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DISCUSSIONS

Social science and infrastructure networks and the human–technology interface

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Abstract Social science research (under the guise of SEI [societal and ethical implications]) in association with nanotechnology infrastructure networks (in this case, the Research Triangle Nanotechnology Network) is challenging due to the unique function of an infrastructure network. Infrastructure networks share laboratory resources and make available to the user in the early stages in the technological process. As such, characterization and fabrication activities demand fine-tuned social science tools appropriate to the subject instant. This article examines the application of a process of "deep assessment" akin to grounded theory that examines a subset of societal and ethical issues derived from assessing activities proximate to users as they interface with the network. It presents assessment data over the last 5 years that is being used to design the research questions and research hypotheses that answer some of the most important societal concerns of the infrastructure network. These highly valued SEI activities are contextually relevant to the operation and management of the facilities in the infrastructure.

Keywords Assessment · Societal and ethical implications · Nanotechnology infrastructure network · National Nanotechnology Coordinating Infrastructure (NNCI) · Research Triangle Nanotechnology Network (RTNN) · Deep assessment · Grounded theory

The NNCI is the National Nanotechnology Coordinating Infrastructure and is composed of sixteen separate nodes (National Nanotechnology Coordinating Infrastructure n.d.). Each node is composed of one or more college or university, and each has offered one or more of its research labs to serve as part of the overall infrastructure. The Research Triangle Nanotechnology network (RTNN) is one of the nodes (Fig. 1).

Labs involved with the NNCI allow and enable external users beyond their own students and faculty. As part of this grant infrastructure, these labs provide a unique coordination that enable users from anywhere to discover where tools she may need may be located and help provide her with advice and directions that help her arrange to become a user.

When a group of subject experts were called by the National Science Foundation (NSF), a group of experts came together to determine what the NNIN (National Nanotechnology Infrastructure Network) should attempt to accomplish; they decided that the call for proposals (CFP) could include work in a field called SEIN (societal and ethical implications of nanotechnology). While the

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primary thrust of the CFP would involve a geographically dispersed set of major research laboratories that would encourage usage by researchers from a variety of disciplines, some of the foci and budget could go to study societal concerns traditionally tackled by social scientists. We leave SEIN generally undefined here, a subject we will address below.

The RTNN was created as a proposed site and was selected and funded as part of the NNCI. The RTNN is primarily composed of four labs on the campuses of North Carolina State University (Analytical Instrumentation Facility or AIF and the NC State Nanofabrication Facility, or NNF), Duke University (Shared Materials Instrumentation Facility, or SMIF), and the University of North Carolina at Chapel Hill (Chapel Hill Analytical and Nanofabrication Laboratory, or CHANL). Our four labs characterize nanomaterials and fabricate advanced nanomaterials. The production levels are conservative (RTNN 2019 Report), and the health and safety concerns are optimized by the nature of the labs' close association with a university. At the RTNN, we serve three missions: the education of the next generation of scientists and engineers, advance research associated with discovery, and outreach to the community, particularly focusing on individuals from underrepresented groups (Research Triangle Nanotechnology Network 2020).

In this article, we will show how a context-dependent, interdisciplinary, deep assessment approach to lab evaluation enables nanolabs to enhance their performance and engage researchers from nontraditional disciplines and underrepresented groups. In the following sections, we discuss the issues addressed by the current SEIN research, how they can vary depending on the context, and how SEIN research might advance nanoscience. We then share our experience of building an interdisciplinary team to expand the scope of SEIN research at our labs. Finally, we share the results of several years of interdisciplinary research and deep assessments at RTNN.

Role of nanoscience in the twenty-first century

As Berube (2006a), author of one of the first books on nanotechnology, argues, nanotechnology may have been oversold. Although it may not have been the new industrial revolution as it was touted a few decades ago, it has made a significant technological impact on science and engineering. Nanomaterials can make things lighter and more resilient, and a number of nanotechnologies have found their way into a range of products, including actuators, catalysts, coatings and paints, emulsions, fabrics, films, filters, labs-on-a-chip, and sensors (National Nanotechnology Initiative n.d.). They can also be found in electronics (such as organic field-effect transistors), construction (anti-graffiti coatings, self-cleaning windows, scratch-resistant paints), packaging (including food packaging that can communicate food safety), energy (especially batteries and inorganic or hybrid organic–inorganic materials for solar panels), health care and medicine (such as bactericides, biochips, drug delivery, labeling and contrast agents, probes, and pharmaceuticals), cosmetics and sunscreens, sports and household products, clothing, automobiles, airplanes (composites, heat shielding), and space vehicles, defensive and offensive weapons systems, etc. (Vance et al. 2015).

SEIN

Deciding what areas of traditional SEIN studies (societal and ethical implications of nanotechnology) might be appropriate to this network demanded a new way of thinking about the full breadth of SEIN. Berube (2006a) wrote about SEIN, and as a template, we turned to a parallel initiative that surfaced during the Human Genome Project called ELSI (Ethical, Legal and Social Implications). Ever since Bruce Seeley, former program director for STS, helped patched together the first NSF investment into one of the first SEIN grants in 2003, a grant to David Berube and colleagues mostly from the University of South Carolina, the field of SEIN studies has focused on two sets of values: the first set was physical and ecological safety, health, and well-being, and the second centered on broad ethical and social or societal issues.

However, early discussions on SEIN generally revolved around the first set of values, human and nonhuman health and safety issues, more than anything else, and the bulk of the funding involved traditional EHS (Environmental Health and Safety) issues (e.g., Kulinowski 2004). Some colleagues complained that SEIN was coopted by some toxicology and health science researchers to focus on environmental health and safety. Of course, there was no co-option per se because even among social scientists, that was the primary focus over nanoscience and nanotechnology at the time.

