Oct. 17, 2017) on "Biochemistry and adaptive colouration of an exceptionally preserved juvenile fossil sea turtle." Bruce et. al. published "Nanosegregation and Structuring in the Bulk and at the Surface of Ionic-Liquid Mixtures" in the *Journal of Physical Chemistry B* that has already been cited 16 times (Google Scholar). Fouqueau et. al. published "The transcript cleavage factor paralogue TFS4 is a potent RNA polymerase inhibitor" in ***Nature Communications***.

Scholarly impact: During 2017, MONT researchers produced 41 journal papers, 37 proceedings papers and presentations, 1 book chapter, and 1 patent. These 80 products represent a 31% increase compared to 2016.

Economic Impact: Industrial users Revibro Optics, Inc. and Agile Focus Designs, Inc. both received NSF SBIR awards to develop active mirror technologies that originated in MONT. Industrial users AdvR, Inc., UTRS, American Chemet and others successfully parlay MONT usage to attract significant government and private investment to develop processes and products. In total MONT served 37 industrial users in Y3.

Education and Outreach Activities

Two international workshops were convened (Goldschmidt Conference 2018 and NanoEarth 2018, co-convened with Michael Hochella of the **NNCI NanoEarth** project). These workshops served as catalytic events to develop a large amount of web resources with contributions from experts in the field. An online digital collection of ~500 articles are cataloged and are currently being reformatted into case studies to assist teaching and learning about nano topics in Mineralogy, Petrology, Geochemistry, Hydrology and related courses in the Earth and Environmental Sciences. The NanoEarth 2018 workshop was convened to produce an invited review article for **Science magazine**, *Natural, incidental, and engineered nanomaterials and their impacts on the Earth system* (planned publication in March 2019), and the accompanying website will be advertised as an educational companion to the article. The websites have been developed to support a campaign to promote "Teaching Nanoscience Across the Earth and Environmental Science Curriculum" in association with the National Association of Geoscience Teachers and the Mineralogical Society of America. These websites are supported by our colleagues at the Science Education Resource Center, Carleton College (MN):

https://serc.carleton.edu/msu_nanotech/goldschmidt2018/index.html
https://serc.carleton.edu/msu_nanotech/nanoearth2018/index.html

In July, 2018, four teachers participated in MONT's **Solar Cells for Teachers** summer course. Teachers use the MMF facility to produce a solar cell that they take home with them. The teachers came from Missouri, Massachusetts, New Jersey, and Wisconsin. Members of MONT engaged with 535 youth and adults during **MSU Family Science Day** in March. MONT's demonstrations, which featured NanoLand and an exhibit created by ICAL with nanoscale images, engaged over 150 fifth graders from local Title 1 elementary schools (high-percentage of free and reduced lunch), as well as many families and members of the community. MONT sponsored the bus transportation for the Title 1 schools. All aspects of the event were free, to make it accessible for all socio-economic groups.

MMF hosted 13 **Montana Apprenticeship Program (MAP)** students in July for a hands-on lab experience. The goal of MAP is to inspire young people to pursue college degrees and increase the number of Native American and other underrepresented high school students entering STEM professions. The students spent two weeks on campus studying introductory engineering and computer science, with a lab experience as the capstone. Nine of the students were Native American.

MMF and ICAL staff participated in the **Montana Science Olympiad** in November 2017. Fifty high school and middle school students from across Montana visited both facilities for tours, demonstrations and hands-on learning. More than 60% of the participants are from rural areas and about 10% were from tribal schools.

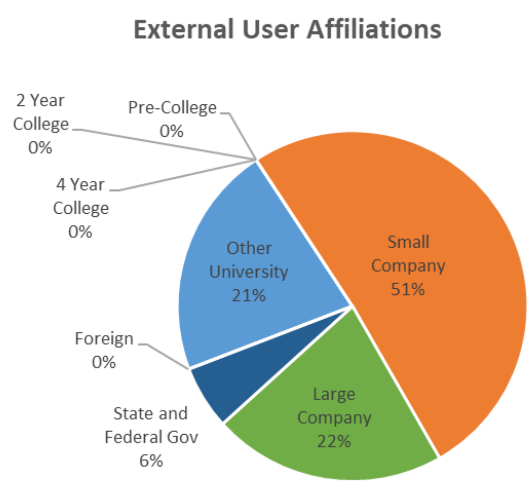
Societal and Ethical Implications Activities

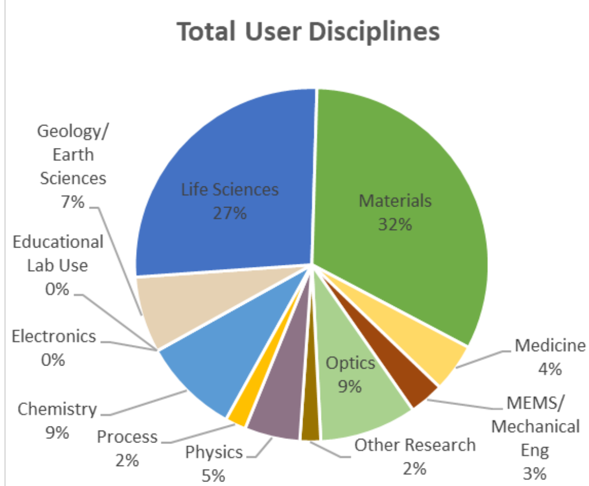
A new module on Professionalism: Responsible Conduct of Scientists has been developed as part of the Teaching Ethics in STEM program as a necessary complement to related work on the Responsible Conduct of Research. This module addresses fundamental principles of power, trust, respect, responsibility, fairness and justice; behaviors that impact workplace climate (microaggressions, implicit bias, empowering bystanders); sexual harassment and bullying; professional relations built on trust; and proactive policies and procedures to ensure a safe, inclusive, welcoming, and productive work environment for all. This module is posted at: https://serc.carleton.edu/geoethics/professionalism.html. Expanded resources on Teaching Ethics and Nanotechnology have been developed and are posted at: https://serc.carleton.edu/msu_nanotech/ethics.html

MONT Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	125	160	158
Internal Cumulative Users	96	124	107
External Cumulative Users	29 (23%)	36 (23%)	51 (32%)
Total Hours	3,599	4,713	5,420
Internal Hours	2,842	3,901	4,541
External Hours	747 (21%)	812 (17%)	879 (16%)
Average Monthly Users	46	51	43
Average External Monthly Users	8 (17%)	10 (20%)	7 (17%)
New Users	36	58	58
New External Users	1 (3%)	9 (16%)	8 (14%)
Hours/User (Internal)	30	31	42
Hours/User (External)	26	23	17

Year 3 User Distribution





11.7. Nanotechnology Collaborative Infrastructure Southwest (NCI-SW)

Facilities, Tools, and Staff Updates

As of Year 3 the ASU Nanofab and Eyring Materials Center (EMC), the largest facilities in the NCI-SW, will be managed by the ASU Office for Knowledge Enterprise Development (OKED). One immediate advantage of this change is the ability for the Nanofab and EMC to compete for internal funding from strategic investments across all OKED-managed core facilities. During Year 3 the Nanofab and EMC acquired: i) A 3-gun sputter tool with a load-lock that will decrease tool cycle time, increase film purity, and improve efficiency by reducing the number of target changes; ii) A Woollam M-2000 ellipsometer that will significantly enhance our thin film measurement capabilities; and, iii) Upgrades to the Tystar diffusion furnaces that will allow a PC-based user interface and control system for programing furnace tube recipes. **This $483k investment by ASU supports workhorse equipment** not easily acquired or maintained by equipment grant programs such as MRI and DURIP.

Carrie Sinclair, the NCI-SW photolithography engineer received an "Outstanding NNCI Staff Member" award in the User Support Category at the NNCI Annual Conference. Carrie believes that one of the unique parts of her job is seeing a new but eager student come into the facility and gain the knowledge and experience that causes the "light to go on." They suddenly understand how things work and integrate together. "Their world opens," says Carrie and seeing that is the best part for her.

Carrie helps students to 'gown up'

User Base

The NCI-SW provides intellectual and infrastructural strengths in renewable energy, health sciences, environmental nanoscience, and the societal aspects of nanotechnology. We reach out to non-traditional users in the medical and geoscience communities. Dan Thompson leads the marketing activities for the ASU NanoFab and EMC Core Facilities with a title of "Contact for Industry, Tech Marketing and Sales Coordinator." He started in this position in July 2017 and has worked first to develop the industrial user base of the Eyring Materials Center, adding several large companies to the list of external users of the EMC. In July 2018 he added the NanoFab to his portfolio and now leads the marketing activities of the two largest ASU core facilities under the NCI-SW umbrella. While having a full-time staff member promoting the ASU core facilities is clearly impacting our external user numbers, we believe our web-based outreach programs and use of social media is increasing awareness of the NCI-SW. These activities are explained below.

Research Highlights and Impact

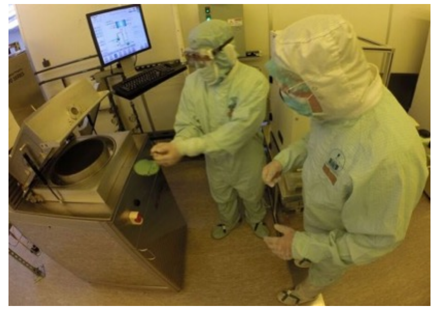
The research focus of the NCI-SW is to provide general R&D micro- and nano-fabrication support across a broad range of disciplines. To encourage use from the non-traditional nano-community we place particular emphasis on reaching out to the medical/health communities as well as to researchers in the geological sciences. Summaries of internal and external user projects are presented in the research highlight slides.

The economic impact of the NCI-SW can be quantified through a collaboration with Rio Salado College. We 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, more than 30 students have enrolled in the AAS Nanotechnology program and three have already graduated.*** The three graduates of the program are in the process of applying for positions at Nanoscience Instruments, Medtronic Inc., and Lawrence Livermore Laboratory. Another of the students was recognized with an award at the ATE-PI conference for his work with the MicroPressure Sensor workshop in Albuquerque.

Education and Outreach Activities

The NCI-SW education and outreach team lead by Dr. Ray Tsui conducted a number of activities as follows.

(i) *Labs for Rio Salado College Students* - This is a new activity for Year 3 of the project. In 2017 Rio Salado College (RSC) started a nanotechnology education program that offers a Certificate of Completion or a 2-year AAS degree. RSC students go through the lecture material online but take many of their labs at ASU.



A student from Rio Salado College being trained in the ASU NanoFab.

(ii) *Research Experiences for Undergraduates and Teachers* - The NCI-SW selected four students for its 2018 Research Experiences for Undergraduates (REU) program. All of them were from a rural community college, with two women and one a Hispanic student. Two community college faculty took part in our 2018 Research Experiences for Teachers program, one of them being African American. These selections continue our effort to address one of the NCI-SW's goals to recruit and retain a diverse population from qualified applicants.

(iii) *Remote Access to Equipment* - We continue to offer remote access (RA) to a desktop SEM over a web-based connection as a no-cost resource in education and outreach. Through Sept. 2018, this RA feature was used in 7 events where users at the remote locations had hands-on experiences imaging various samples. Five of the RA sessions were conducted with K-14 schools and introduced this capability to about 100 students and over 20 educators. Another two sessions were part of outreach events open to the public, with an exposure to over 800 event participants. There have also been discussions with Native American high schools in New Mexico to set up RA sessions for their students.

(iv) *Lab Tours and Public Events* - The NCI-SW took part in two major public outreach events. The first was held on the ASU campus as part of the school's annual "Open Door" activities. Hands-on activities included the use of an optical microscope to view patterned wafers, real-time remote access to the SEM, and demos to illustrate the use of nanotechnology in paper money and producing stain resistant fabric. There were over 760 visitors, well above the 480 we saw in 2017. The second event was "Geeks' Night Out" held by the City of Tempe in which the main campus of ASU is located. As in past years, it was a collaboration between ASU and RSC. Similar activities as in Open Door were offered. The event had visitors of all ages, making it a true K-to-Gray learning experience. Six tours of the NanoFab and EMC were conducted for K-14 schools in Year 3, totaling more than 245 students and 27 educators.

Educators taking part in the Intro. to Nanotechnology Workshop.

(v) *Introduction to Nanotechnology Workshop* - The Science Foundation of Arizona, another partner in the NCI-SW, hosted a full-day workshop on May 23, 2018 to follow up and expand on the inaugural, half-day event held in April 2017. Over 15 educators from middle schools through 2-year colleges in AZ experienced an informative day of science and hands-on experiments to learn ways to integrate nanoscale concepts into classrooms or summer camps. Educators also saw a live demo on how to remotely access the SEM at ASU.

(vi) *Newsletters, Webinars and Social Media* - A series of regular webinars have been hosted and archived by the NCI-SW on the web site. During Year 3 we have continued a series of quarterly newsletters. The newsletters profile center news, and include a section in which a graduate student explains their research project using language accessible to our target audience.

To track the impact of our web presence the NCI-SW has developed a dashboard that serves as a user interface to data collected by Google Analytics. The data confirms the importance of having the website actively managed. We believe that is also true for the social media platforms that the NCI-SW engages in. Coinciding with the change in management of the NCI-SW website we engaged with the Seidman Institute (part of the ASU WP Carey Business School) to more effectively use our Twitter feed. The results have been impressive, with a 3X increase in the number of followers. It seems likely that the growth in our number of Twitter followers may be helping drive potential users to the NCI-SW website.

Societal and Ethical Implications Activities

Dr. Jameson Wetmore and his colleagues run the NCI-SW SEI user facility, working with visiting scholars and running training workshops. An important example of this effort was a visit from Christopher Scott, Associate Director of the Center for Medical Ethics and Health Policy at Baylor College of Medicine. He met with all of the members of the ASU SEI user facility on how to involve stakeholders in thinking about the future of genome editing technologies. His visit convinced him of **the importance of the methods developed at ASU and he asked three SEI faculty to be included on the R01 NIH grant** that he submitted in the spring. Dr. Wetmore also works closely with science museums across the country. This decade long project introducing nanotechnology to the general public through science centers was recognized with a "Distinguished Contribution to Making and Doing" award at the 2017 annual meeting of the Society for Social Studies of Science.

The SEI user facility sponsored a third version of Science Outside the Lab with speakers from NIOSH, the EPA, the US Supreme Court, and Bernie Sanders' staff. After receiving more applications than any previous SOtL, we accepted **15 participants from 9 different NNCI** institutions to take part in this weeklong residential program in Washington DC during June.

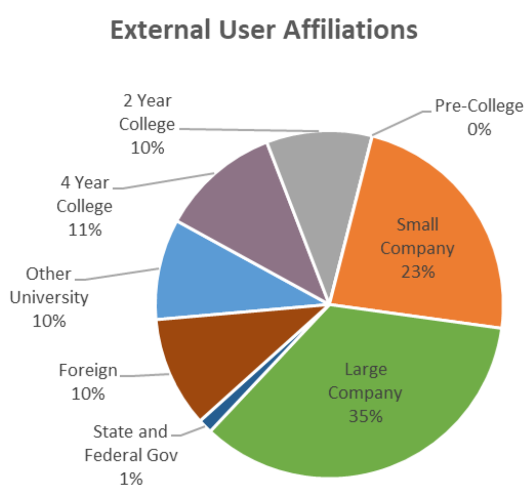
Computation Activities

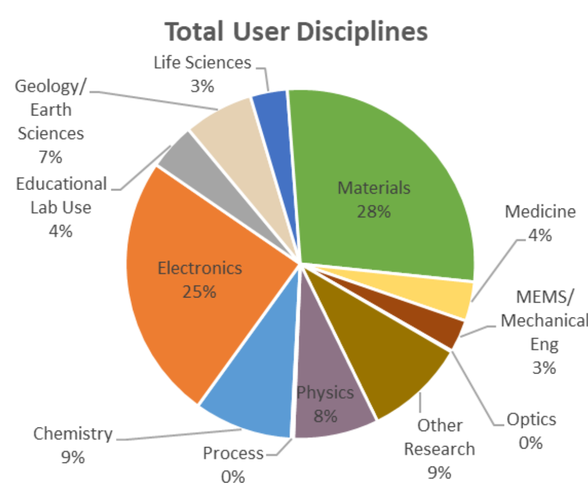
Dr. Dragica Vasileska, Professor of Electrical Engineering at ASU, is coordinating the computational activity for the NCI-SW. Dr. Vasileska has been a long-time contributor to the NCN's nanoHUB, and her software tools are some of the most highly used on the nanoHUB site. During Year 3 Dr. Vasileska developed a 2D diffusion-reaction solver for modeling CdTe solar cells, and implemented a graphical user interface (GUI) for the tool that is now deployed on nanoHUB.org. This work grew out of a collaboration with First Solar Inc. in 2017 to understand the anomalous diffusion of copper in thin films of CdHgTe.