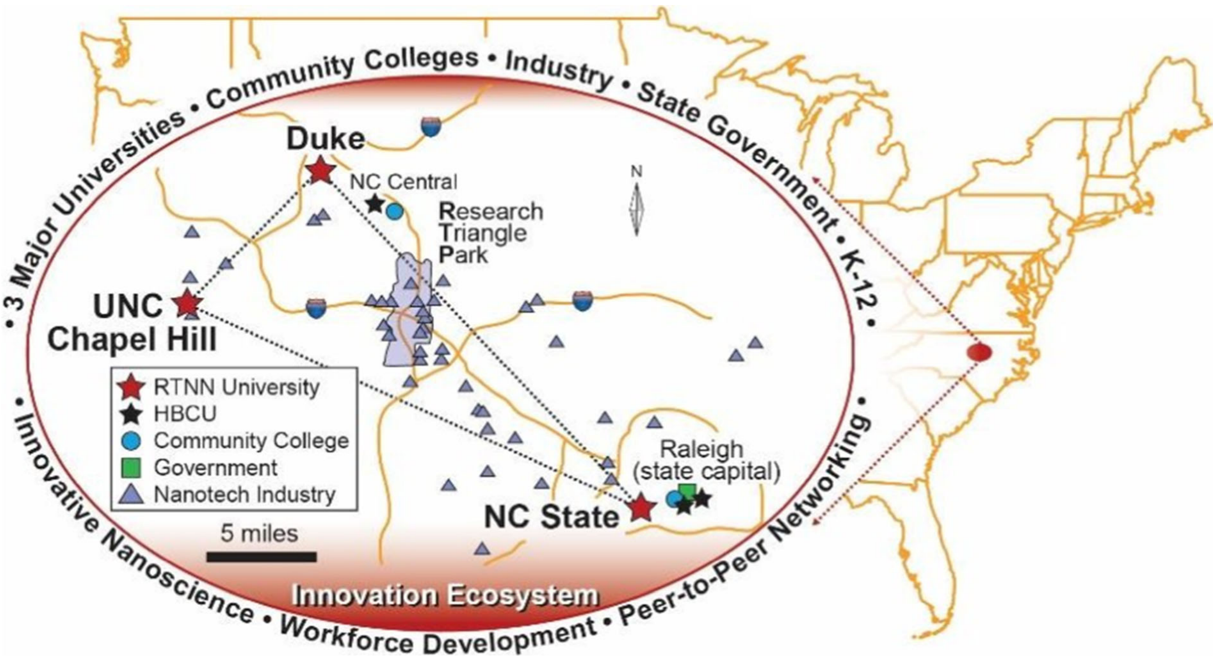

Fig. 1 The RTNN is a model innovation ecosystem of academic, public, and private entities in a strong regional partnership that will translate innovative programs to the national network

Over time, the field broadened with scientists in toxicology and public health attending to the first set of issues, while the second set, the ethical and social issues associated with nanotechnology, was the subject of artists, anthropologists, economists, ethicists, historians, philosophers, political scientists, science fiction scholars, and social scientists. In response to the growing importance, the second set of values, NCSU's Public Communication of Science and Technology Lab (PCOST), a social science lab, has engaged SEIN to address them. Additionally, because the RTNN is an infrastructure network within a network, it also engaged a subset of the first set as well, a concern of some SEIN traditionalists.

In year 1 of the RTNN, it was apparent we needed a better way to investigate societal and ethical issues since the mission of the entire network was a geographically dispersed infrastructure network and not some hypothetical world where nanotechnology was omnipresent. To date, most SEI studies involved grand issues, such as rich–poor gap and environmental racism, cross tabulated against a broad-based nanotechnology world (Roco and Bainbridge 2004). This approach would not work for us since the role played by SEIN researchers in an infrastructure network like the RTNN would be different from one with a finite singular mission, and we responded appropriately. Societal implications are mostly anchored to applications or technology rather than to research per se (Berube 2018).

Much of the work done in fabrication and characterization in our labs is several steps ahead of the application such that traditional societal concerns fit awkwardly. There are hundreds of critiques against technology as a subject and technologies as applications (e.g., Ellul et al. 1964; Postman 1993). Some are very real and very serious, and others are grotesquely exaggerated. Critics sometimes yearn for pre-industrial society in their comments, yet few seem willing to relinquish the conveniences of contemporary civilization. Take for example, the rich–poor gap. Technologies benefit those with wealth more than those without for a multitude of reasons. This gap is a criticism of all technology and not nanotechnology per se. The blame as well as the solution rests in something bigger than nanotechnology (pun intended).

While there may be value in discussing technology as a class of things, it is clearly illogical to burden nanotechnology with all the sins of technology and demand it rise above them in some way. No one since critiques of technology arose has been able to articulate reasons why we should shackle nanotechnology with all the societal misgivings associated with technology or why nanotechnology is a particularly worthy and important case study for a critique against technologies in general.

This does not mean a disservice to ethics or safety per se. If we learn that a site has an employee who is concerned over the disposal methods of a waste product, we would strive to learn as much as we can about the situation because potential safety issues befoul the very core of a vibrant and creative infrastructure network. Another example, should we discover that an intellectual property issue might be frustrating highly interesting and productive lab research, we would learn as much as we can and turn and focus on this business ethics issue. In both instances, the context determines the criticism.

Our argument has been that if SEIN has any meaning, it must be contextualized in the oftentimes different settings in which we conduct nanotechnology research. Each of these settings may call for different sets of SEIN values. These values, in turn, call for the emphasis of a set of variables that offer special SEIN insights into what we are detailing, including infrastructure networks.

The early work in fabrication may be so many steps removed from the consumer that it is natural to question the causality between nanotechnology infrastructure facilities and broad critiques of applied technology. Most fabrication work done in our labs is performed under a Technology Readiness Level (TRL) 1–3, meaning we are using basic research to establishing processes and fabricate prototypes and components for prototypes. In our opinion, what SEIN research seems to have failed to do since the late 60s when the nanotechnology surfaced has been to tie some unique societal characteristics of nanotechnology that needs to be addressed as a fundamental and essential critique of nanotechnology per se.

This has been especially true since the most extreme manifestations of nanotechnology have fallen out of the debates over nanotechnology. Scientists and engineers have learned the limitations of nanoscience and the reluctance of a consuming public to blindly buy products with a suspicious use of nanotechnology (Berube 2006b). The social issues consistently raised and discussed about nanotechnology continue to be associated with mundane environmental and health issues involving production, application, and disposal of nanomaterials of all sorts (Berube 2018).

As such, it seems inappropriate to attach broad discussions of societal implications of nanotechnologies to experiments involving fabrication and characterization in university-based nanotechnology infrastructure facilities. New societal issues need to surface that are inherent to what the infrastructure network is trying to accomplish. We now turn our attention to new societal issues that need to be considered.

The infrastructure was designed to provide research opportunities to scientists and engineers who wanted to use some tools that were not easily available to them. Research laboratories at Research-1 (R1) institutions provide access to very expensive and often unique capabilities and tools that are far beyond the means of small colleges and universities, community colleges, and start-up companies.

At the early SEIN meetings in the 90s, we discussed the health and safety of people in the labs working on nanoparticles and nanomaterials and those who would consume them when nano-products are marketed and needed to deal with them when discarded. In addition, we considered the impacts associated with ecological exposure to nanomaterials and effects on the environment and non-human species. A smaller group of experts came from STS (Science, Technology and/in Society) programs and raised issues related to law, equity, and justice.

When we began studying the human–technology interface, we decided that other researchers in SEIN would examine the interactions between consuming publics and nanotechnologies while we considered the interactions between the expert user community and the instruments and services in the shared facilities where they elect to work. Most of the people who enter our shared facilities are users, and, by and large, they are scientists and engineers from fields such as materials science, electrical engineering, and chemistry. They must interact with the shared facilities staff who register them to use the laboratories, help them understand the laboratories' protocols, answer their questions and train them to operate instruments, oversee and maintain the instruments, and converse on methods and shared experiences.

When we began establishing protocols associated with the function of the multi-institutional network, we approached underrepresented populations as a dual challenge. First, we wanted to encourage women and people of color to come and use the facilities in our labs and to leave satisfied with their experience in our labs. Second and less obviously, we wanted to encourage users from nontraditional fields of study to use our labs, and over the last few years, we have had users from agriculture, anthropology, forest biomaterials, geology, textiles and non-wovens, zoology, and other fields. In addition, we have attracted users from high schools and community colleges.

The infrastructure in the network enables the fabrication of new nanomaterials and nanotechnologies as well as the characterization of nanomaterials and nanostructures. Our users, the scientists and engineers who utilize the facilities, are working to produce advanced platform technologies and new tools to create and enable technologies that produce tools to deal with difficult, messy, and wicked societal problems. Ultimately, the goal for researchers and lab personnel involves providing research opportunities to scientists and engineers to engage with nanotechnology without negatively impacting broader social goals including health and safety concerns inside and outside the labs.

Piggybacking off some of the literature in team science (Bozeman and Youtie 2017; National Research Council 2015), we were interested in better understanding how to maximize the powerful benefits found in interdisciplinary research activities while minimizing the inherent conflicts that surface when two or more disciplinary experts come together to focus on a shared challenge. While struggling with many of the precepts surfacing from this new field of study, we remained committed to examining the forces that facilitated and frustrated truly cross- and interdisciplinary research.

Team science

When interdisciplinary studies became fashionable as an approach to help resolve big problems that heretofore failed to be resolved or even mitigated by traditional disciplinary approaches, the research question surfaced regarding how multidisciplinary approaches may work and how experts from different disciplines working together may be more efficacious. What surfaced was "team science."

The team science literature is extensive but not expansive per se. The working assumption is that when groups of experts from different disciplines decide to work together, they are challenged by a host of problems (Bennett and Gadlin 2012). These problems challenge the capability of an interdisciplinary research team to function efficiently and productively. In turn, we may need interdisciplinary efforts to solve a set of wicked questions (Brown et al. 2010). Some of these wicked questions are pertinent to nanoscience and nanotechnology. Some are ethical: Those who will benefit the most from nanoscience should shoulder the associated risks. Some are technical: The size of nanoparticles makes them capable of passing through the blood–brain barrier, which makes them strong contenders for a set of unique therapies, but at the same time, high bioavailability of the particles could entail unexpected consequences (Berube et al. 2011).

Team science researchers gathered data from interdisciplinary teams, and they used standard social science methodologies: ethnographies, interviews, focus groups, surveys, and some experiments. The first problem with the team science field has been generalizability. What we learn from one set of interdisciplinary experts might not crossover to another. Put simply, each context has a unique set of variables, some of which the experts might not be aware and some of which the team science researchers might not be aware. We decided to let data speak for itself, and once our sample was large enough, we used cross tabulations to determine research questions. Using a version of Glaser and Strauss' (1967) "grounded theory" including observations, memo writing, diagramming, and early concatenations of user data, we are building a series of research questions specific or, better yet, proximate to infrastructure networks (Charmaz 2006; Bryant and Charmaz 2007; Lempert 2007).

We married this to proximity, a term in causality theory and legal jurisprudence that argues that the strongest determination of variance in a phenomenon is a function of the proximity of cause and effect (Zipursky 2009). In the counterfactual, "but for" the infrastructure network, a world where the NNIN and the NNCI did not exist, there might be fewer start-ups or less available venture capital for the ones that do emerge on their own. These attributes are proximate to what an infrastructure network does. On the other hand, while the rich–poor gap is important, an infrastructure network like ours and our colleagues is insufficiently proximate to the rich–poor gap to explain its variance and affect meaningful formative changes. We know that the solution to the rich–poor gap is the redistribution of wealth and not an infrastructure network per se. However, too much work in SEIN involves borrowing a theory and seeing how it applies rather than examining the phenomenon and then developing the research questions and hypotheses. As such, we decided to emphasize proximate societal issues emphasizing the juxtaposition of researcher characterization and fabricating nanomaterials and their satisfaction with the experience in terms of how the experience translates into sometimes more consequentialist values, such as entrepreneurship and regional and national growth and development. We do this in our labs through what we call “deep assessment.”

How deep is deep assessment?