NCI-SW Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	705	810	963
Internal Cumulative Users	536	600	739
External Cumulative Users	169 (24%)	210 (26%)	224 (23%)
Total Hours	43,098	49,370	46,647
Internal Hours	32,883	38,270	37,954
External Hours	10,215 (24%)	11,100 (22%)	8,693 (19%)
Average Monthly Users	271	313	284
Average External Monthly Users	43 (16%)	49 (16%)	47 (17%)
New Users	275	333	675
New External Users	47 (17%)	53 (16%)	102 (15%)
Hours/User (Internal)	61	64	51
Hours/User (External)	60	53	39

Year 3 User Distribution





11.8. Nebraska Nanoscale Facility (NNF)

Facility, Tools and Staff Updates

The enhancement of our NNF facilities has proceeded in the last year through funds received from the University of Nebraska, U.S. Army Research Office and NSF-NNCI. The Surface and Materials Characterization Facility added an X-Ray Photoelectron Spectrometer (XPS/UPS) with UV Photoelectron Spectroscopy option. An X-Ray Fluorescence Spectrometer (XRF) has been added to the X-Ray Characterization Facility. The Nanoengineering Facility purchased an Optomec LENS Metal Hybrid 3D printer, two Lumex Avance-25 metal 3D printing systems and a bio 3D printer for tissue engineering. A cell-culture laboratory also has been added to the Facility. The Nanofab Cleanroom Facility installed a second Ion-Beam-Milling and Deposition System. A Turbovac iCart pump station and a 4-inch Sample Table for HEX Deposition with heating to 300°C were added to the Nanomaterials and Thin-Film Facility. An AR200 Laser measurement sensor from Acuity with computer and software for TEM sample-thickness measurements were purchased for the Electron Nanoscopy Instrumentation Facility. New staff members partially supported by NNF include Drs. B. Balasubramanian and W. Zhang, who have established new XPS and high-field instrumentation.

User Base

The expansion of the external user base from academia and industry has been significant from the start of NNF in 2015, from 10 to 76 external users. This relies in large part on the NNF-supported technical staff: Drs. Jacob John, Anand Sarella and Andrei Sokolov. The Coordinator prepared outreach materials such as brochures, fliers and promotional slides for promoting and creating awareness about the NNF capabilities throughout the region. The Coordinator also initiated communications with potential users, arranged meetings and discussions, scheduled facility tours, and made frequent trips for meetings and presentations in order to expand the external user base.

Outreach to New Regional Users: The Facility Coordinator has organized outreach to more than 125 companies, of which more than 90 companies have requested materials describing the capabilities of the NNF. Due to these outreach efforts, more than 42 companies visited the NNF for tours and discussions so far and 30 of them have started using NNF capabilities and expertise. Some recent company interactions include Elemetal Fabrication, NovaTech, NuTek Food Science, Kawasaki Motors, Snyder Industries, Valmont Coatings, Toray Industries, Dynetics, Royal Engineered Composites, Nebraska Irrigation, Hughes Brothers, Quantified AG, Vishay Dale Electronics, Teledyne ISCO, Bosch Security Systems, Continental ContiTech, Centennial Plastics, and MFS/York. The Facility Coordinator also generates collaborations with colleges and universities in the region and the interested users are invited for a tour of NNF. NNF also provides remote services for users who are either located far away from our facility or have difficulty in making frequent trips to our site.

NNF Seed Grant for External Users: The NNF Facilities Seed Grant program aims to provide resources to industries, start-up companies, and students from 4 and 2-year colleges for facilitating development of new nanotechnology-enabled products, proof-of-concept development that involves characterization of nanomaterials, fabrication of devices and testing.

Academic, Industry User Workshop and Minicourse: Our second User Workshop, held on May 16, 2018, was a successful event with 30 attendees, mostly from industry. The User Workshop enables engineers from industries to know more about the NNF capabilities and potential benefits of becoming new users. A survey was was given at the end of the workshop and a summary of responses showed 100% strongly agreed that they understood what work could be done using NNF and how to become a user after the event. Over 90% believed their work would benefit from using the NNF facilities and/or were interested in becoming users. The Minicourse was held May 14-16, 2018. The attendance was 20, a number that was limited to enable each researcher to have both lecture and hands-on experience by our Facility Specialists.

Nanotech Lab Course for Users: This is a new one-credit hour per semester course, which provides students with an introduction to the large variety of instruments available at NNF. The purpose of this course is to help students master experimental skills in their own research area and to broad their horizon in experimental nanotechnology methods, complementary to that area.

Research Highlights and Impact

Research Strengths: NNF supports and facilitates major centers and programs such as NSF MRSEC, NIST-SRC: Center for Nanoferroic Devices, NSF/DOD, NSF DOE projects and several others. The faculty users are primarily focused in the research areas such as polarization and spin phenomena in nanoscale structures, high-energy magnets, earth-abundant materials, spintronic devices, nanoferroic devices, nanomagnetics, functional nanostructures, laser processing, solar cells, nanomaterials for energy, complex nano-hybrid materials, nanophotonics, metamaterials, nanocrystals, graphene nanostructures, oxide films and interfaces, nanomachines, nanobiology, nano-biosystems, sensors and devices, catalysis, metal-organic frameworks, etc.

User Accomplishments: Ten spinoff companies were established over the years by the faculty and student users of NNF. They are Rare Earth Salts, LNK Chemsolutions, Rieke Metals, Vajra Instruments, J. A. Woollam Co., Ground Fluor Pharma, Ossient, Inc., Photonic Solutions, Inc., Nanofiber Co., and Surface Integrity.

Selected Research Highlights: NNF user Alexander Sinitskii and his team developed a new form of nano-ribbon made from graphene, and when they integrated a film of the nano-ribbons into the circuitry of a gas sensor, it responded about 100 times more sensitively to molecules than did sensors featuring even the best-performing carbon-based materials. [*Nature Communications* **8**, 820 (2017)]. NNF user S. Morin and his colleagues have developed a method for more strongly bonding plastics with silicones, offering new possibilities for fabricating fluid-carrying channels that are commonly used to direct the motion of soft robotic components. By helping rubber and plastic stick together under pressure, the researchers have simplified the production of small fluid-carrying channels that can drive movement in soft robotics and enable chemical analyses on microscopic scales [*Advanced Materials* **30**, 1705333 (2018)]. NNF Director David Sellmyer's group has reported the formation of skyrmions just 13 nanometers wide, the smallest possible size in the material. Researchers had previously created skyrmions with a diameter of about 50 nanometers. Because creating and moving a skyrmion demands far less energy than aligning those polarized groups of atoms, researchers see the magnetic spiral as an appealing alternative for digital storage [*Nanoscale* **10**, 9504 (2018)].

Economic Impacts: NNF critically supports all research in materials and nanoscience at the University of Nebraska. The related annual research expenditures are $22.8 M in FY 2018, 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 in the Midwest region. Access to NNF enables the companies to improve manufacturing processes, facilitate R&D programs, and develop and test new products. Access to the NNF resources and seed grants enables smaller companies to obtain SBIR and other grants, which results in business expansion, and more jobs.

Education and Outreach Activities

REU Programs**:** Selected students and visiting professor/student pairs from regional universities and four-year colleges performed research under faculty supervision and participated in summer projects in NNF Labs. NNF hosted a Japanese student from Japan for a 10-week summer research project as part of the NNCI International REU program. One student from a past summer REU program was chosen to travel to Japan as part of the NNCI summer exchange program and one received a Barry Goldwater Scholarship award. NNF also supported the summer CREST REU program between California State Univ.-San Bernardino and the Univ. of Nebraska MRSEC by providing undergraduate students access to facilities.

High School Intern Program: NNF hosted a STEM summer program for 12 high school interns June-August 2018. Faculty from Chemistry, Physics, and Engineering provided opportunities for high school students to work in their research labs for 10 weeks with the help of a graduate student mentor to guide and train them in research techniques.

K-12 Diversity Programs for Title 1 Schools*:* (1) After-School, In-School, and Summer Nano Camps for diverse middle school student populations and 1st generation, college-bound high school students. These programs included Harry-Potter-themed nanoscience hands-on activities, STEM/Nano kit experiences and tours of nano-related research in NNF faculty labs and equipment. (2) Nanoscience curriculum development for rural Nebraska schools in partnership with the 4-H program.

Teacher Conferences/Workshops: NNF trained and resourced hundreds of K-12 teachers with STEM/Nano-related information at teacher science fairs and conferences, preservice teacher workshops, and through online educational videos, lesson plans, and other materials. The events NNF participated in were the University of Nebraska Preservice Teacher Workshop and Nebraska K-12 Education Summit.

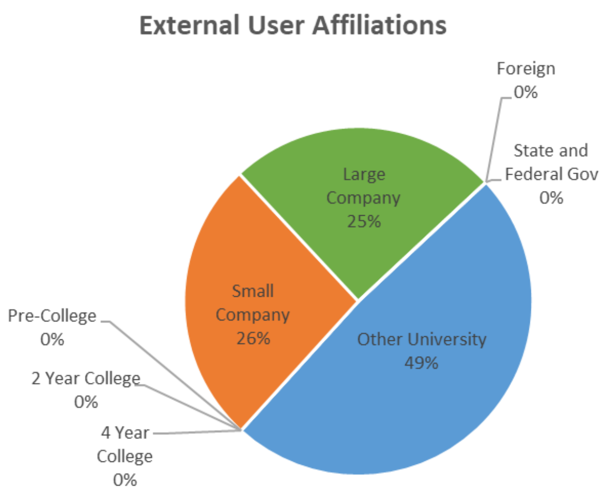
NNF Special Events: NNF sponsored a variety of events throughout the year such as: (1) NanoDays, a nationwide festival of educational programs about nanoscale science and engineering which was held at our local mall and attended by about 400 students and interested general public. (2) Student Conferences included the Conference for Undergraduate Women in Physical Sciences, WoPhyS where NNF partnered with MRSEC, along with other sponsors, to bring together outstanding student researchers in science. (3) NNF hosted Junior/Senior High Tours to hundreds of interested junior and senior high students, parents and teachers visiting the UNL campus to learn more about what UNL has to offer in nanoscience research. NNF helped coordinate tours and hands-on experiences with a variety of departments.

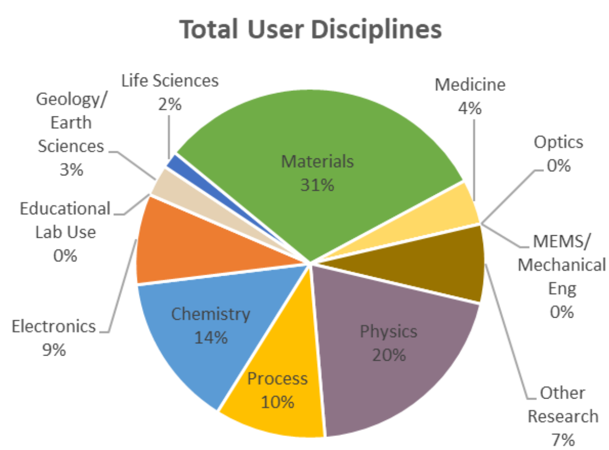
Traveling Nanoscience Exhibit: Our 400-sq.-ft. hands-on exhibit was viewed in three Nebraska museums this past year by over 50,000 people. The three museums partnered with NNF to reach thousands of underserved populations in Nebraska and Iowa with the Nano mini-exhibit, including both rural populations and the growing number of ethnic minorities in urban communities.

NNF Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	314	357	381
Internal Cumulative Users	295	321	305
External Cumulative Users	19 (6%)	36 (10%)	76 (20%)
Total Hours	23,445	20,102	24,008
Internal Hours	23,123	19,278	22,260
External Hours	322 (1%)	824 (4%)	1,748 (7%)
Average Monthly Users	40	120	132
Average External Monthly Users	3 (8%)	7 (6%)	19 (15%)
New Users	47	54	124
New External Users	0 (0%)	1 (2%)	6 (5%)
Hours/User (Internal)	78	60	73
Hours/User (External)	17	23	23

Year 3 User Distribution





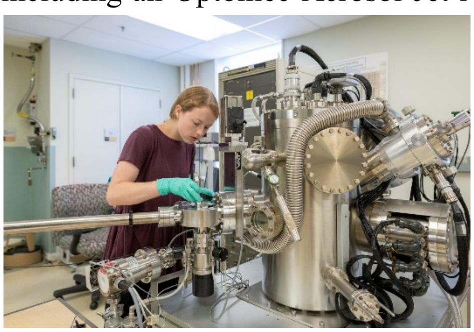
11.9. NNCI Site @ Stanford (nano@stanford)

Facility, Tools, and Staff Updates

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 laboratory that can deposit films of GaAs or GaN; a JEOL e-beam lithography tool that can inscribe sub-10-nm features over 8-inch wafers; a Cameca NanoSIMS 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 microscope with world-leading spin sensitivity. The facilities occupy ~30,000 sqft of space including 16,000 sqft of cleanrooms. 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 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 Mineral Analysis Facility (MAF)*** and the ***Stanford ICP-MS/TIMS Facility***.

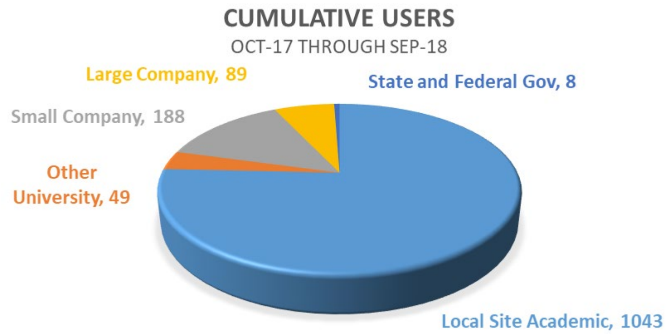
New capabilities: During this reporting period we added several new capabilities to our offerings, including an Optomec Aerosol Jet AJ 300 which is a non-contact, direct-write system with the ability to conformally print just about any ink, to feature sizes as small as 10 um; an Alveole PRIMO which is an add-on module that turns a conventional Leica DMi8 laser fluorescence microscope into a 375 nm, direct-write system; a DISCO DAG810 Backgrinder used to rapidly and accurately thin down substrates and components, including silicon, glass, compound semiconductors, and resins; an Asylum MFP3D Atomic Force Microscope and two Bruker DektakXT surface profilers.



Personnel: Dr. Marcin Walkiewicz joined SNSF as the manager of the scanning probe microscopy laboratory and supervises all shared atomic force microscopes (AFM) and Raman instruments. Dr, Roy Kim joined SNSF as the TEM Scientist to support operations of the FEI Titan Environmental TEM. Graham Ewing joined SNF as the Laboratory Operations Engineer. Connie Chiang joined SNSF as a Financial Analyst.