We introduced the term deep assessment (Bogomoletc et al. 2019) because we believe it speaks more clearly to the scientists and engineers and our goal of a comprehensive assessment of our facilities. Deep assessment is an epistemological tool that involves allowing the data to speak and to tell the researcher what the research questions should be rather than bringing the questions preconceived to the data. It was an amalgamation of “grounded theory” and proximate causality (Derrington 1991). When we created the RTNN network node of the NNCI, we committed ourselves to ongoing and comprehensive program of “deeper” assessment proposed at some other sites, which limited data collection to simple user data. Of course, all assessment is an important component of any program, and teams with formative and evaluative assessment tend to produce much more powerful results.

The process

We initiated our assessment and evaluation program at the outset of the award. The NNCI Coordinating Office has since provided models for overall assessment to maintain some level of data commonality between all sixteen nodes. The RTNN elected to collect data beyond the minimum user demographics and the number of papers or patents associated with users. We opted to collect broad demographic data (individual and institutional) and satisfaction data, and we have extended our data collection to our users and to our outreach activities including tours, workshops, conferences, and educational initiatives, including a large on-line Coursera™ course pioneered by Duke University, and a unique free facility access opportunity called “Kickstarter” found at all three RTNN universities.

The first educational initiative is the Coursera course launched in 2017 called “Nanotechnology: A Maker’s Course” (https://www.coursera.org/learn/nanotechnology). At our last annual meeting, we reported over 13,500 total learners and over 9700 active learners, and over 1700 people have completed all course components. We have had over 64,500 visitors with over 90% of respondents “likely” or “very likely” to recommend the course. The second is the Kickstarter, a program that increases access to nanotechnology by lowering barriers of entry into shared facilities, particularly by researchers who are from non-R1 institutions (Carnegie classification). One barrier that this program addresses is the initial facility cost to test out new ideas or explore the usefulness of a facility or equipment for the first time. Applicants submit requests, which are subject to approval by the Executive Committee of the RTNN. If approved, each institution has a mechanism to provide access to their facilities at no cost to the participant (access is limited to $1000 billed at the internal rate). The return rate of Kickstarter awardees to RTNN facilities is 40%, with these participants returning to our facilities with their own financial support (> $125,000 in facility fees).

It is worthy to note that collaboration between public and private universities closely co-located, as at the RTNN, is quite unusual. The RTNN is a collaboration between three different R1 universities in North Carolina in a centralized location known as the Research Triangle. While we are fierce competitors in basketball, the practicality of sharing high-cost shared infrastructure locally motivates strong links through the RTNN. For example, we secured IRB approval for all SEIN work at all three universities in the RTNN. Since all the data is collected, tabulated, and concatenated by Berube’s team (primarily including Ekaterina Bogomoletc and Nicholas Eng) at NCSU, we are the IRB central for the RTNN. We collect data from lists of email addresses shared quarterly by each lab. The surveys are sent via email, and respondents are asked to visit a Qualtrics™ page where they can take a brief survey. When surveys are deemed inadequate, we use semi-structured interviews where a graduate research assistant contacts the user and records their response over the telephone, transcribes it, and performs a content analysis. Each lab actively encourages users to participate in the data collection, and users who respond to our requests are eligible to participate in an annual drawing for an iPad™.

While these initiatives were ongoing, we had two major challenges that arose. First, it involved developing methods that are productive for some of the unique data sets we produce. For example, since our “Kickstarters” are given monetary credit toward their research expenses, their reported overall satisfaction levels were extremely positive. We needed a content method that finely discriminated between a swarth of highly positive comments. We wanted to discriminate between comment without creating problems that did not exist. Second, we had to collect sentiments from a sample (the users) who were unaccustomed to answering simple surveys. For instance, the Kickstart program attracts bench scientists and academics as well as young entrepreneurs. We needed to acclimate them to the work of the social scientists. This required highly focused and brief questionnaires, pokes, signage, and enticements.

One of the unique qualities of our team at the RTNN was our commitment to reaching underrepresented populations. Almost all grant supported programs want high levels of female and persons of color, but our team wanted to supplement this standard requirement by bringing into the lab users from disciplines who traditionally would not use a characterization and fabrication facility, a fundamental requirement for convergence.

In addition, we wanted the research questions selected for study to be produced from data rather than be asserted by the researcher or generated from a survey or transferred from a different context. Recent research has uncovered a "bias bias" (Gigerenzer 2018) where we find what we are looking for not because it is there but due to how we try to uncover it. It is much like the confirmation bias, which makes it difficult to introduce a sample to new information that may disagree to what they already believe to be true (Nickerson 1998). Even when they search for information, they search where they most likely may find information that agrees with their already held belief.

Researchers tend to find what they are looking for because they approach data with a preconceived research question. While we would hope that should be the function of expertise, it is often more intuitive than that. Experts, not unlike the inexpert (a term we find less insulting than laypeople or the general public), are subject to confirmation bias reading what they want to read from the data they collect or even designing data collection to accommodate the findings (Nickerson 1998). As such, we now describe our research procedures that focus on allowing the data to drive research questions.

Research procedures

We conducted a series of quarterly user surveys from March 2016 to March 2019. After the first round of surveys in March 2016, we continually refined our research procedures and measurement tools. More specifically, starting from August 2016, we combined demographic and satisfaction portions of the survey to be able to identify trends in lab usage across different groups of users. When it comes to procedures, the labs collected users' emails and shared them with the assessment team four times per year based on the pre-approved schedule. An anonymous survey with two reminders was sent out using Qualtrics platform. The total number of users surveyed from March 2016 to March 2019 was 11,578, with a response rate of 12.5%, i.e., 1451 surveys were completed. During our assessment, we consider the data collected from the beginning of the assessment process in our work. However, for this article, we only used the data collected from August 2016 to March 2019 as the refined procedures and measurement tools enabled us to engage in a deeper assessment of the labs. Within the period from August 2016 to March 2019, we sent out 9966 surveys. With a response rate of 12% or 1217 completed surveys. Only respondents who had not completed the survey in the previous 6 months, those who could not remember if they had completed the survey, and those who gave their consent were part of this analysis ($N = 990$).