User Base

Between October 2017 and September 2018, the NNCI Site @ Stanford University served a total of 1,377 users: 1,043 internal users, 277 industrial users, 8 government users, and 49 external academic users. Billed user fees during this time accumulated to about $7.4M of which about $2.8M was collected from external users.

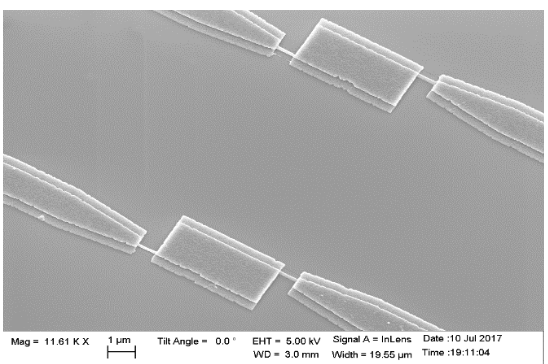


With Stanford being in the heart of Silicon Valley, the NNCI Site @ Stanford was able to serve external users from ***105 small companies*** and ***32 large companies***. Furthermore, users from ***23 US academic institutions***, ***2 government labs*** and 4 international organizations added to a growing, diverse user base.

During calendar year 2017 we captured 259 journal publications, 71 conference publications, 6 patent applications filed, and 3 patents issued. We note here that publications are all self-reported. We estimate the total number of publications to be about three times higher but continue struggling to capture all publications.

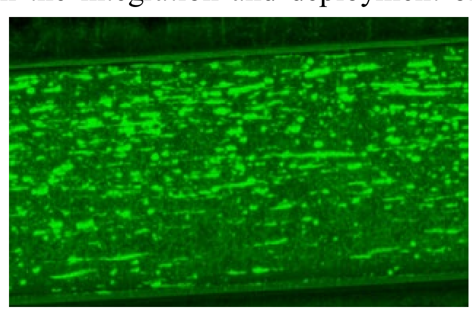
Research Highlights and Impact

Rigetti Quantum Computing has been researching Josephson junction design and fabrication techniques for the fabrication and testing of Josephson parametric amplifiers (JPA). Rigetti Computing has recently raised $70M to develop quantum computers. The company was founded in 2013 and has currently about 200 employees. Using the JEOL 6300-FS electron-beam lithography system as well as the wet benches, a two-layer resist stack is spun, baked, selectively exposed to engineer undercuts, and developed, allowing for double-angle evaporation of aluminum separated by an oxidation step. The so formed SQUID provides a non-linear inductance and is the key operational component of a Josephson parametric amplifier. This device was critical in the integration and deployment of Rigetti's 8Q and 19Q systems.

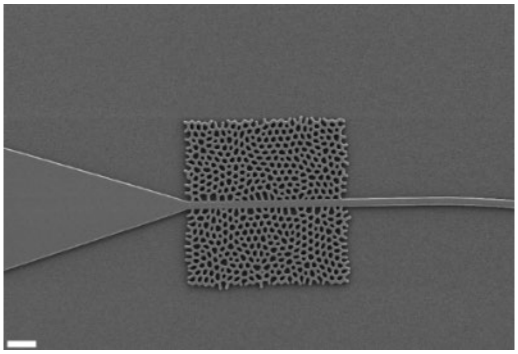


SQUID of a JPA after metallization, with both aluminum layers easily visible.

Confluent Medical Technologies is the largest and market-leading contract manufacturer of specialized medical devices. Its portfolio of services includes Nitinol components. At the NNCI site @ Stanford Confluent Medical researchers are using X-ray CT scan to obtain 3D characterization of nonmetallic inclusions and voids in nitinol material. The data will be used to develop improved models for predicting durability of nitinol medical components.



Sliced view of the reconstructed sample volume using XCT to visualize voids in nitinol samples.



Waveguide running through a HUDS (scale 2um).

Professor Man's research group at ***San Francisco State University*** utilizes the Stanford site to develop submicron hyperuniform disordered (HUD) photonic bandgap (PBG) structures to make the light flow in arbitrarily shaped, wavy, curved and sharp bending. This "free-form" of light guides could help in designing photonic integrated circuits for signal processing and telecommunications, which is funded by National Science Foundation.

In July, Stanford hosted a two-day ***direct-write workshop***. The first day was a closed session of the NNCI Lithography Working Group. The second day of the event was a symposium that was open to the public and featured technical presentations by applications specialists that focused on the wide variety of new direct-write capabilities currently available at nano@stanford and across other NNCI sites. 115 individuals were attendance, with more than half from outside Stanford, including 11 from other universities in addition to the NNCI sites. This symposium provided an excellent opportunity not only to learn about what our newest equipment can do, but also to engage with each other, and with the providers of the equipment that our researchers depend on.

Education and Outreach Activities

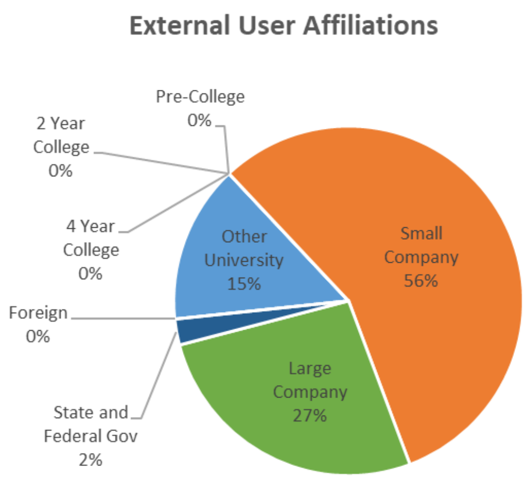
The NNCI Site @ Stanford is dedicated to developing and implementing activities targeted at youth, school teachers, and the general public that will increase their interest, understanding, and involvement in STEM. These initiatives range from volunteer participation in outreach events to more in-depth workshops that span multiple days. During the reporting period, over 1,500 people were involved in these type of activities with the NNCI Site @ Stanford. We developed a ***Summer Institute for Middle School Teachers*** (SIMST) program that enables middle school teachers in the local bay area community to learn about nanoscience and how to incorporate the content into their classroom. 15 teachers participated in June 2018 in a one-week workshop. The selection process for SIMST emphasized diversity, including teacher and their school diversity. 5 teachers were from Title 1 schools. Most schools had primarily underrepresented demographic groups. We continued engaging with the teachers as they implemented their lesson plans. We started discussions with other NNCI sites to deploy developed materials at other sites. The first implementation will be at Georgia Tech with support provided by the NNCI Site @ Stanford. Selected partner institutions serving diverse audiences are being supported by Stanford. During this reporting period we have strengthened our partnership with

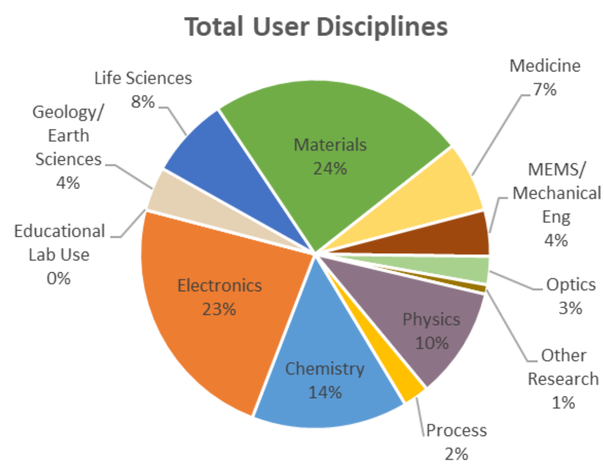
California State University, East Bay (campus visits, support for fab and characterization, submission of article to educational journal) and initiated a new partnership with ***Cañada College***.

nano@Stanford Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	1,142	1,287	1,377
Internal Cumulative Users	952	1,027	1,043
External Cumulative Users	190 (17%)	260 (20%)	334 (24%)
Total Hours	113,089	113,193	135,054
Internal Hours	94,996	91,248	105,083
External Hours	18,093 (16%)	21,944 (19%)	29,971 (22%)
Average Monthly Users	520	572	601
Average External Monthly Users	74 (14%)	92 (16%)	115 (19%)
New Users	550	579	584
New External Users	97 (18%)	143 (25%)	194 (33%)
Hours/User (Internal)	100	89	101
Hours/User (External)	95	84	90

Year 3 User Distribution





11.10. Northwest Nanotechnology Infrastructure (NNI)

Facilities, Tools, and Staff Updates

Facilities

In the past year, both UW and OSU have made massive infrastructure investments – building, renovating, and expanding dedicated nanotechnology spaces – to increase regional capacity for nanoscale research and development. In fall 2017, UW opened a $87.8M building, home to the newly established Institute for Nano-Engineered Systems (NanoES), containing 8,300 sf of learning space and 43,000 sf of flexible research space, including 15,000 sf of facility space for vibration and EMI sensitive equipment. UW also completed a $37 million phased renovation and expansion of the Washington Nanofabrication Facility (WNF), tripling its ISO Certified cleanroom space to 15,000 sf. OSU completed a $12.8 million phased renovation and expansion of its Advanced Technology and Manufacturing Institute (ATAMI) on the HP campus in Corvallis, adding 8,000 sf of new leasable laboratory spaces and added nearly 1,500 sf of laboratory space for system integration and testing next to the OSU cleanroom at the Materials Synthesis and Characterization (MaSC) facility.

New Tools and Capabilities

University of Washington:

- Nanoscribe Photonic Professional GT: nanoscale 3D printer, funded by an NSF MRI award, has enabled an explosion of grayscale and high aspect ratio lithography.
- SPTS vapor phase etchers: Xactix e2 XeF_2 silicon and Primaxx uEtch VHF oxide etchers were commissioned in Q1 2018.
- Ritetrack SVG 90S: coat and develop track, with wafer uniformity of <1.5% and wafer-to-wafer variability of <0.7% at a rate of 25 wafers per hour, has substantially enhanced WNF lithography capabilities.
- LatticeGear breaker station for precision cleaving has been a valuable addition in cross-sectioning small via arrays.
- Picosun ALD systems: installed during late 2018, these two systems are slated for several applications including barrier and electroplating seed metallization for very high-aspect ratio through silicon vias (TSVs).
- Biolin Scientific QSense Quartz Crystal Microbalance w/ Dissipation monitoring (QCM-D) and 4 flow cells installed Feb 2018.
- Hysitron TI980 Nanoindenter, funded by NSF MRI and opened to MAF users in June 2018.
- 2nd FEI Tecnai TEM is being installed in Q4 2018 with a Hummingbird *in situ* liquid, heating, mixing TEM holder.
- FEI Apreo SEM with sTEM detector is being installed in Q4 2018.
- EKSPLA Picosecond Vibrational Sum Frequency Generation (SFG) Spectrometer commissioned April 2018.
- EVOS Cell Imaging Systems commissioned October 2017.
- FEI Titan Krios G3 cryo-TEM was installed in 2018, and an NIH-funded FEI Arctica cryo-TEM has just arrived.

Oregon State University:

- MappIR (Pike Technologies) for FTIR transmission and reflectance mapping data; coordinated with spin-off Inpria.
- Ambient-Pressure X-ray Photoelectron Spectroscopy and Scanning Tunneling Microscopy (AP-XPS/AP-STM) funded by NSF MRI.
- LPKF ProtoMat S103 micromill, LPKF MicroLine 2820P laser system for rapid prototyping of circuits.

Staff Updates

NNI administrative coordinator Jessica Manfredi transitioned to a role at a regional college and was replaced by Tosha Missel in June 2018. NNI brought on Dr. Renske Dyedov as communications manager in September 2018. WNF hired Sithika Ky as an additional field service engineer. Dr. Michael Khbeis, Director of WNF, announced in November 2018 he is leaving NNI to pursue new challenges in the commercial sector. Senior staff personnel will sustain WNF operations until a new director is hired. Dr. Igor Lyubinetsky, who ran the AP-XPS facilities, retired in June 2018 and was replaced by Dr. Rafik Addou.

User Base

Usage of NNI facilities has significantly increased following the completion of major renovations. In the last 6-month reporting period, NNI facilities logged 55,798 user hours generating $3.77 million in user revenues from 714 unique users, including 485 internal users, 33 external academic users, and 196 external industrial users (143 small companies, 47 large companies, 3 government, and 3 international). New user training increased 55% over the reporting period to 206 new users trained, meaning 29-percent of users are new. Of the 714 unique users, 192 were Asian, 1 Black, 1 Native American, 1 Pacific Islander, 334 White, 162 unspecified, and 23 declined to specify. Users came from the following disciplines: chemistry (103), electronics (83), educational lab uses (47), geology (6), life sciences (59), materials (206), medicine (18), MEMS/mechanical engineering (115), optics (31), physics (30), process development (7), and other (9).

Research Highlights and Impact

Academic work supported by NNI during this reporting period ranged from photonics-based single quantum emitters, conformal transparent glucose sensors, and combined optical tweezing resonant mass MEMS for biological applications. During this period, NNI has also supported a wide variety of external industrial clients including Modern Electron (Bellevue, WA), Silicon Designs, Inc. (Kirkland, WA), Intel, Inc. (Hillsborough, OR) and HP, Inc. (Corvallis, OR). NNI has engaged locally with numerous companies, academic institutions, and professional organizations (IEEE and SMTA) by providing tours, demos, internships, short courses and workshops. Vendor workshops covered subjects such as impedance microscopy (PrimeNano), QCMD (Biolin Scientific), AFM (Asylum Research), nanoindenter (Hysitron/Bruker), and vacuum systems (K.J. Lesker). In addition to holding tours on request, NNI facilities held an open house in October 2018 to engage UW researchers. National activities included hosting the annual NNCI meeting in September 2018 which was attended by 121 NNCI-affiliated individuals, as well as representatives from NSF, 31 academic institutions, and 50 vendors. NNI also represented NNCI at several national events such as TechConnect World Innovation Expo and SMTA Puget Sound Expo, both in May 2018, and Semicon West and Intersolar in July 2018. Notably, NNI's Atmospheric Pressure-XPS capabilities were highlighted at the AP-XPS Workshop in Shanghai, China, the AVS Symposium in Tampa, FL, the Pacific Northwest AVS Symposium in Richland, WA, and the Pacific Coast Catalysis

Society Meeting in Corvallis, OR. 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 nanotechnology research and innovation.

Education and Outreach Activities

During this reporting period, NNI continued to expand its portfolio of E&O activities with the goal of impacting K through gray audiences throughout the Pacific Northwest.

Pre-college Outreach — During this reporting period, NNI reached more than 2,600 individuals at regional STEM career. NNI participates in UW's Engineering Discovery Days, attended by 8,764 students and 1,781 chaperones. NNI partners hosted the 1st annual "Introduce a Girl to Nano" day, attended by 277 girls. The SESEY (Summer Experience in Science and Engineering for Youth) program brought 54 high school students from underrepresented groups to campus for a week-long camp with career development and research experiences in NNI laboratories.

National Nanotechnology Day —NNI partnered with the Pacific Science Center to host the 2nd annual National Nanotechnology Day, with hands-on activities for 2,057 guests (K-gray).

First Nations Engagement — In March and April 2018, NNI hosted 33 Native American students during Native American Student Day, followed by 11 8th & 9th grade students from Paschal Sherman Indian School for hands-on learning in nanotechnology. NNI's Native American lab assistant joined NNI as a part-time program coordinator for First Nation engagement.

Educators-in-Residence — In partnership with our EIR, NNI is developing a dozen classroom tested nanotech teaching modules. We are partnering with OSU's Pre-College programs to distribute these kits to teachers throughout rural Central Oregon school districts.

REU and Undergraduate Research — NNI faculty offer undergraduate research opportunities through various mechanisms including the Johnson Internship, a paid summer research opportunity, and STEM leadership program, aimed at underrepresented groups.

Short courses — Twice in 2018, WNF offered a five-day survey course to students, faculty and industry professionals, as an introduction to key nanofabrication techniques, tools and methods. These intensive short courses included lectures coupled with hands-on laboratory sessions to give attendees a more thorough understanding of fabrication technologies as well as firsthand experience using fabrication equipment.