The surveys included demographic questions (e.g., race, ethnicity, education, role at the home institution) and questions regarding the use of RTNN's peer-to-peer program, remote use of our facilities, and the use of other NNCI facilities, in addition to questions about users' satisfaction. To assess levels of users' satisfaction, we asked participants to describe their levels of (1) overall satisfaction, (2) satisfaction with physical facilities, and (3) satisfaction with support staff and technicians at the labs. For this question, we used 7-point Likert-type scales with 1 = very dissatisfied and 7 = very satisfied. These questions were treated as separate variables. Those who used multiple labs were asked to complete the same survey for each of the labs and were treated as a single case for the analysis of users' demographics ($N = 990$) but separate cases for the satisfaction analysis provided below ($N = 1262$).

Findings

One-way ANOVA tests were conducted on satisfaction variables for the four most popular labs: AIF, CHANL, NNF, and SMIF. We found that one of our laboratories had significantly lower overall user satisfaction than the other laboratories. The term significantly lower means there was a small percentage likelihood that our data risked Type I error. The consequences of making a Type I error mean that changes or interventions are made, which are unnecessary, and thus waste time, resources, etc. While these observations are important to management, they do not support any conclusion on mis-, mal-, or non-feasance. What this data does is provide is a glimpse into operations that may assist management in becoming better.

First, a one-way ANOVA was conducted on the overall satisfaction of the labs. There was a significant difference in overall satisfaction between the labs [$F(3, 1215) = 20.90, p < .001$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for NNF (M = 5.49, SD = 1.61) was scored significantly lower than AIF (M = 6.25, SD = 1.19), CHANL (M = 6.22, SD = 1.17), and SMIF (M = 6.35, SD = 1.02) (Fig. 2).

Another one-way ANOVA was conducted on the satisfaction with the support staff and technicians of the labs. There was a significant difference in satisfaction with the support staff and technicians between the labs [$F(3, 1214) = 8.11, p < .001$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for NNF (M = 5.94, SD = 1.44) was scored significantly lower than AIF (M = 6.38, SD = 1.18), CHANL (M = 6.36, SD = 1.18), and SMIF (M = 6.48, SD = 1.04).

Finally, a one-way ANOVA was conducted on the satisfaction with physical facilities. There was a significant difference in satisfaction with physical facilities between the labs [$F(3, 1215) = 8.11$, $p < .001$]. Post hoc comparisons using the Tukey HSD test indicated that the mean score for NNF (M = 5.37, SD = 1.60) was scored significantly lower than AIF (M = 6.29, SD = 1.10), CHANL (M = 6.10, SD = 1.21), and SMIF (M = 6.32, SD = 1.23).

Although the difference between the labs proved to be statistically significant, one might ask if this finding would be meaningful in the context of RTNN labs. Looking at the values used to assess the level of satisfaction, we would argue that being close to "somewhat satisfied" based on their mean score, the lower levels of satisfaction of NNF users would rightfully prompt a series of research questions: Was one of our labs less well equipped for the expectations of users coming to a R1 research lab? How do we decide when a facility is underequipped? What constitutes underequipping for a nanotechnology fabrication facility? Is there a significant relationship between being dissatisfied with a facility and dissatisfied with support staff and technicians? Can and should these points of dissatisfaction be approached separately? Can or should they be approached serially?

After a few weeks of discussion, we shared the data with appropriate NCSU university leadership, and the data was used to support facility upgrades, new tools, and accelerating the search for a new director. This was an unexpected finding from assessment and was used to help administrators make data-informed decisions about major infrastructure expenditures and facility leadership.

Our deep assessment also brought about a number of new challenges we had to overcome. The first of which is the overwhelming positivity of our Kickstarter participants. The semi-structured interviews of our Kickstarter participants produced many pages of text that was skewed significantly positive. Most of these users were pleased with the access and had many nice things to say about the personnel and the facilities. As such, we needed to pursue different ways of coding that can discriminate between heavily skewed textual data.

Instead of searching for simple positive valence or negative valence, we elected to evaluate the data by examining how soon in the interview were positive remarks made? Were the positive remarks primarily a function of free access time or were other variables involved? Were remarks made comparatively and superlatively? Were the remarks enhanced by illustrations or other punctuators? Was more than one punctuator used? This project remains ongoing, and results from this analysis will be reported in the future.

Second, our data prompted new research questions that we had not previously considered. These questions arose from a number of interesting correlations we found in our analysis—four of which are presented here. First, one-way ANOVA tests were conducted on the satisfaction variables across fields. The groups with sample sizes above 30 participants were selected for the analysis: Chemistry ($n = 247$), Electronics ($n = 126$), Materials Science ($n = 454$), Physics ($n = 111$), Textiles ($n = 31$), Biology ($n = 62$), and Others ($n = 175$).

When it came to the overall satisfaction across fields, there was a significant difference in satisfaction between the fields [$F(6, 1199) = 4.69, p = .000$]. Post hoc comparisons using the Tukey HSD test indicated that the mean satisfaction score for those in the field of

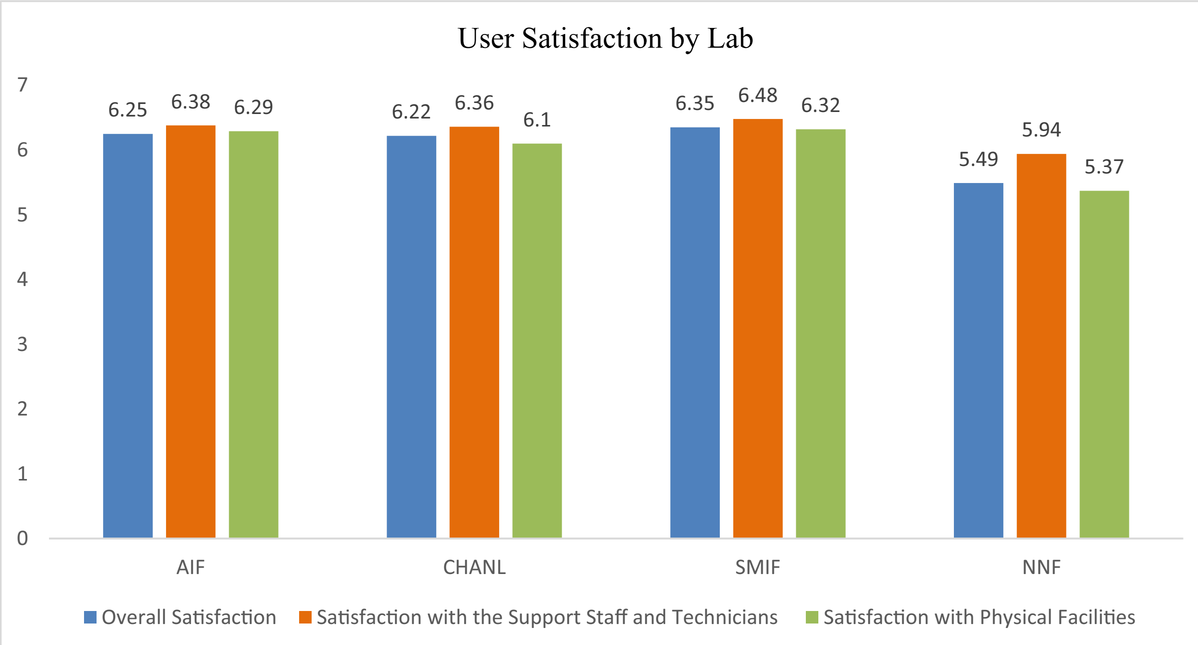

Fig. 2 User satisfaction across labs

Electronics (M = 5.73, SD = 1.50) was scored significantly lower than Biology (M = 6.47, SD = .97), Chemistry (M = 6.28, SD = 1.08), Materials Science (M = 6.22, SD = 1.22), and Others (M = 6.24, SD = 1.17). This finding was sustained in terms of the satisfaction with the physical facility across fields. There was a significant difference in satisfaction between the fields [$F(6, 1199) = 2.95$, $p = .007$]. Post hoc comparisons using the Tukey HSD test indicated that the mean satisfaction score for Electronics (M = 5.83, SD = 1.31) was scored significantly lower than Biology (M = 6.45, SD = 1.04) (Fig. 3).

We were somewhat surprised that the satisfaction levels of those in the electronics field were significantly lower than chemistry and material sciences since the roles played by tool sets in nanoscience characterizations and fabrication facilities are not unknown or uncommon among these two disciplines. It may be that those in electronics may be more experienced users and less starry-eyed when they see high-quality research tools. Hence, these individuals may have come to our research labs with higher expectations than others.

The higher levels of satisfaction reported by users from biology and disciplines that may be new to using nanotechnology facilities may be explained by the novelty of using our facilities. We are encouraged to see this trend and are hopeful that this recognition of our labs may increase their future likelihood to participate or engage in highly interdisciplinary or convergence research science.

Second, we found that women are more likely to return to RTNN labs than men. Since we are committed to encourage new users, especially from varied institutions, we found this data highly noteworthy. Overall, RTNN users who identified as female demonstrated the highest level of overall satisfaction with their visit (M = 6.26, SD = 1.06), satisfaction with physical facilities (M = 6.20, SD = 1.11), and satisfaction with support staff (M = 6.47; SD = 1.00) compared with other groups (genders) of users. RTNN users who chose not to indicate their gender demonstrated the lowest level of overall satisfaction (M = 5.80; SD = 1.65), satisfaction with physical facilities (M = 5.84; SD = 1.52), and satisfaction with support staff (M = 6.01; SD =1.53 comparing with other groups (gender) of users. A chi-square of independence was conducted to analyze the relationship between gender and the willingness to return to the lab if needed. A significant interaction was found, X^2 $(1, N - 1175) = 5.205$, $p < .05$. Since the RTNN involves many women, we were intrigued with this finding. We speculate that the addition of women among the administration and support staff may have built a culture that led to this outcome. Since the RTNN also plays a major role on the NNCI diversity committee, we were pleased that our labs were performing so well among women. This finding should

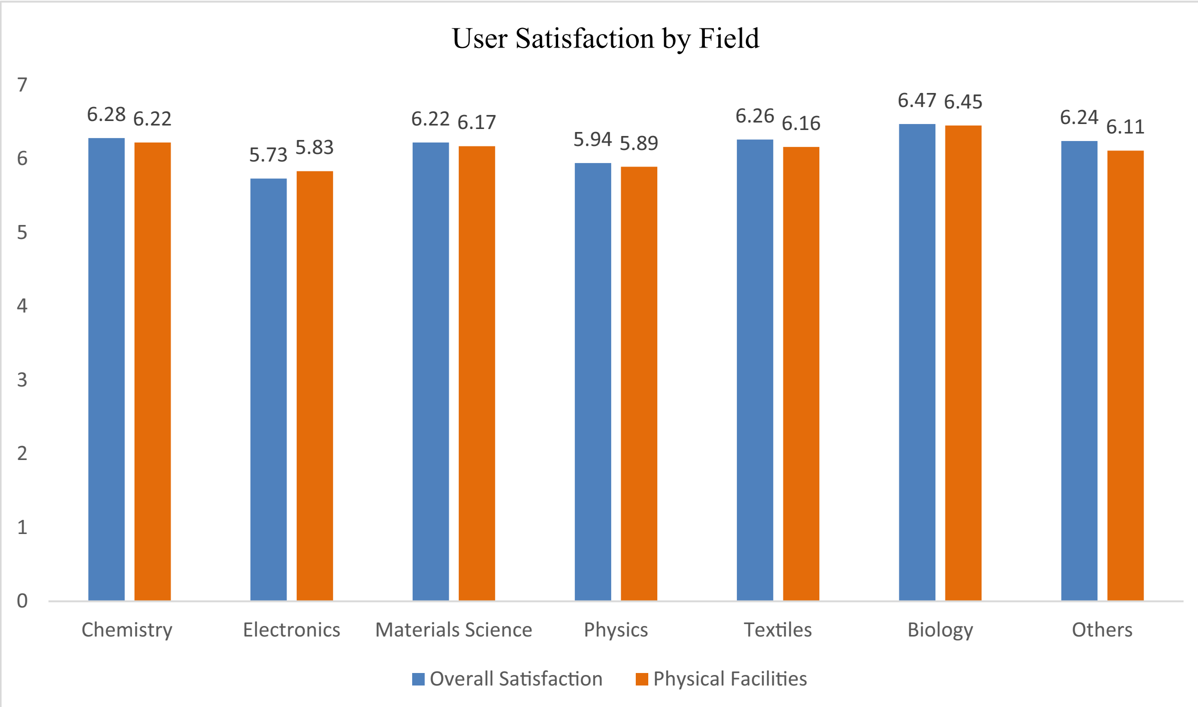

Fig. 3 User satisfaction by field

be interpreted with acknowledgement of the gender breakdown of our users. Among the completed surveys, 63.5% were filled out by male participants ($n = 801$), 29.7% were completed by female participants ($n = 375$), and 6.8% were completed by those who chose not to respond the question about their gender ($n = 86$).