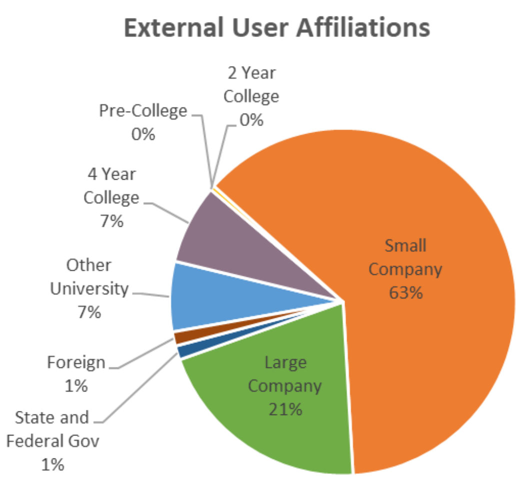
Assessment — NNI has integrated assessment activities into events beginning Summer 2018. Participant surveys are used to evaluate public perception of nanotechnology and E&O activities.

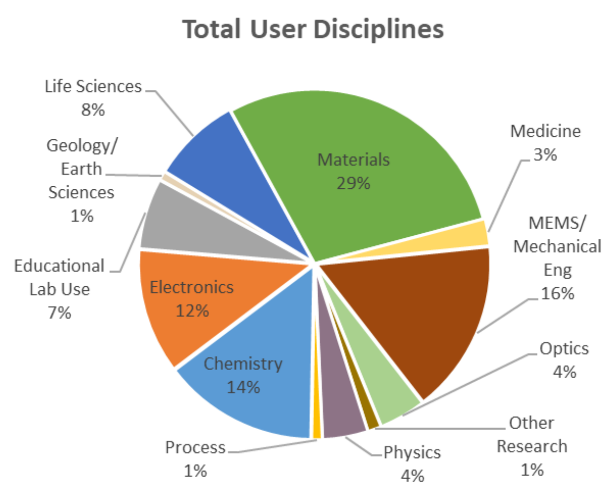
Workforce Development — WNF continued to expand its workforce development efforts, growing annual undergraduate process engineering apprentices to 22 UW students with 10 interns working through various workforce development channels, including international exchange summer programs with KAUST, Women in Science and Engineering (WISE), and several regional colleges. WNF is expanding its technician development efforts by reaching out to regional colleges to identify candidates that are looking for employment with NNI user companies or intend to transfer to UW or OSU. This program is needed to keep pace with growing regional demand. Workforce development pipelines continue to expand with several NNI undergraduate assistants interning at companies such as Intel, Micron, and Analog Devices and multiple candidates becoming employed by these companies annually. NNI interns are a diverse group, including 7 women, 4 URM/EOP students (Native Hawaiian/Pacific Islander, Latino, and 2 Native Americans), and students from across the engineering and STEM majors and colleges.

NNI Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	638	708	714
Internal Cumulative Users	396	486	485
External Cumulative Users	242 (38%)	222 (31%)	229 (32%)
Total Hours	38,350	46,562	55,925
Internal Hours	21,822	30,600	27,695
External Hours	16,528 (43%)	15,962 (34%)	28,230 (50%)
Average Monthly Users	267	277	266
Average External Monthly Users	103 (39%)	98 (35%)	93 (35%)
New Users	126	159	206
New External Users	41 (33%)	37 (23%)	57 (28%)
Hours/User (Internal)	55	63	57
Hours/User (External)	68	72	123

Year 3 User Distribution





11.11. Research Triangle Nanotechnology Network (RTNN)

Facility, Tools, and Staff Updates

Staff: In Year 3, a new Business Officer joined the Analytical Instrumentation Facility (AIF), and a post-doctoral fellow was promoted to manager of AIF's X-ray diffraction (XRD) laboratories. The Shared Materials Instrumentation Facility (SMIF) hired a new program coordinator, and a first year graduate student joined the SEI team. **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 an atomic force microscope (AFM), an X-ray diffractometer, a 3D laser scanning confocal microscope, an ion mill, a 3D printer (for use with microCT), an electron backscatter diffraction detector, an e-beam deposition system, a scanning electron microscope (SEM), a nanomechanical test system, an HMDS/image reversal oven, and a desktop microCT. In addition, an MRI was awarded for a nanoCT system, which will be purchased in Spring 2019. **Techniques:** We have developed new techniques for mask writing, bonding glass to cured SU-8, wide bandgap etching, diffusible iodine-based contrast enhanced computed tomography (DiceCT), and multilayer polymer film identification using time of flight secondary ion mass spectrometry (ToF-SIMS).

User Base

The RTNN is committed to bringing in new, non-traditional users with greater than 50% of current users from non-traditional disciplines, such as textiles, biology, and agriculture. *Satisfaction*: Unique, IRB-approved surveys were created for collecting demographic and satisfaction data from users. Overall, users were very satisfied with their experiences (6.32 ± 0.99, 7=very satisfied). More than 99% of users indicated that they would return to the lab if further work was necessary. These results demonstrate an improvement in users' satisfaction compared to the previous year (Year 2: 6.04 ± 0.74). NC State Nanofabrication Facility (NNF) users had markedly improved satisfaction levels (5.98 in Year 3 vs. 5.06 in Year 2). The improvements resulted from our efforts to address issues raised in Year 2 feedback. NNF hired a new Director of Operations, and he has worked diligently to promote the facility (e.g., new website, marketing brochure), upgrade tools, and implement procedures to create a new standard of excellence.

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: awareness of the facilities and how to access them, distance to travel to the facilities, and cost to utilize the facilities. To address these barriers, we have implemented targeted, innovative programs and activities.

RTNN Kickstarter Program: This program supports use of the facilities by new, non-traditional users by providing free initial access. To date, 54 projects have been selected for over 1,000 hours of use (Year 3, 12 projects, >180 hours use). The majority of participants are from non-R1 colleges/universities (42%), start-ups (30%), and K-12 students/classrooms (11%). Thirty percent of participants who completed the program continued work in the facilities with their own financial support resulting in >$70,000 in subsequent revenue. This shows that the program is a pathway to bringing in new users and increasing sustainability of nanotechnology facilities. *Assessment:* Semi-structured interviews have been conducted with 13 participants. Respondents are happy with the program and have indicated they will return. A common theme from respondents is gratitude for RTNN staff.

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. It includes 8 modules, each focused on a different fabrication or characterization concept. Students first learn the science behind a specific technique or instrument. In-lab demonstrations of the equipment follow each lecture with simple explanations of each step in the process. Since the course launch, over 22,000 people have visited the course website, over 9,000 have enrolled, and over 1,100 have completed the course. Students hail from more than 130 countries; learners from India (31%) and the United States (17%) account for 48% of total learners. Several participants have engaged with RTNN outside the course (e.g. Kickstarter program, facility tours, subscription to newsletter, etc.). *Assessment:* Surveys were sent to students after course completion. Overall, students were very satisfied with the course: 6.53 ± 0.70 (7=very satisfied) for course materials; 6.48 ± 0.68 for course instruction, and 6.50 ± 0.75 for multimedia content of the course. 93% of respondents noted they were "likely" or "very likely" to recommend the course to others. 91% of respondents noted they had a better knowledge of the capabilities of RTNN's facilities.

Workshops, short courses, symposia: In Year 3, RTNN held 27 technical workshops and short courses (>140 participants) on engaging and relevant topics. The RTNN also helped to plan and execute the Carolina Science Symposium. This event is student-focused, giving many early career students their first opportunity to present research in a professional setting. We rebranded the event (formerly the MRS/ASM/AVS joint symposium), identified speakers, publicized, and handled logistics like poster judging. These efforts led to the largest attendance (>100) in event history.

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 >700 unique visits monthly (>75% increase in past year). We also maintain two subscription lists to share information and opportunities: one to principal faculty (>250 nanotechnology faculty) and one to other stakeholders (>2,000 subscribers). We have worked diligently to broaden our reach by adding new contacts to our subscribers list and have increased the number by over 95% in the past year. Newsletters are sent using a formal, attractive design through the Bronto software platform.

Last year, we launched our social media campaign. We continue to be active on multiple platforms including Twitter, Facebook, and LinkedIn. Through these forums, we promote our activities, events, and opportunities to reach a broad audience, many of whom are not connected through our website or subscription lists. These platforms are a great way for our education and outreach participants to share their experiences and spread the word about new opportunities. We have seen a 36% increase in Facebook followers and 150% increase in Twitter followers over the past year.

Research Highlights and Impact

Core technical capabilities and specialized expertise in the RTNN span the following areas: interfaces, metamaterials, fluidics and heterogeneous integration; nanomaterials for biology and environmental assessment; organic and inorganic 1-D and 2-D nanomaterials; and textile nanoscience and flexible integrated systems.

Scholarly and Economic Impact: Work performed in the RTNN led to >240 publications by our users. In 2017, the RTNN impacted $73.5 million in research activity, as defined by annual research expenditures, for projects that utilized the facilities. 26 patents were filed and 15 patents were issued. Our Kickstarter program has given 16 start-ups free access to the facilities, facilitating the success of these nascent business ventures.

Education and Outreach Activities

2018 NNCI REU Convocation: RTNN welcomed over 50 guests to NC State at the NNCI REU Convocation. Participants from 10 NNCI sites shared their summer research with peers as well as NNCI faculty, staff, and students. Attendees also participated in professional development activities that included updating their LinkedIn profiles and learning how to effectively communicate science. Poster sessions were held on the campuses of Duke and UNC to give students a broader perspective of nanotechnology in the Research Triangle. **Outreach to K-12 Students:** In Year 3, we reached over 4,500 students through our outreach programs with >60% of participants from underrepresented groups in STEM. **Immersive Lab Experiences**: We have created five experiences for G6-12 students where students actively work in the facilities: microcomputed tomography, SEM, photolithography, electromagnetism, and nanoparticle synthesis. *Assessment:* We obtained IRB approval to survey middle school students who participated in the SEM immersive lab experience. The survey consisted of two parts. Students first graded their overall experience, labs, and staff (F to A+). Then, students told a story about their experience. The overall experience received an average grade of A-; the labs an A-; and the staff an A. The students' stories communicated the benefits of the first-hand experience and interpersonal communication between staff and students. Even small interactions left bright impressions. **Visits to Schools**: RTNN staff traveled to K-12 schools, interacting with over 1,100 students. These visits were paired with hands-on activities to engage students. For example, we brought a portable, desktop SEM into classrooms. For one of our school visits, RTNN staff traveled to Fayetteville, North Carolina to engage with science classes at John Griffin Middle School. Fayetteville is home to Fort Bragg, one of the largest army bases in the United States. Greater than 60% of students enrolled at John Griffin are underrepresented minorities in STEM, and the majority of students have at least one parent actively serving in the military. Over three days, >600 6-8th grade science students as well as 10 special needs students learned more about nanotechnology and had the opportunity to use the desktop SEM. **Girls STEM Day @ Duke:** In May 2018, the RTNN, in partnership with the Triangle Women in STEM, Duke's Pratt School of Engineering and Trinity College of Arts and Sciences, Credit Suisse, and IBM, hosted over 100 North Carolina girls as well as Girl Scouts and their families. These young women experienced significant hands-on time in the facilities–including use of an SEM–and earned badges in forensics, digital photography, and robotics for their work. **Community College and Teacher Workshops:** Participants in our third annual two-day workshop for community college educators used multiple tools in the clean room to fabricate a functional LED device. Time was also devoted to developing curricula that incorporates nanotechnology. We also held short workshops for local K-12 educators introducing the facilities, describing our programs, and explaining how to engage with the RTNN. **Other:** We hosted many booths at school science nights, participated in numerous North Carolina Science Festival activities, and welcomed tour groups in facilities and remotely.

Societal and Ethical Implications Activities

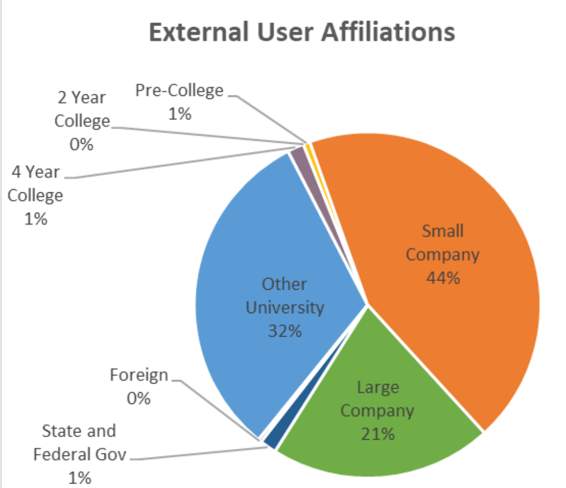
The goal of the SEI program is to leverage the RTNN team and user base to enhance the instruction and understanding of how users and society engage with nanotechnology**. Deep Assessment:**

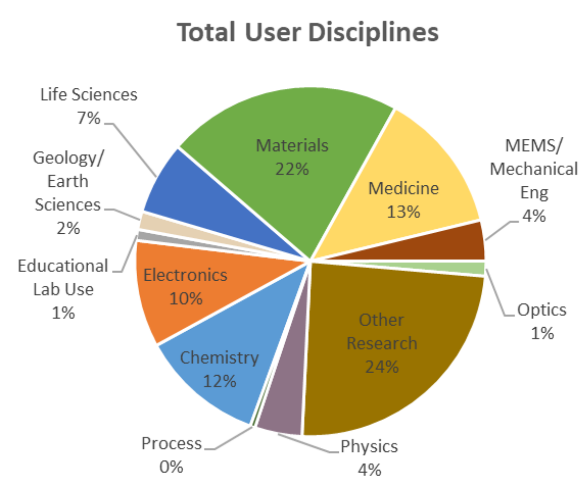
Surveys were designed and implemented for specific activities: facility users, Coursera students, Kickstarter participants, immersive lab participants (middle school students), symposia, workshops, and tours. This data is used as an iterative tool to improve RTNN's programming. **Social Media:** We have a cross-platform presence on social media, and we use this to alert the public to nanotechnology news, policy issues, and events and respond to inquiries. **Team Science:** We have begun to compare and contrast data among the facilities, especially when it comes to staff-related satisfaction. We have collected comments from users and are using these to profile lab dynamics.

RTNN Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	1,177	1,454	1,377
Internal Cumulative Users	975	1,096	1,054
External Cumulative Users	202 (17%)	358 (25%)	323 (23%)
Total Hours	53,044	51,747	55,684
Internal Hours	46,908	43,053	46,422
External Hours	6,136 (12%)	9,694 (17%)	9,263 (17%)
Average Monthly Users	395	422	420
Average External Monthly Users	50 (13%)	63 (15%)	71 (17%)
New Users	433	527	695
New External Users	71 (16%)	69 (13%)	82 (12%)
Hours/User (Internal)	48	39	44
Hours/User (External)	30	24	29

Year 3 User Distribution





11.12. San Diego Nanotechnology Infrastructure (SDNI)

During the current reporting period, SDNI has continued to focus on improving operations and processing expertise. The UCSD leadership is very supportive of SDNI's efforts to expand the interface to industry, especially to small companies, and our facilities are becoming increasingly recognized as a crucial enabler for new companies focused on device development. We were able to overcome serious challenges in facility staffing, and we have used these challenges as an opportunity to further strengthen our operations.

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

Facility: We have continued improvement and tuning of the lab management system of our primary facility, Nano3, based on the commercial Facility Online Manager (FOM) software. We have upgraded the Chipscale Photonics Testing Facility (CSPTF) access system to track user access similarly to that of the Nano3 Cleanroom and Characterization Facility.

Tools: During Year 3, we have made the following investments in purchases/installations of tools and tool upgrades. All purchased systems have been successfully installed and operational.

1) FEI Quanta FEG 250 ESEM (Nano3): The Quanta FEG 250 Scanning Electron Microscope features three modes of operation: high vacuum, low vacuum and ESEM. Achievable resolution is 1.2nm at 30kV and 2.3nm at 1kV with beam deceleration in high vacuum.
2) FEI Apreo SEM (Nano3): Apreo HiVac is a Schottky Field Emission Scanning Electron Microscope (FESEM) that combines high and low-voltage ultra-high resolution capabilities with an electrostatic lens design. Achievable resolution is 0.8nm at 15kV and 1.0nm at 1kV using the immersion lens.
3) J.A. Woollam M-2000D Spectroscopic Ellipsometer (Nano3): The J.A. Woollam M-2000D spectroscopic ellipsometer is a powerful and versatile tool for thin film characterization.
4) Heidelberg MLA150 Laser Writer (Nano3): The Heidelberg maskless aligner (MLA150) is a laser direct write lithography tool with high writing speeds. It allows users to directly pattern photoresists without the need for photomasks.
5) Magnetron Sputter Sources (Nano3): We have been working on replacing sputter cathodes with cathodes that enable our users to independently change target materials. The source replacement is now 80% complete. About 50% of our users can now independently change sputter targets, greatly improving their processing efficiencies.
6) Additional sample holders for Vistec EBPG5200 Electron-Beam Writing System (Nano3): We procured two additional sample holders (~$100k) for our electron-beam writing system to improve the efficiency of our operation by allowing more samples to be written unattended.
7) Measurement stations for grating coupled photonic circuits (CSPTF): The CSPTF has created a permanent measurement station for grating coupled photonic circuits produced by photonic foundries.

Staff Updates: During the reporting period, we hired 4 staff members (two with a PhD degree) to replace three members who left SDNI to lead another university facility (UC Davis) or join industry.

User Base

During NNCI year 3, SDNI served a total of 692 individual users from 189 user groups. 46% (87) of the user groups were non-UCSD groups (51 groups from small companies, 21 groups from large companies, 12 groups from non-UCSD academic institutions, and 3 groups from state/federal government institutions). Most of the work carried out at SDNI is extremely multi-disciplinary, but the self-identified disciplines for our user groups were 41% Materials, 20% Life Sciences/Medicine, 20% Electronics, 7% Optics, 4% Physics, 4% Chemistry, 2% Education, 1% Medicine, 1% MEMS/Mechanical Engineering. 21% of our users received direct services, carried out by SDNI staff.

Research Highlights and Impact

Scientific impact:

Topological semiconductor laser: The research, published in Science, by Prof. Boubacar Kante's group shows the world first topological semiconductor laser. Under magnetic field, only one topological lasing mode exists without the counter propagating mode. Topological laser mode is robust against perturbations. By breaking time reversal symmetry, a topological laser can potentially operate without an optical isolator. The work was selected as one of top ten physics breakthroughs in 2017. SDNI staff have provided essential technical supports, consultation, and nanofabrication services to enable the demonstration of the device.

Atomic-level interfacial structures for low dimensional condensed matters: Prof. Jian Luo's group controls the effects of electric fields in nanomaterials fabrication via altering the atomic-level interfacial (grain boundary) structures. SDNI's DualBeam FIB system was used to prepare specimens. The research leads to the development of energy-saving, ceramic fabrication methods. The group has discovered that an electric field plus water vapor can "flash" ZnO (T_m = 1975°C) at room temperature to subsequently sinter it to ~98% density in 30 seconds, while the conventional sintering of ZnO takes place at >1000°C for hours.

Detection of single photons for biological (vision restoration) and non-biological (imaging and quantum computing) applications: Through collaborations between Nanovision and Prof. Lo's group, a semiconductor device using a mesoscopic cycling excitation design has been demonstrated to detect single photons, facilitated by the SDNI facility and its staff scientists. When fabricated into a retinal prosthesis, the device can restore human vision for patients with macular degeneration. When used as photodetectors, the devices can find applications for night vision, LIDAR for autonomous vehicles, and quantum computing.

Economic impact:

SDNI has constantly trained users advanced nanofabrication and material characterization through short courses, hands-on education programs, and internships. It is estimated that over 80 PhDs, 20 postdocs, and 20 student interns working at SDNI have entered the workforce each year.

SDNI has helped several startup companies raise funding and produced new products. SDNI has helped Roswell Biotechnologies to produce biosensors that combine molecular electronics with CMOS chips for third generation DNA sequencing. With the support from SDNI staff, the company has won government contracts and raised major investments from venture funds. As another example, SDNI's microfluidic staff have produced thousands of microfluidic device samples to support the product development for NanoCellect Biomedical, a startup company developing microfluidic cell sorters and single cell analysis systems for gene editing, drug discovery, and immunotherapy. With the support of SDNI, the company has won 14 NIH grants for over $11M and raised $15M venture fund led by world class investors such as Illumina Venture. NanoCellect's microfluidic products are now sold worldwide. There exist many other cases showing the economic impact of SDNI. To name a few more examples, SDNI has supported Bionano Genomics, the world leader in DNA mapping that went public in 2017, to produce 40nm nanofluidic channels; SDNI has supported Nanovision Biosciences to produce retinal prosthesis to restore human vision; and SDNI has helped Obsidian Sensors, a spin-off from Qualcomm, to develop its MEMS bolometer sensors for autonomous vehicles and night vision. In the past 12 months, SDNI has contributed to the generation of over 200 new engineering/scientist positions.

Education and Outreach Activities

SDNI has led and participated in a number of outreach and education activities, and obtained positive (4.1/5.0 overall satisfaction) feedback from these activities, including 52 weeks of science, Boys and Girls Club of Logan Heights Branch, Science Field Day Competition & Science Clubs, and Johns Hopkins Talented Youth Program, etc.

SDNI has hosted the REU (11 students) program to train undergrads (7 out of 11 being women or minority students) on research. SDNI also supported 2 high school science teachers in the RET program. The RET programs from previous years have now been taught in high school classroom.

SDNI's most important accomplishment in outreach/education is the development of "remote hands-on SEM lab education program." We have collaborated with Zeiss, Qualcomm Institute, and high school teachers to create remote hands-on nanotechnology program where high school and community colleges science teachers can have their class interact, in real time, with the SDNI scientists during class time and conduct experiment with mobile devices. The experiments are closely related to their curriculum as the contents are designed jointly by high school science teachers. We have conducted several beta tests with chosen high schools and community colleges. In 2019 we will be offering the program in 10 schools to collect more feedback.

Computation Activities

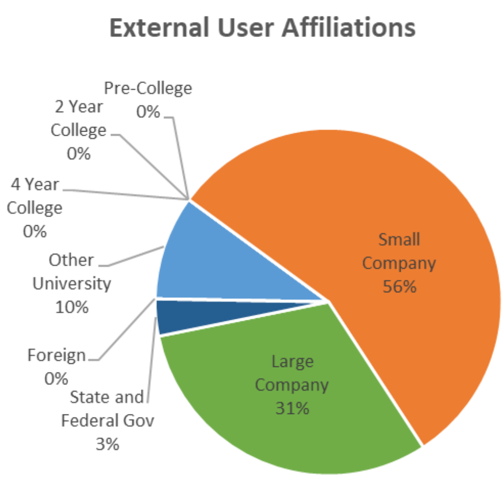
OOMMF (Object Oriented Micromagnetics Framework): We updated the GPU OOMMF version to make it faster and to make it compatible with newest releases of CUDA and Linux kernels.

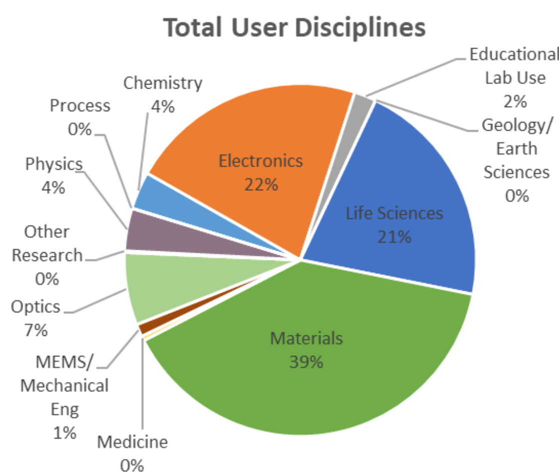
FastMag: We have improved the module for computing coupled magnetization-eddy current dynamics. This module now includes functions allowing computing the eddy current based on an integral equation formulation and based on the differential equation formulation.

SDNI Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	650	644	692
Internal Cumulative Users	495	478	518
External Cumulative Users	155 (24%)	166 (26%)	174 (25%)
Total Hours	47,893	50,497	49,519
Internal Hours	40,890	38,890	39,372
External Hours	7,003 (15%)	11,607 (23%)	10,147 (20%)
Average Monthly Users	290	385	300
Average External Monthly Users	49 (17%)	56 (20%)	54 (18%)
New Users	183	210	225
New External Users	34 (19%)	50 (24%)	46 (20%)
Hours/User (Internal)	83	81	76
Hours/User (External)	45	70	58

Year 3 User Distribution

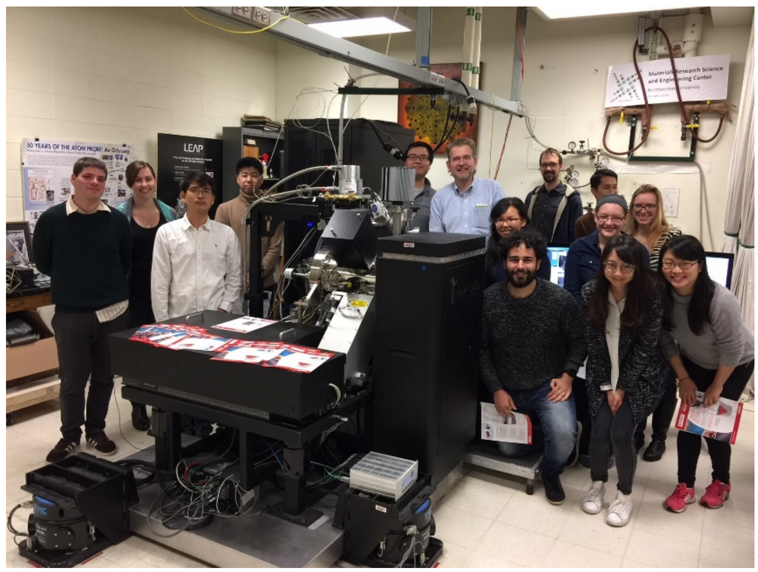




11.13. Soft and Hybrid Nanotechnology Experimental (SHyNE) Resource

Facility, Tools, and Staff Updates

The Soft and Hybrid Nanotechnology Experimental (SHyNE) Resource is a joint venture between Northwestern University and University of Chicago. SHyNE Resource provides researchers from academia, government, and companies large and small with access to user facilities with leading-edge fabrication and characterization tools, instrumentation, and expertise within all disciplines of nanoscale science, engineering and technology. Northwestern University, under the leadership of site director, Professor Vinayak Dravid, partnered with University of Chicago and co-director Professor Andrew Cleland to represent the Midwest within the NNCI. 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) and the University of Chicago (PNF).



NUCAPT facility users at an open house to celebrate the upgrade of the atom probe tomograph to a LEAP5000XS.

SHyNE facilities are actively engaged in acquiring, updating or replacing key equipment within the facilities through a combination of internal and external funding mechanisms. In total, more than **20 new instruments** and numerous tool upgrades were installed in Year 3. Many new fabrication tools were added across the two fabrication facilities including two new e-beam evaporators in the PNF and new ALD, laser cutter and maskless aligner tools in NUFAB. Highlights on the characterization side include two state-of-the-art S/TEM instruments (JEOL ARM200CF and ARM300CF) that are now up and running in NU*ANCE* Center, the NUCAPT facility upgraded to a LEAP5000XS configuration (See figure above), and IMSERC completed a major upgrade of NMR capabilities. Maintaining an active and engaged user base for SHyNE facilities is contingent upon the successful recruitment and retention of high quality staff. **Eight new technical staff** joined the SHyNE team in Year 3, six of whom are in newly created positions and many receive partial funding through NNCI.

New technical staff in Year 3:

1. Xiaobing Hu, TEM Facility Manager, NU*ANCE* Center
2. Shaoning Lu, Research Associate, NUFAB
3. William Mohr, Equipment & Research Engineer, NUFAB
4. Chrystian Posada, Process Engineer, PNF
5. Samuel Kaehler, Equipment Engineer, PNF
6. Arsen Gaisin, Mass Spectrometry Specialist, IMSERC
7. Charles Bressan, Core Technician, SQI

8. Suvendu Biswas, Assistant Core Scientist, SQI

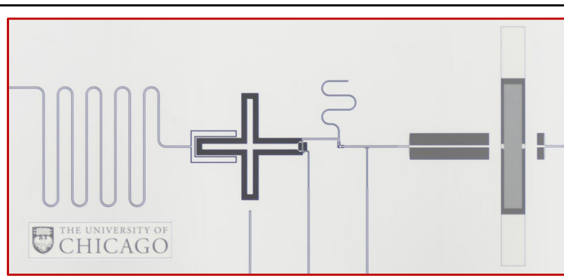
User Base

For Year 3, SHyNE facilities had **1660 unique users** who logged over **137,000 hours** of instrument time generating $4.4M in revenue. External users represented 13% of total users and 11% of revenue. SHyNE actively engages local and regional companies, colleges, universities, non-profit organizations and governmental agencies to recruit new users. This is accomplished by a number of marketing strategies including: exhibitions at conferences and trade shows, production of a web portal, a marketing video and promotional materials, networking with alumni, coordination with university-wide corporate engagement and media relations offices, and an active social media presence.

In Year 3, SHyNE rolled out a SEED (SHyNE External Experiment Development) funding program to recruit new external users by providing small grants for up to $2500 in facility usage. Three proposals were funded for new users from the Illinois Institute of Technology, Argonne National Lab and Biomsense (an early-stage startup). In Year 4, our primary focus will be on recruiting additional external academic users through a combination of an active marketing campaign, redevelopment of our web presence and continuation of the SEED program.

Research Highlights

The research output facilitated by SHyNE facilities is substantial, including more than **300 publications**, which *specifically cite* the NNCI grant and/or one of the facilities funded through SHyNE. We expect the actual output is much higher and are actively working with University administration to find strategies to approach total compliance with facility acknowledgement. In addition, we found **84 patents, patent applications and invention disclosures** that benefited from SHyNE facilities in their conception.

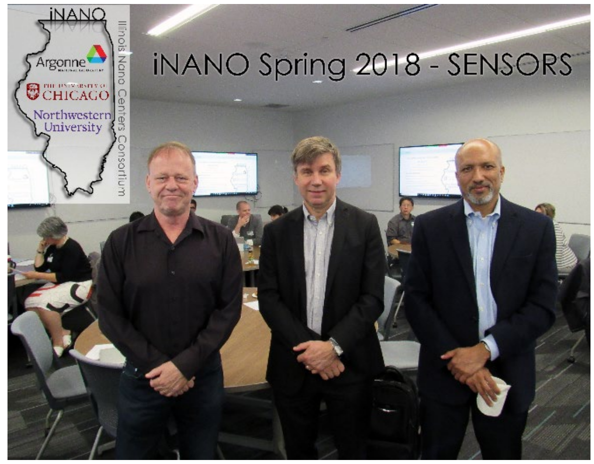


Optical micrograph of assembled device yielding quantum-controlled surface acoustic wave phonons.