Third, we discovered some differences between first-time and repeat-time users. Our sample consisted of 33% first-time users ($n = 417$) and 67% returning users ($n = 844$). An independent sample t test was conducted to compare the levels of satisfaction with physical facilities for first-time and returning users. The test demonstrated a significant difference in the scores for first-time users (M = 6.27; SD = 1.19) and returning users (M = 6.06; SD = 1.26; $t(1258) = -2.089$, $p = .037$. Additionally, an independent sample t test was conducted to compare the levels of satisfaction with support staff for first-time and returning users. We found no significant difference in satisfaction with support staff for first-time users (M = 6.42; SD = 1.21) and returning users (M = 6.31; SD = 1.18); $t(1257) = -1.506$, $p = .132$. This finding suggests that there may be a novelty effect for first-time users and also points to the exceptional work of our support staff.

Finally, we found some differences across primary roles at home institutions. One-way ANOVA tests were conducted on satisfaction variables across primary roles at home institutions. We included the following roles in the analysis: Academic Lab Staff ($n = 75$), Graduate Student ($n = 633$), Industry Lab Staff ($n = 116$), Post-Doctoral Research Scholar ($n = 130$), Professor ($n = 121$), Undergraduate Student ($n = 103$), and Other ($n = 74$). Community College Professors ($n = 2$) and K-12 Students ($n = 5$) were excluded from the analysis due to the insufficient sample size. First, a one-way ANOVA was conducted on overall satisfaction across primary roles at home institution. There was a significant difference in satisfaction between the roles [$F(6, 1243) = 2.71$, $p = .013$]. Post hoc comparisons using the Tukey HSD test indicated that the mean satisfaction score for professors (M = 5.94, SD = 1.71) was scored significantly lower than undergraduate students (M = 6.45, SD = .93) (Fig. 4).

In addition, a one-way ANOVA was conducted on satisfaction with support staff and technicians across primary roles at home institution. There was a significant difference in satisfaction between the roles [$F(6, 1243) = 3.59$, $p = .002$]. Post hoc comparisons using the Tukey HSD test indicated that the mean satisfaction score for professor (M = 6.06, SD = 1.64) was scored significantly lower than industry lab staff (M = 6.54, SD = .95) and undergraduate students (M = 6.61, SD = .82). In addition,

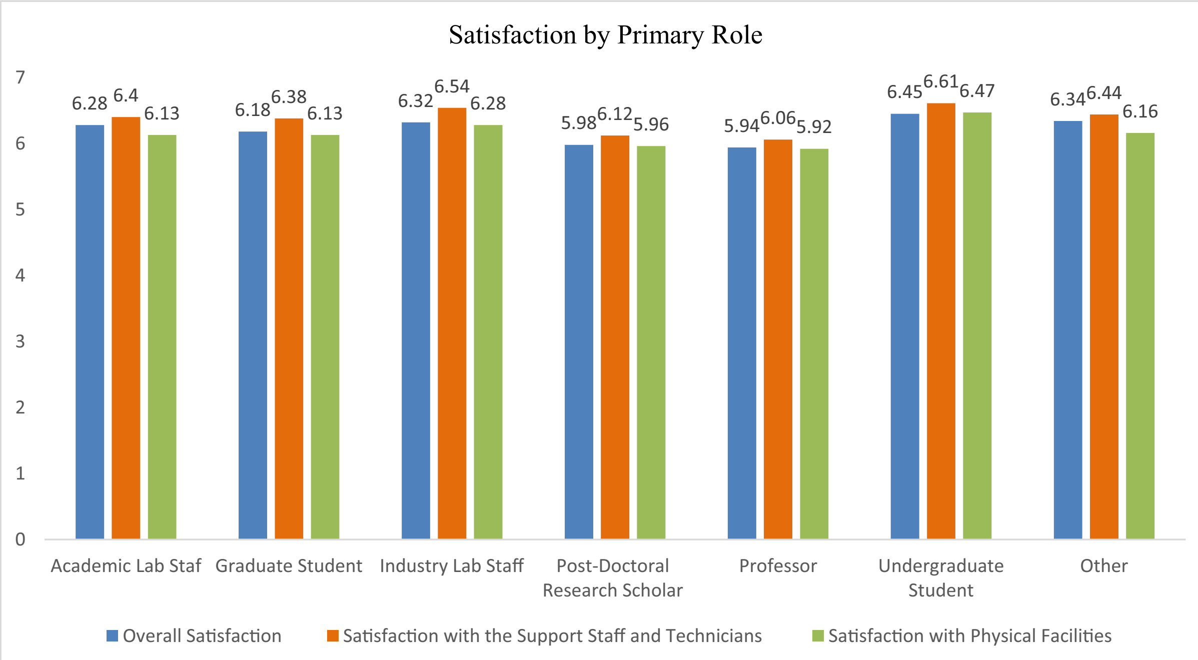

Fig. 4 User satisfaction by primary role

the mean satisfaction score for post-doctoral research scholar (M = 6.12, SD = 1.41) was scored significantly lower than undergraduate student (M = 6.61, SD = .82). Last, a one-way ANOVA was conducted on satisfaction with physical facilities across primary roles at home institutions. There was a significant difference in satisfaction between the roles [$F(6, 1243) = 2.61$, $p = .016$]. Post hoc comparisons using the Tukey HSD test indicated that the mean satisfaction score for undergraduate student (M = 6.47, SD = .77) was scored significantly higher than postdocs (M = 5.96, SD = 1.36) and professors (M = 5.92, SD = 1.66).