Research activities resulted in many high-profile publications in journals such as *Science*, *Nature*, *Nature Photonics*, *Nature Astronomy, Nature Chemical Biology, Nature Chemistry* and *Nature Nanotechnology*. Of particular note, SHyNE facilities were utilized by groups from University of Chicago and Argonne National Laboratory to fabricate a device for the quantum control of surface acoustic wave phonons as shown at left [*Nature* **563**, 661-665 (2018)]. The Salehi-Khojin group at the University of Illinois at Chicago utilized SHyNE facilities to characterize novel lithium-oxygen batteries [*Nature* **555***,* 502–506 (2018)]. In addition, the Hersam group developed multi-terminal memtransistors from polycrystalline molybdenum disulfide for brain-like neuromorphic computing [*Nature* **554**, 500-504 (2018)].

Education and Outreach Activities

Education and outreach activities are a critical part of SHyNE's mission and include academic courses with laboratory components, an REU program, hands-on workshops, seminars, vendor symposia/demos, facility tours/demos (K-12, higher education and public). We provide facility tours for more than **1000 visitors** in Year 3. Over **1450 students** participated in courses utilizing SHyNE facilities in Year 3. SHyNE facilities hosted workshops and seminars reaching more than **900 participants**. SHyNE sponsored **three REU students** in a unique, facilities-focused REU program that exposed undergraduates to advanced instrumentation as a key component of their projects.



iNANO 2018 keynote speakers Tom Meade, Philippe Guyot-Sionnest and Supratik Guha (L-R).

Key workshops and seminars:

1. "Zeiss Amplified Materials Imaging Workshop", hosted by NU*ANCE*, XRD and co-sponsored by NU-MRSEC.
2. "X-Ray Photoelectron Spectroscopy Workshop", hosted by NU*ANCE*, and co-sponsored by Thermo Scientific and NU-MRSEC
3. "Midwest Microscopy and Microanalysis Society (M3S) Spring Meeting" hosted by NU*ANCE*, co-sponsored by NU-MRSEC and supported by numerous vendors.

In addition to these activities, SHyNE resource led the establishment of a new confederation of nanocience facilities called the Illinois Nano Centers Consortium (iNANO). This program seeks to bring together researchers, staff and external users of several regional institutions (NU, UChicago and ANL) with interest and capabilities in nanoscale fabrication and characterization. We held a kick-off meeting in Spring of 2018 on the topic of Sensors (see figure above), with speakers and panel discussions related to biological, environmental and optical/electrical/mechanical sensing. We are currently planning a second event for Year 4, and looking to expand participation to other regional universities.

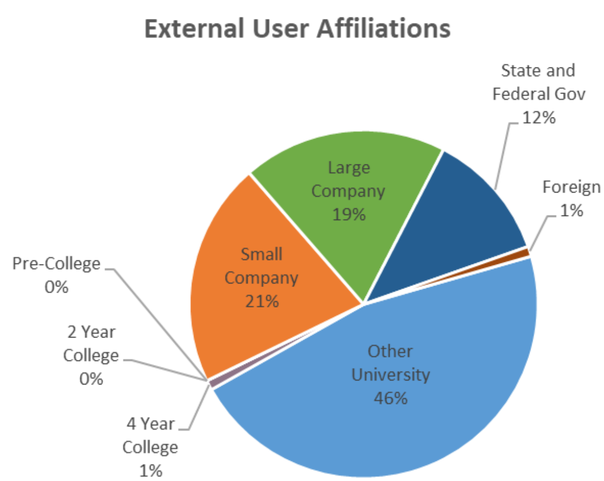
Societal and Ethical Implications Activities

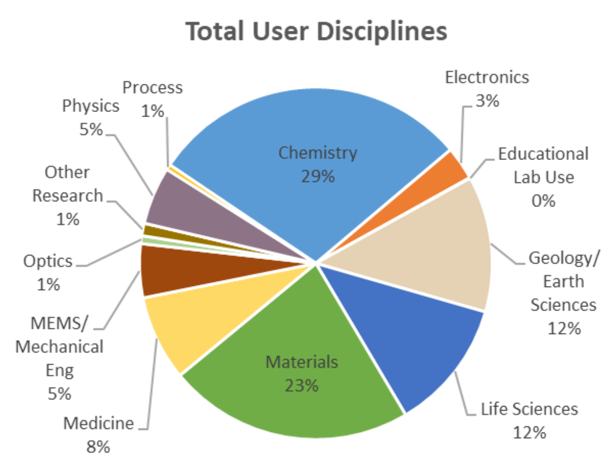
While not a formal SEI activity, SHyNE continues to grow and develop our novel NanoJournalism program in collaboration with Northwestern's Medill School of Journalism. In Year 3, we held a science communications workshop led by Medill's Abigail Foerstner and focused on helping scientists communicate their research to a lay audience. We also continued our NanoJournalism internship program by hiring a Medill undergrad, Daniel Fernandez, to embed in our facilities, learn about how scientific research is carried out and generate stories about these activities.

SHyNE Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	1,446	1,620	1,660
Internal Cumulative Users	1,230	1,404	1,444
External Cumulative Users	216 (15%)	216 (13%)	216 (13%)
Total Hours	138,000	132,673	137,375
Internal Hours	128,838	127,127	131,206
External Hours	9,162 (7%)	5,545 (4%)	6,169 (4%)
Average Monthly Users	679	802	797
Average External Monthly Users	54 (8%)	54 (7%)	52 (7%)
New Users	699	698	605
New External Users	152 (22%)	140 (20%)	86 (14%)
Hours/User (Internal)	105	91	91
Hours/User (External)	42	26	29

Year 3 User Distribution





11.14. Southeastern Nanotechnology Infrastructure Corridor (SENIC)

Facility, Tools, and Staff Updates

SENIC continues to build upon the "one facility, two locations" approach to the partnership, and the two sites have also continued to exchange best practice techniques for installing and maintaining common toolsets.

At Georgia Tech IEN, construction was completed for a lab dedicated to Pulsed Laser Deposition (PLD). The PLD tool was installed in July 2018 and will be used to deposit thin films to overcome the limitations of current CMOS technology. Installation and infrastructure enhancements supporting the new Elionix 100 keV electron-beam lithography tool concluded in March 2018. The tool is operational as of April 2018 and meets or exceeds factory specifications. Using university support, the Materials Characterization Facility (MCF) purchased a new confocal Raman microscope from Renishaw that opened to new users in July 2018. The MCF also added instruments distributed from an analytical lab on campus that closed in 2018, including FTIR, FTIR microscope, polarized-light microscope, and tools and supplies for metallographic sample preparation.

The IEN Laboratory Operations Support Team has added two new key positions. A Process Engineer provides technical assistance to cleanroom users on materials characterization tools including scanning electron microscopes, laser profilometers, DLS particle size and zeta potential measurements, surface energy instruments, and FTIR, as well as conducting remote work for materials characterization and analysis. A Research Technician supports key laboratory processes and tools relating to plating and printed circuit board manufacturing to include maintenance, training, and process development in a pilot line and research environment. The MCF has also added a new postdoctoral researcher to increase PI's knowledge and usage of STEM (monthly usage has doubled) and plans to partially fund another to do the same for low-temperature STM/AFM. The ISO/IEC 17025 certified JSNN/Gateway Material Testing Center (GMTC), which offers ASTM, AATCC, ISO testing is now fully staffed with two full-time staff and three part-time technicians. GMTC specializes in material testing for automotive, aerospace and textile industries. Based on the experience of IEN, during the past year JSNN also formed a Technical Support team whose responsibilities include user consultation, training, process and characterization support, remote jobs and data analysis, if requested by the user. JSNN also created an online user consultation and training request form which helps the Technical Support team to better manage training and process/characterization consultation requests. Lastly, JSNN/Gateway hired a full-time Equipment Manager to oversee cleanroom and other lab operations, in addition to managing the Technical Support team, and a part-time staff member to help meet the growing demand for analytical characterization remote service requests.

Over the past year, the SENIC facilities at Georgia Tech and JSNN have invested approximately $4M in 25 tool acquisitions and upgrades including the following:

Lithography & Direct Patterning: Elionix ELS-G100 EBL (new purchase); Heidelberg MLA150 Maskless Aligner (new purchase); Optec WS-Flex Laser Micromachining (new purchase); Stratasys J750 multi-material 3D printer (DURIP funding; new purchase)

Deposition: Control Layer II Sputterer (new built); Trion Sputterer (upgrade); CVC E-beam Evaporator (upgrade); Control Layer SEF Sulfurization Furnace (upgrade); Veeco/Ultratech S200 ALD (new purchase); Arradiance GEMStar PE ALD (new purchase)

Etching: PlasmaTherm ICP (used tool purchase)

Imaging & Metrology: Thermo Scientific Escalab Xi+ (new purchase); Varian 820-MS ICP-MS (new purchase); Horiba Raman Confocal Microscope (new laser; tool upgrade); Kruss Tensiometer (new purchase); Rheosense m-VROC Viscometer (new purchase); CytoViva Hyperspectral Microscope (new purchase); Thermo Scientific Microtome (new purchase)

Georgia Tech has made a concerted effort to make high-resolution TEM more accessible and useful to the user community. In addition to vendor presentations, we have also hosted a Hitachi HTA applications scientist who lectured and performed hands-on instruction as part of the TEM course for students in the school of Materials Science and Engineering. The MCF and allied PIs have made ~$100k in investments over the past year (~$2M over the past 3 years) to enhance capabilities for in-situ and analytical measurements. As a result of these efforts, usage of high-resolution TEMs at Georgia Tech (FEI Tecnai F30 and Hitachi HD-2700) is approximately 50% greater compared to the same period last year.

User Base

Marketing of SENIC continued through the website (http://senic.gatech.edu/), as well as additional promotion and communication efforts through email and social media, with SENIC-specific efforts on Facebook, LinkedIn, and Twitter. JSNN also recently hired a full-time staff member for user outreach, marketing and collection/analysis of usage statistics and production of a SENIC quarterly newsletter.

Based on recommendations of the SENIC advisory board, user recruitment events such as SENIC webinars and presentations at various university sites in the southeastern region were held. SENIC Ambassadors (existing users) hosted outreach representatives for presentations at University of South Carolina, University of Georgia, and Georgia State University. These events were well attended by the faculty and students from the host universities and by local industry representatives. SENIC staff attended or exhibited at local and regional conferences and events to help recruit new users including MicroTAS (Oct 23-26, 2017, Savannah, GA), Southeastern Regional Meeting of the ACS (Nov 7-10, 2017, Charlotte, NC), and Southeastern Association of Shared Resources (June 27-29, 2018, Atlanta). In addition, SENIC continued to interact with county economic development officials. In May 2018, IEN held its annual User Science and Engineering Review (USER) Day in conjunction with the Technical Exchange Conference at which facility users presented research posters. JSNN hosted its 6th Annual Nanomanufacturing Conference (Sept. 2018) with over 160 attendees focusing on "Innovation to Commercialization."

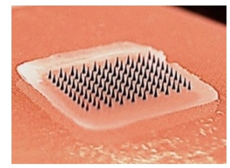
During this third year of the NNCI program (Oct. 2017-Sept. 2018), the SENIC facilities have served more than 1,300 individual users (a 10% increase over year 2), including more than 260 external users (a 19% increase over year 2) representing 96 companies, 29 colleges and universities, and 14 other institutions. Several users have accessed capabilities at both SENIC locations with minimal difficulty. The majority of users access the facilities on-site, although 176 users obtained services remotely, and some users operated in both on-site and remote fashions. Monthly users averaged 546 (a 10% increase over year 2), and 32 new users were trained each month on average (386 total during the reporting period, a 23% increase over year 2).

As part of a network-wide NNCI effort, SENIC participated in the second annual user satisfaction survey. The online survey was emailed to all IEN and JSNN users and received 117 responses (as of 12/11/18). Overall, the results are very positive: 91% of respondents were able to complete their work on-time, and 98% would refer SENIC to a colleague. The average facility rating was 4.5/5 and overall site rating was 4.5/5, both slight improvements since 2017.

Research Highlights and Impact

Notable new users came to SENIC from Duke, Vanderbilt, NC State University, San Jose State University, University of Central Florida, Lubrizol, QuSwami, 3M, Alcon, Alcorix, Alienus, Applied Novel Devices, Delta Flight Products, Indian Well Mining Company, Mavric Semiconductor, Nanophotonica, Ruger, RTI International and Savannah River National Lab. Example research highlights include:

Flu Vaccine Delivery via Transdermal Patch (Mark Prausnitz, Georgia Tech)

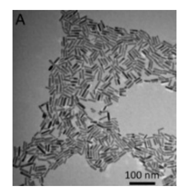


A press-on patch that delivers flu vaccine painlessly worked as well as an old-fashioned flu shot with no serious side effects was reported in the journal *Lancet*. The team at Georgia Tech, and spin-off company Micron Biomedical, demonstrated the first test using real flu vaccine, and the results show it caused immune responses very similar to those elicited by syringe dosing. **This story was reported by NBC, CBS, BBC, NIH, and other media outlets.**

Brain-Mimicking Nanomaterials for A.I. Retina Receive $7 Million Research Grant (Alan Doolittle, Georgia Tech)

A team of Georgia Tech and Binghampton University researchers were funded by the DoD to expand work on new metal oxide materials to emulate the way human neural networks buzz with electric potential on a cellular level and provide neuristers for practical use in brain-like computing.

Thwarting Metastasis by Breaking Cancer's Legs with Gold Rods (Mostafa El-Sayed, Georgia Tech)

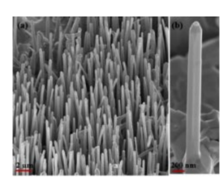


This research team has developed a new photothermal gold nanorod therapy to thwart cancer's spread through the body. The research was funded by the NSF and NIH and published in *Proceedings of the National Academy of Sciences.*

Solid-State Nanopore Analysis of DNA Base Modifications (Adam Hall, Wake Forest University)

This group, a collaboration between Wake Forest and Viginia Tech, has developed a new approach for the targeted detection of diverse modified bases in DNA. This technique provides exceptional modularity via selection of targeting enzymes, which was established through the detection of four DNA base elements, thus demonstrating the potential for a quantitative nanopore assessment of a broad range of base modifications. A recent publication appeared in *Nano Letters* and was highlighted on the cover.

GaAsSb Nanowires in the Telecommunication Wavelength Range (Shanthi Iyer, JSNN)



This research group, in collaboration with the Reynolds group at NC State, have developed a self-catalyzed growth approach for axial GaAs$_{1-x}$Sb$_x$ nanowire (NW) arrays with bandgap tuning corresponding to the telecommunication wavelength of 1.3μm. The results were published in *Scientific Reports*.

Scholarly impact can be measured indirectly using 2017 publications (with approximately 50% PI compliance): 363 journal publications, 331 conference presentations (papers, talks, or posters), 8 book chapters or books, and 21 patents, patent applications, or invention disclosures.

While economic impact can be difficult to quantify, there are individual examples. ClassOne Technology, Inc. uses SENIC (both IEN and JSNN) for equipment process qualification and validation. According to Byron Exarcos (CEO), "with the work conducted at SENIC, ClassOne has been able to win business at the world's premier and most advanced fabs across the world for our Solstice automated plating system." BNNano, Inc., with facilities in Burlington, NC, is currently the only company in the world for high volume manufacturing of Boron Nitride Nanotubes and NanoBarbs™ and uses JSNN characterization facilities for quality control and process verification. Steve Wilcenski (CEO) estimates that SENIC facility access saved them $100K in 2018. Finally, SBIR grants were recently awarded to AxNano and Kepley Biosystems.

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 14,000 individuals from young children through adults.

The following SENIC internship opportunities are available for college students:

- GT-IEN: NSF REU Site (2018-2020): SENIC Undergraduate Internship in Nanotechnology (SUIN) - Summer Internship for Students from Southeastern Institutions host 10 students/year for 10 weeks of research with a GT mentor and faculty member.
- JSNN: NIH: *Maximizing Access to Research Careers* (MARC) Undergraduate Student Training in Academic Research (U-STAR) Fellowship Program - This program offers students (2/year) underrepresented in the biomedical sciences an opportunity to engage in research projects and focused workshops and courses to prepare them for graduate school.
- JSNN: *Forsyth Technical Community College* – Four interns/year from Nanotechnology and Biotechnology programs receive up to 160 hours of on-site and paid workforce training in one of the JSNN core labs.

In order to strengthen the nanotechnology community among students at SENIC institutions, the Graduates in Nanotechnology (GIN) group was formed in 2018. Meetings are being video conferenced so students (undergraduates and graduates) from both Georgia Tech and JSNN can participate. Activities to date include Researchers' Open-Mic Presentations (ROMP) and a guest speaker. The purpose of ROMP is for students to share problems they're having with their research in order to receive feedback from the interdisciplinary GIN group. Students from the group are also planning a seminar series.

IEN hosts 16 Nano@Tech seminars each academic year with speakers primarily from the local community, which includes Georgia Tech faculty, as well as faculty from neighboring universities and researchers at companies in the region. JSNN also holds at least 12 seminars per year with speakers primarily from colleges, universities and industries in North Carolina. Both of these events are live-streamed and video archived. IEN's NanoFANS Forum, a biannual symposium at the intersection of life sciences and nanotechnology was held in October 2017 (Microfluidics in Cell Biology) and May 2018 (Biophotonics in Medical Diagnostics) with nearly 100 attendees at each. A variety of different vendor-supported and sponsored workshops were also held at both SENIC locations. Short courses were conducted with a special focus on hands-on experiences for the participants: “Soft Lithography for Microfluidics” (April and Sept. 2018), “Microfabrication” (March and August 2018), and “Materials Science SEM and X-Ray Microanalysis” (Oct. 2018). Using SENIC funding students from JSNN are provided scholarships to attend any of the Georgia Tech workshops.

SENIC has been active in providing outreach to K-12 students, teachers and the general public. Unique to JSNN is the NanoBus, an after-school mobile hands-on laboratory which includes an STM, 3-D printer and a variety of lab activities. Staffed by JSNN students, the NanoBus visited 18 schools between September 2017 and May 2018 reaching over 2000 students. In its third year, JSNN has continued to host the Canterbury Summer Science Academy for a week-long summer science camp. A new program, the JSNN-Draelos Science Scholars program, provides opportunities for high-school students to work in JSNN labs for 6 weeks to develop a passion for research and scientific study. SENIC reaches K-12 students with school visits, both on and offsite, occurring each month of the year. IEN also has a strong relationship with Atlanta Public School’s Gifted and Talented program, providing spring research internships for high-school students, and annually hosting their kickoff event for 150 students.

JSNN hosted the Annual Gateway to Science event during the NC Science Festival which included demos, tours, and videos on careers in nanotechnology. For outreach to K-12 teachers, IEN exhibited and provided a workshop at the Georgia STEM Forum as well as the Georgia Science Teachers Association meeting. SENIC exhibited at the North Carolina Science Teachers Association meeting as well as the National Science Teachers Association (NSTA) Charlotte Area Conference on Science Education. At the NSTA annual meeting in Atlanta in March 2018 SENIC personnel supported the joint NNCI/NNCO booth and provided a professional development workshop.

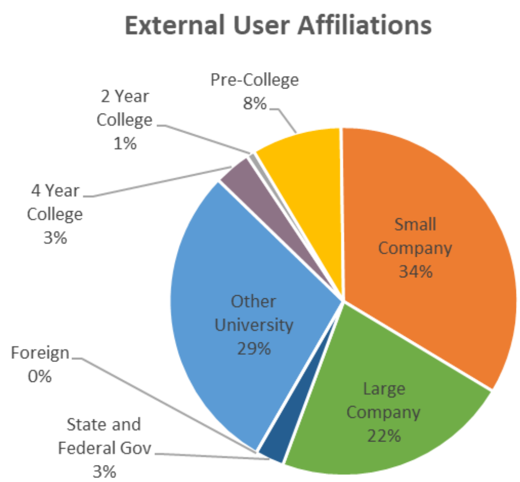
Societal and Ethical Implications Activities

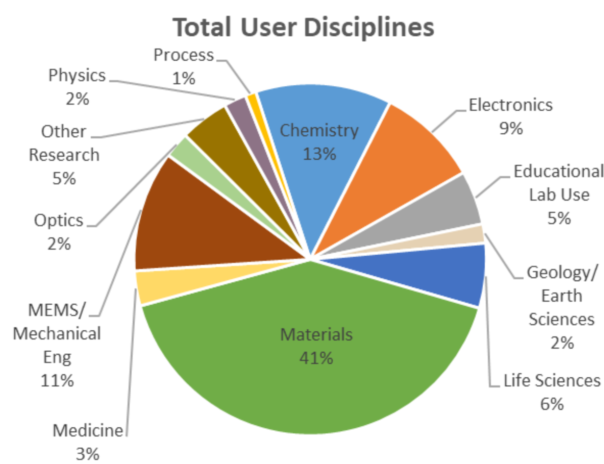
The aim of the SEI work at SENIC is to increase attention to application and commercialization of nanotechnology, while still attending to social and ethical implications. We continue to work toward development of a model which incorporates societal impacts in a pragmatic manner that parallels elements of the I-Corps program (“I-Corps Plus SEI”). We developed an exercise from this model, which was piloted at the January 2018 NNCI Winter School as well as at the Georgia State University Faculty Entrepreneurship & Innovation Workshop (with a national I-Corps trainer) in May 2018. In addition, we have used nano-informatics approaches, text mining of nanotechnology publication and patent title and abstract records, to identify emergent nanotechnology topics and broaden SENIC outreach. We have completed an SEI training video, “8 Things You Need to Know About Social Implications of Nanotechnology Research”, and this has been posted on the SENIC website and is being considered for use in the new user orientation. Finally, at the suggestion of the NSF Reverse Site Visit Review panel, we have added a new member to the SENIC External Advisory Board, Dr. Daryl Chubin who has been a director at the former Office of Technology Assessment, OSTP, NSF, and AAAS, and whose specialty is increasing access to science and engineering among minorities.

SENIC Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	1,067	1,196	1,311
Internal Cumulative Users	903	975	1,048
External Cumulative Users	164 (15%)	221 (18%)	263 (20%)
Total Hours	79,581	85,275	99,118
Internal Hours	71,659	73,499	85,730
External Hours	7,922 (10%)	11,733 (14%)	13,388 (14%)
Average Monthly Users	447	498	546
Average External Monthly Users	60 (13%)	63 (13%)	83 (15%)
New Users	313	313	386
New External Users	67 (21%)	110 (35%)	123 (32%)
Hours/User (Internal)	79	75	82
Hours/User (External)	48	53	51

Year 3 User Distribution





11.15. Texas Nanofabrication Facility (TNF)

Facility, Tools, and Staff Updates

NSF NNCI Texas Nanofabrication Facility (TNF) is composed of three Centers at the University of Texas: Microelectronics Research Center (MRC), the Texas Materials Institute (TMI), and the NASCENT Nanosystems ERC.

- MRC (former NNIN site) core focus is Micro and Nanofabrication in a 12,000 ft^2 100 shared cleanroom lab.
- TMI core focus is imaging and spectroscopic characterizations such as TOF-SIMS, XPS, SEM, TEM, AFM, etc. TMI has been relocated and centralized in the new Engineering Education and Research Center (EERC), a $350M building of the Cockrell School of Engineering. EERC will focus on education and interdisciplinary research.
- NASCENT **N**anodevice **M**anufacturability **Fab** (nm-Fab) has 5,000 ft^2 cleanroom space dedicated to Roll-to-Roll (R2R) and flex wafer-scale nanomanufacturing systems. A novel R2R film deposition system was installed in March 2018; a R2R etch tool is being developed. NASCENT –ERC has strong education and outreach programs that increases the broader impact of the MRC education program (see Education Activities). NASCENT-ERC mission is also to seek industrial partnership to accelerate the design, development and commercial deployment of the center's nanomanufacturing systems. That effort attracts new external users to the TNF shared facilities.

TNF offers over 130 state-of-the-art tools necessary for micro and nanofabrication, as well as an extended suite of characterization tools, crystal growth and nano-manufacturing systems. TNF acquired new capital investment worth $2M in 2017-18 that complements its existing strengths.

- AJA International Orion Ion Miller,
- KJL E-beam evaporator with a load lock.
- Replacement of the stage on Zeiss SEM
- Fully automated 2-D flake transfer system in a Glove box
- Aberration corrected JEOL TEM

TNF has a network of 24 professionals (undergrad student workers both as trainer and troubleshooter of various state of the art tool, technicians, engineers, and administrative staff) dedicated to their user base: graduate students, professors, start-ups, small and large company users. 6 FTE are supported by NNCI, the rest with UT institutional funds.

User Base

A proven way to increase the user base is to organize technical workshops. Banerjee has offered short courses to industry covering nanoelectronics, solid state memory and CMOS to advertise TNF. This is now part of an on-line certificate program at UT. In the past year, TNF in collaboration with vendors, offered lectures and equipment demonstration sessions. A couple of tours and workshops have been organized at MER and TMI throughout the year. TMI has hosted a series of technical training on the transmission electron microscope for graduate students. A video training of our state of the art tools like Raith and Fiji ALD has been planned and executed and will be posted online shortly to educate prospective users.

The NNCI at TNF for the past 6 months -Oct'17 to Mar'18-, hosted 442 unique users, averaging 4890 lab hours/month for a revenue of ~ $100k/month through user fees. In the year 2, the no of unique users was 696, used 4862 lab hours/month for a revenue of ~ 96k/month through user fees. TNF had 23% outside users cumulatively at the end of the first year, and 24% outside users (company and external academic) in the last 6months. The external institutions at NNCI TNF shared facilities in the year 3 (last 6 months) are breaking down between 32 companies (small and large) as well as 8 academic institutions from outside UT Austin including one international university. More than half of the current companies which benefit from the TNF shared facilities were already users at TNF in the past year. This proves a good and lasting relationship between TNF and their users and demonstrates the NNCI financial and scientific impacts. TNF will continue to organize activities such as technical workshops that are known to attract users from within and outside the University. The NASCENT Industrial Liaison Officer will continue to work closely with TNF to promote the shared facilities to industrial partners. User profiles including demographics and research fields (i.e. disciplines) are reported voluntarily through an online survey by each user during the orientation session. Half of the TNF users self-declared their research project to be related to Materials (34%) or Electronics (16%) disciplines at the end of year 2. The TNF shared facilities are utilized by 43% Under Represented Minorities (URMs) and 24% Women, the number is very close to the milestone set before year 1.

Research Highlights and Impact

This past year, TNF researchers published over 136 papers, including 45 by external users, and filed 4 patent applications. Papers were published in high impact journals such as the Nature group journals, Physical Review Letters, Nano Letters, Physical Review B and PNAS. There were breakthroughs in graphene and silicon MEMS microphones, 2D electronics and cancer detection sensors, among many others. A particular strength of TNF is the number of external startups who use the facility. A couple of vignettes are described below.

GraphAudio is a de-centralized company structure by design, with multi-regional and multi-institutional strengths. The technology originated from work done at UC Berkeley. Executive management and finance is located in Los Angeles, with sales and product engineering in Silicon Valley at UC Berkeley. Engineering and manufacturing processes are being developed and optimized at TNF, and software development is located in Brooklyn New York with the aid of Columbia researchers. The NNCI-funded entities in Austin were chosen for initial development activities due to the cost-effective facilities, substantial talent base related to graphene synthesis, and the excellent environment for start-up technology companies. The first two GraphAudio engineering hires were UT Austin PhDs, and additional hires are planned as the engineering and manufacturing group grows. Initial work has successfully demonstrated feasibility of novel graphene-based transducers for audio applications in support of GraphAudio's mission to become the global leader in acoustic sensing, micro-speakers and microphones in mobile, consumer and enterprise electronics.

Applied Novel Devices (AND) is another startup that has used TNF and the previous NNIN supported facility to develop advanced power transistors. Power devices such as MOSFETs and Insulated Gate Bipolar Transistors (IGBT) are used in a variety of high-growth applications including computers, communications, automotive and industrial supplies, to switch, shape or transfer electricity under varying power requirements across the voltage spectrum. While the active device thickness for vertical power MOSFETs and IGBTs has been constantly shrinking, the substrate thickness needed for manufacturing has been increasing to enable handling and processing of larger diameter wafers. These substrates have traditionally been mechanically thinned after device fabrication to minimize the negative impact of the thick substrate on performance and form-factor. However, the traditional back-grinding processes cannot thin the device below 60-70µm and consequently limit the device performance. In addition, the cost of grinding and thinning wafers reduces operational margins and poses a need for effluent handling and disposal. AND Inc. has developed a thin crystalline technology that can peel off 20 - 50µm of silicon from semi-processed wafers and enable reuse of the parent wafer. Using this exfoliation technology, AND has recently demonstrated the world's first Thin Crystalline (~30 Microns) Silicon Vertical Power MOSFET fabricated without grinding away the substrate.

Education and Outreach Activities

The TNF NNCI REUs are recruited nationwide, with emphasis on women and minorities. A cohort of 5 REUs is hosted by TNF, jointly with 5 REUs from NASCENT ERC each summer for 9 weeks. We will host the 2020 REU convocation. TNF is leveraging and supplementing the NASCENT ERC education/outreach/assessment activities by offering cleanroom tours (over 6 per year), seminars, equipment hands-on demonstrations, equipment training staff expertise, and interactions with faculty and graduate students. A fun and educational workshop and cleanroom tour was organized on October 9th 2018 for the high school students and it will be continued throughout the year every four months.

TNF has developed an On-line Certificate Course Development for Nanotechnology for industry. Banerjee has offered short courses to industry covering nanoelectronics, solid state memory and CMOS to advertise TNF. The topics are Nano-enabled Transistors, Sensors and Memory. Module 1 covers Semiconductor physics and carrier transport. Module 2 is on MOSFETs. Module 3 describes Advanced MOSFETs and Scaling. Module 4 deals with Logic and Memory, and the final Module 5 covers Flash and Hard Drives.

Societal and Ethical Implications Activities

Prof. Kahlor, TNF Site Director, continued our focus on finding ways to integrate SEI into TNF daily operations. Years one and two were spent on research analysis and content development, as well as training an MA student in SEI. In that work, her team drafted and tested on various audiences multiple iterations of a training video focused on SEI. She ended with a 15 min. professional quality video. In the last 12 months, the video has been shared with Jamey Wettmore and the other SEI representatives from the NNCI nodes. The video will be embedded in a survey so that we can collect brief pre- and post-viewing data. There is interest in then working to integrate the video in trainings across the nodes. An SEI survey has been developed in 2018. During this year, the SEI team has continued to edit and seek feedback on the SEI training model. Dr. Kahlor first presented a pilot verson of the training model in October 2017 at the National Nanotechnology Coordinated Infrastructure (NNCI) Annual Conference in a session dedicated to SEI. A follow-up phone conference a couple weeks allowed the other SEI project leaders to provide substantial feedback on the module. This follow-up was arranged by Jameson Wettmore at ASU. In April 2018, Kahlor's team launched an online pilot version of the training module to be included in the MRC users training program. The module is embedded in an online survey format that allows us to collect pre- and post-SEI training data from users. The SEI training (video module and survey) takes about 30 minutes to complete. Our current analysis of that user data (detailed below) is based on a sample size of 45 trainees who completed the SEI training online.