We expect that these observations will serve as inflection points for producing more rounds of SEIN research using multiple methods as PCOST continues to examine some of the social and ethical implications of infrastructure networks and the human–technology interface.

Discussion

No one should read this article and conclude that ethical and social or societal issues associated with nanoscience and nanotechnology should be restricted to economic ones; that would be a gross overgeneralization of the arguments made above. We are arguing that one of the best ways to assess nanoscience and nanotechnology from a SEIN perspective is to consider context and proximity. Merely critiquing nanotechnologies by bundling it with other technologies (nanosized and even larger) and generally ignoring the specific characteristics of the nanomaterial in question is very similar to the term shift fallacy and risk-profile shift, which we have addressed elsewhere (Berube 2008).

Simply put, not all nanomaterials are alike:

- Some industries may use a nanotechnology to produce a finished product, but that product may not in itself contain nanoparticles.
- Nanoparticles can be functionalized in many different ways and as such be differentiated from another nanoparticle of the same sort but functionalized in a different way.
- Nanoparticles can be freely mobile in the waste stream or bound within a matrix, such as polymers, though their status at the end of their life cycle remains unknown.
- Nanoparticles aggregate during use, and in some instances, their characteristics may be enhanced or degraded with use and maybe through disposal as well (Berube 2008).

We would expect toxicologists studying nanomaterials to restrict their observation to the case instant say zinc oxide and not draw generic claims from a study of carbon nanotubes. When this overreach occurs, it constitutes a terms shift fallacy, a risk-profile shift, and sloppy work. We should expect no less from a SEIN researcher. As such, we hope that this article will provide not just a framework of how deep assessment could be conducted but also how doing so can illuminate contextual and proximity issues that may not have been previously considered.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

References

Bennett LM, Gadlin H (2012) Collaboration and team science: from theory to practice. J Investig Med 60(5):768–775. https://doi.org/10.2310/JIM.0b013e318250871d

Berube DM (2006a) Nanohype: the truth behind the nanotechnology buzz. Prometheus Books

Berube D (2006b) The 'magic' of nano. Nanotechnol Percept 2: 249–255

Berube D (2008) Rhetorical gamesmanship in the nano debates over sunscreens and nanoparticles. J Nanopart Res 10:23–37. https://doi.org/10.1007/s11051-008-9362-7

Berube D (2018) How social science should complement scientific discovery: lessons from nanoscience. J Nanopart Res 20:120. https://doi.org/10.1007/s11051-018-4210-x

Berube D, Cummings C, Cacciatore M, Scheufele D, Kalin J (2011) Characteristics and classification of nanoparticles: expert Delphi survey. Nanotoxicology 5(2):236–242. https://doi.org/10.3109/17435390.2010.521633

Bogomoletc E, Eng N, Berube D (2019) Social science and the infrastructure networks and the human- technology interface. A paper presented at the SRA National Conference. Arlington, VA. December 10

Bozeman B, Youtie J (2017) The strength in numbers: the new science of team science. Princeton University Press

Brown VA, Harris JA, Russell JY (2010) Tackling wicked problems: through the transdisciplinary imagination. Earthscan

Bryant A, Charmaz K (2007) Grounded theory research: methods and practices. In: Bryant A, Charmaz K. (eds) The sage handbook of grounded theory (pp. 1–28). SAGE

Charmaz K (2006) Constructing grounded theory: a practical guide through qualitative analysis. SAGE

Derrington D (1991) Proximity, the standard of care and damage: relating the elements of negligence. Univ Qld Law J 10:272–277

Ellul J, Wilkinson J, Merton RK (1964) The technological society (Vol. 303). Vintage Books

Gigerenzer G (2018) The bias bias in behavioral economics. Rev Behav Econ 5:303–336. https://doi.org/10.1561/105.00000092

Glaser BG, Strauss AL (1967) The discovery of grounded theory: strategies for qualitative research. Aldine Publishing

Kulinowski K (2004) Nanotechnology: from 'wow' to 'yuck'? Bull Sci Technol Soc 24(1):13–20. https://doi.org/10.1177/0270467604263112

Lempert LB (2007) Asking questions of the data: memo writing in the grounded theory tradition. In: A. Bryant & K. Charmaz. (Eds), The sage handbook of grounded theory (pp. 245–264). SAGE

National Nanotechnology Coordinated Infrastructure (n.d.) About the NNCI. https://www.nnci.net/about-nnci

National Nanotechnology Initiative (n.d.) Benefits and applications. https://www.nano.gov/you/nanotechnology-benefits

National Research Council (2015) Enhancing the effectiveness of team science The National Academies Press 10.17226/19007

Nickerson RS (1998) Confirmation bias: a ubiquitous phenomenon in many guises. Rev Gen Psychol 2(2):175–220. https://doi.org/10.1037/1089-2680.2.2.175

Postman N (1993) Technopoly: the surrender of culture to technology. Vintage Books

Research Triangle Nanotechnology Network (2020) About. https://www.rtnn.ncsu.edu/about

Roco M, Bainbridge WS Eds. (2004) Societal implications of nanoscience and nanotechnology II: maximizing human benefit. Report of the National Nanotechnology Initiative Workshop, December 3–5, 2003, Arlington, VA: National Science Foundation

RTNN (2019) Report (2019). Annual Reports. https://www.rtnn.ncsu.edu/wp-content/uploads/sites/12/2020/08/RTNN-Glossy-Report-2019-Final.pdf

Vance ME, Kuiken T, Vejerano EP, McGinnis SP, Hochella MF Jr, Rejeski D, Hull MS (2015) Nanotechnology in the real world: redeveloping the nanomaterial consumer products inventory. Beilstein J Nanotechnol 6:1769–1780. https://doi.org/10.3762/bjnano.6.181

Zipursky BC (2009) Foreseeability in breach, duty, and proximate cause. Wake For Law Rev 44:1245–1275 https://ssrn.com/abstract=1601303