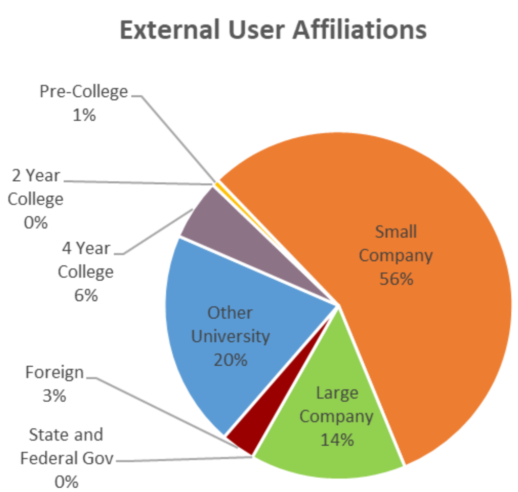
In November, Kahlor's project assistant, Xiaoshan (Shan) Li, presented the team's SEI work during the *Texas Nanofabrication Facility NNCI Coordinating Office Visit* on November 30th.

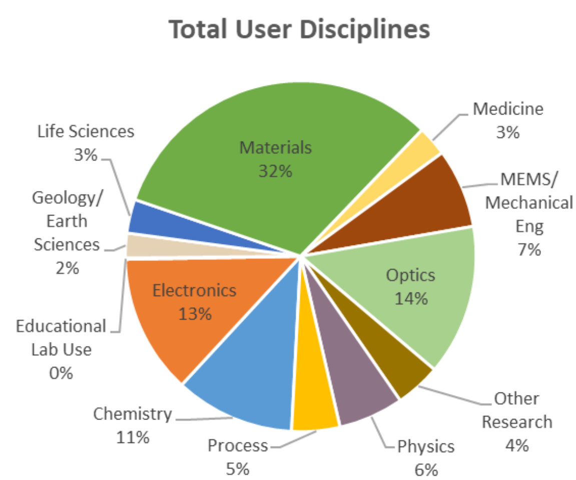
In December 2017, Dr. Kahlor co-chaired a panel on *Nanotechnology and Converging Technologies* at the 2017 NSF Nanoscale Science and Engineering Grantees Conference in Arlington, VA. After the panel, Kahlor, connected with Dr. David Gottfried from Georgia Tech Institute for Electronics and Nanotechnology and was able to get additional detailed feedback from him on the module.

TNF Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	653	696	833
Internal Cumulative Users	500	529	674
External Cumulative Users	153 (23%)	167 (24%)	159 (19%)
Total Hours	67,570	58,354	63,645
Internal Hours	53,484	45,952	46,464
External Hours	14,084 (21%)	12,402 (21%)	17,181 (27%)
Average Monthly Users	244	272	287
Average External Monthly Users	45 (18%)	50 (19%)	59 (21%)
New Users	99	193	80
New External Users	48 (48%)	45 (23%)	33 (41%)
Hours/User (Internal)	107	87	69
Hours/User (External)	92	74	108

Year 3 User Distribution





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

Facility, Tools, and Staff Updates

Tools:

- A new Cary 5000 UV-vis-NIR replaced the 13-year old UV-vis system in the VTSuN lab. The new system gives more reliable and consistent results, and provides continuous service for NanoEarth users with no lost time due to continuing repairs of the old system. The new system was installed with a WinUV operation program which makes the new system particularly user friendly and efficient. This modular Windows-based system is fully compatible with the NanoEarth facility management program (FOM).
- A new Helium-neon laser (633 nm) has been purchased and will soon replace the present continuously attenuating laser on our WITec Raman microscope. The new laser will increase the power selection range, enhance Raman signal detection capability (especially for minerals which generally have lower Raman effects), and greatly improved data collection time.
- WITec Raman-AFM program upgrade includes a new license of WITec Suite Five and a TrueMatch database management software for Raman spectrum analysis.
- Linkam THMS600 heating and freezing stage (-196~600°C) was purchased; it attaches to the Raman microscope and other optical microscopes to study the effect of temperature on chemical and structural properties.

Staff: Our TEM Specialist, Debora Berti, left NanoEarth to pursue her Ph.D. at Texas A&M University. After her departure, we began a search for a suitable replacement. At the end of year 3, we had interviewed three qualified candidates, one of whom (Dr. Liz Cantando) has joined us in year 4.

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.

In addition to making personal connections with researchers, NanoEarth has recruited users at several targeted conferences including Goldschmidt2018, the premier international conference on geochemistry and related subjects, organized by the European Association of Geochemistry and the Geochemical Society. We have also hosted a booth in collaboration with other NNCI sites at the Southeastern Regional Meeting of the American Chemical Society (SERMACS).

We also attract underrepresented and non-traditional users through our MUNI (Multicultural and Underrepresented Nanoscience Initiative) which provides full financial support for underrepresented individuals and groups to visit our facilities for both research and educational purposes. In our third year, we organized and paid for the research and educational visits or remote instrument usage of 58 underrepresented individuals from 21 different institutions.

Research Highlights and Impact

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

Leading Academic Highlight (from external users at five universities in China, Canada, and the U.S.), published in *Nature Communications*, entitled "*Discovery and ramifications of incidental Magnéli phase generation and release from industrial coal burning*": This work was reported in many dozens of news outlets internationally. It reports on the discovery of a previously unknown toxic airborne nanoparticle originating from titanium oxide minerals naturally present in coal. A follow-up paper on its toxicity to the lungs of live mice will be submitted to *PNAS*.

Leading Industry Highlight (from a team of lead external users - the company and participants are not named for proprietary purposes - and internal users), *Scalable Purification of Nanoparticle-Containing Liquid Waste Streams*: This work 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%. Results are currently being prepared for publication and the development of a standard operating procedure.

Education and Outreach Activities

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

- Pulse of the Planet: Syndicated radio producer Jim Metzer (multiple radio media major-award winner, plus multiple NSF, Grammy Foundation, and Fulbright grants) has already produced a total of 30 NanoEarth-sponsored Pulse of the Planet radio shows related to Earth and environmental nanotechnology. Over a million people have been reached via the live national listening audience and podcast streams/downloads.
- NanoEarth served as a major sponsor for the 2017 HBCU/MSI Research Summit organized by Virginia Tech's Office of Recruitment and Diversity Initiatives. Additionally, NanoEarth recruited, financially supported, and hosted attendees from Hampton University, Johnson C. Smith University, Norfolk State University, and North Carolina A&T for meetings, instrument demonstrations, and networking. 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.
- NanoEarth faculty and staff led a team of 20 undergraduate and graduate students to the USA Science and Engineering Festival at Washington DC. Over three days, the team engaged with over a thousand festival attendees with demonstrations and conversations showing the ubiquitous nature of nanoscale sciences and fundamental scientific theory underlying nanoscience.
- NanoEarth hosted 15 leading Earth and environmental nanoscience and engineering international-class experts for three days in April 2018 to produce an invited review/perspectives paper for *Science*, entitled "Natural, Incidental, and Engineered Nanomaterial Impact on the Earth System". This event was supported by the NSF and occurred in coordination with the MONT NNCI-node and the Colorado School of Mines.

- In partnership with David Mogk (Montana State's NNCI node), Paul Westerhoff (ASU's NNCI node), and Jim Ranville (Colorado School of Mines), Mike Hochella (NanoEarth) hosted a two-day workshop entitled "Nanoscience in the Earth and Environmental Sciences – From Theory to Practice" at Goldschmidt2018 in Boston. Forty participants attended. Goldschmidt is the foremost, annual, international conference on geochemistry and related subjects, organized by the European Association of Geochemistry and the Geochemical Society.
- In partnership with Virginia Tech's Nanoscience undergraduate major in the College of Science, NanoEarth hosted NanoCamp events in both the VTSuN and NCFL facilities. During the 3.5 days of NanoCamp, 40 9^{th}-12^{th} grade campers participated in over 8 hours of activities with NanoEarth team members.
- In coordination with VT's Nanoscience undergraduate degree program, NanoEarth hosted a workshop for local high school teachers. The purpose of the workshop, which provided continuing education credit, was to provide teachers with nano-related hands-on activities and lesson plans that they could take back to their classrooms. Six teachers attended this inaugural workshop.
- Through the NanoTechnology Entrepreneurship Challenge (NTEC), NanoEarth, the VT Apex Center for Entrepreneurs, and the VT Sustainable and Economical Materials Strategic Growth Area (SGA) combined resources to provide more than $7,500 to support four student-led entrepreneurship teams which resulted in two IP disclosures.
- The Third Edition of the book *Nanotechnology Environmental Health and Safety: Risks, Regulation, and Management* (Elsevier) was launched. The book is co-edited by M. Hull (NanoEarth/VT) and D. Bowman (ASU) and includes chapters contributed by members of NanoEarth (e.g., Pruitt et al) as well as other NNCI node sites (e.g., Youtie et al/Georgia Tech).
- NanoEarth hosted Anna Maria Petkoska, a high school student from Macedonia, from July 9-30, 2018 for an REU-like experience. Anna is interested in STEM fields and was mentored by NanoEarth and a small local business, CSI: Create. Solve. Innovate. LLC, on projects related to natural and sustainable porous materials.

<u>Societal and Ethical Implications Activities</u>

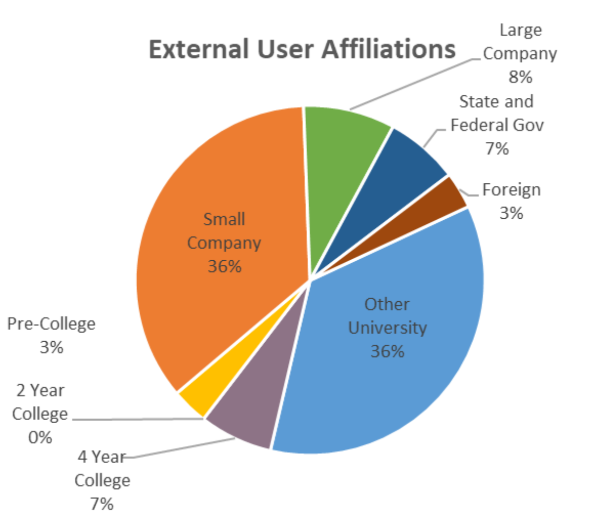
NanoEarth participates in Societal and Ethical Implications (SEI) of nanotechnology activities that are coordinated across participating NNCI nodes under the direction of Professor Jamey Wetmore of the Nanotechnology Collaborative Infrastructure Southwest (NCI-SW) node. SEI activities initiated within 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 at UPenn, and will help form the basis of inter-node SEI activities in the future.

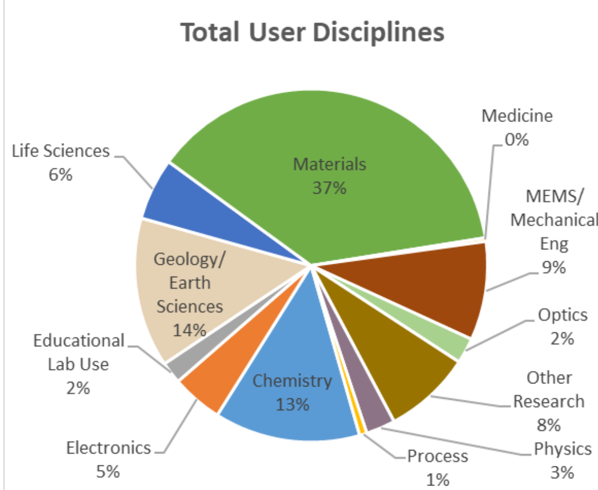
NanoEarth continues to manage access requests for users of the Nanotechnology Consumer Products Inventory (CPI). While the inventory no longer receives funding support from the Pew Charitable Trusts, NanoEarth faculty, staff, and students have played a vital role in sustaining this critical nanoinformatics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

NanoEarth Site Statistics

Yearly User Data Comparison			
	Year 1	**Year 2**	**Year 3**
Total Cumulative Users	277	307	299
Internal Cumulative Users	232	245	240
External Cumulative Users	45 (16%)	62 (20%)	59 (20%)
Total Hours	7,627	18,056	16,455
Internal Hours	6,196	14,277	14,073
External Hours	1,431 (19%)	3,779 (21%)	2,382 (14%)
Average Monthly Users	78	90	93
Average External Monthly Users	9 (12%)	14 (15%)	13 (14%)
New Users	277	134	94
New External Users	45 (16%)	27 (20%)	0 (0%)
Hours/User (Internal)	27	58	59
Hours/User (External)	32	61	40

Year 3 User Distribution





12. Program Plans for Year 4

Many of the program aspects for the Coordinating Office (see Section 2 for details) will remain the same as we go into Year 4. The role of the Coordinating Office will continue to be 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 goal is to ***make the network greater than the sum of its parts***.

To achieve these objectives, the three Associate Directors of the CO will continue to coordinate activities in Education & Outreach, Societal and Ethical Implications, and Computation across the network. Moreover, the CO will continue its support of the Subcommittees and Working Groups, as well the NNCI website development and the NNCI Annual Conference. 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 and Working Groups. 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 4.

A number of specific activities planned for Year 4 are highlighted below:

- *NNCI Website*: The CO will continue to include new content on nanoscale applications to highlight the networks capabilities, add scientific highlights as well as commercialization highlights (“nuggets”), and update, with site input, the current tools and experts databases.
- *NNCI Annual Conference:* The 4th NNCI Annual Conference will be hosted by CNS and will be held at Harvard University in Boston October 23-25, 2019. The program will continue to be refined slightly based on feedback from the Advisory Board and the attendee survey conducted at the 3rd NNCI Annual Conference.
- *REU Convocation*: The 3rd annual REU Convocation will take place at CNF (Cornell University) August 10-13, 2019.
- *Subcommittees and Working Groups*: The CO will continue to emphasize the importance of the subcommittees and working groups to coordinate network activities and develop/share best practices. Participation in subcommittees and working groups will be further promoted and the formation of additional working groups will be encouraged and supported. 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. The CO will look into disseminating developed recommendations and best practices and adjust its procedures/programs where needed. Limited funds are available to support working group events, such as targeted symposia and workshops.
- *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).

- *Marketing:* The CO, with assistance from all of the NNCI sites, will continue to market the NNCI at conferences and trade shows and through printed and electronic collateral. Moreover, marketing efforts targeting specific groups, such as start-up companies receiving SBIR/STTR funding, will be coordinated across the network. In doing so, the CO will review how we can improve our marketing efforts (using scientific and commercialization highlights, for example), how we can further promote diversity (diversity initiatives/highlights, for example), and how we can reach new user communities.
- *User Survey:* The CO will further refine the annual user satisfaction survey and will administer this survey again in Summer 2019.
- *Data Collection, Reporting and Impact:* The CO will continue to collect statistical data on network usage and report these data to the NSF as part of the annual reporting. Together with the metrics subcommittee, the CO will explore how the scholarly output as well as the economic impact of the NNCI can be assessed (and promoted) more consistently, including suggesting ways to have NNCI support acknowledged in publications more consistently. Finally, the CO will work towards more unified reporting as requested by the NSF review panel while still allowing sites to highlight individual strengths and unique programs. In doing so, the CO, in partnership with the sites and relevant subcommittees, will work on both qualitative and quantitative means to better showcase the NNCI impact on individual NSF directorates and divisions.
- *NNCI Emerging Areas and Network Outlook:* The CO will continue work with the NNCI sites and appropriate subcommittees to identify emerging areas of nanoscale science, engineering, and technology that could further grow the user base and will identify acquisition needs for specialized instrumentation needed to support these emerging areas. The goal is to develop a clear vision for the future of the NNCI network, how it impacts national research priorities such as artificial intelligence, quantum, and medical innovation, and how it has to evolve and address its challenges going forward.
- *NNCI National and International Connections:* The CO will work with NNCI sites and the Regional and Global and Regional Interactions Subcommittee to connect with other nationally-funded academic centers as well as international "nano" networks and facilities supported by government, the private sector, and international partners.
- *NNCI Site Interactions:* The CO will further promote and incentivize where possible site to site interactions, including but not limited to multiple sites supporting a given user project, sites sharing resources and best practices, and staff exchanges between sites. Toward this goal, the CO will work with the Global & Regional Interactions Subommittee to develop and support a staff exchange program.
- *Prioritization of NNCI CO Funds:* With continuing and increasing 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 with its goal of being greater than the sum of its parts.