

An assessment of engaged social science research in nanoscale science and engineering communities

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Abstract

Increased funding of nanotechnology research in the USA at the turn of the millennium was paired with a legislative commitment to and a novel societal research policy for the responsible development of nanotechnology. Innovative policy discourses at the time suggested that such work could engage a variety of publics, stakeholders, and researchers to enhance the capacity of research systems to adapt and be responsive to societal values and concerns. This article reviews one of two federally funded social science research centers—the Center for Nanotechnology in Society at Arizona State University (CNS-ASU)—to assess the merits of this form of *engaged social science* research in which social science contributes not only to traditional knowledge production but also to the capacity of natural science and engineering researchers and research communities for greater reflexivity and responsiveness, ultimately producing more socially robust research systems.

Key words: technology policy; nanotechnology; engaged social science; science and society; impact assessment; research center.

1. Introduction

Operative from 2005 to 2016, the Center for Nanotechnology in Society at Arizona State University (CNS-ASU) was larger of the two multi-institutional research networks funded by the US National Science Foundation (NSF) to focus on the societal aspects of nanotechnology (NSF awards #0531194 and #0937591).¹ CNS-ASU productively generated research knowledge (Youtie et al. 2019) and method experimentation (Guston 2014a,b) in its own right as a social science research center. Center researchers published 386² articles up to its final report (Guston et al. 2016). It developed and expanded upon key concepts and methodologies for the social study of emerging technologies, including those related to anticipatory governance, responsible innovation, foresight methods and practice, and laboratory-based socio-technical integration. CNS-ASU also aspired to disseminate and apply that knowledge, build stakeholder capacities, develop researcher awareness (reflexivity within research systems), and catalyze changes within nanoscale science and engineering (NSE) researcher and stakeholder communities. In particular, with its vision of anticipatory governance, the center proposed that through foresight, engagement, and integration

activities, stakeholders throughout national research systems could reflect on societal concerns and adjust research outcomes accordingly to better serve public needs and values (Barben et al. 2008). This article assesses the Center's effectiveness in doing so. This article extends the research done by Youtie et al. (2019) on the knowledge production of CNS-ASU to investigate the nonauthorship-related impacts of the Center. Using data from a survey of CNS-ASU participants, we report on a self-assessment of the types and quality of Center outcomes to inquire into the potential for social science research centers to facilitate change within national research systems. Combined, both papers provide a comprehensive assessment about the extent to which CNS-ASU was able to respond to the complex policy issues around nanotechnology by conducting engaged social science.

We examine the outcomes and impacts of the Center, assessing if it achieved its mission of performing *engaged social science* (Sismondo 2008; van de Ven 2007). In this case, the engaged research sought to understand and facilitate change as enacted by Center participants, that was responsive to the public policy discourse at the time of its inception, and that was supported by ASU's uniquely interdisciplinary institutional environment (Crow and

Dabars 2015). In the first section, we provide a brief institutional history of the Center, a description of its mission, and a review of its activities. We then describe the survey protocol developed to identify information about impact and outcomes from CNS-ASU participants. These participants were academic (ranging in seniority from top faculty to new graduate students, and in discipline from social science and humanities to NSE researchers) and nonacademic (commercial and civil society stakeholders, as well as general publics). The survey questions measured learning and use of concepts, as well as skills-building and perceived impacts. In this article, we provide and analyze the results from the survey. In the discussion section, we assess the Center in terms of its mission to better understand if and how a university-based social science research center can work with natural science and engineering researchers to create and test methods that engage researchers, publics, and stakeholders in the long standing goal of enhancing the responsiveness of research systems to societal concerns and public values.

2. Nanotechnology and societal implications research

At the end of the twentieth century, advances in instrumentation, scientific discoveries, and policy expectations helped focus research, industrial, and policy interests on the ability to manipulate matter at or close to the nanometer (1×10^{-9} m) (McCray 2005; Cyrus 2011). Matter at this scale can behave in accordance with quantum mechanics, giving rise to novel material properties potentially useful for product design and innovation across numerous industrial sectors (The Royal Society and the Royal Academy of Engineering 2004). A variety of existing scientific disciplines with the ability to manipulate matter at or close to the nanometer were subsumed under the term ‘nanotechnology’ as part of national science policy funding strategies emphasizing the commercial and competitive advantages of products and processes enhanced by nanomaterials (Jones 2010; Reinsborough and Sullivan 2011; Toumey 2010).

After a speech by President Bill Clinton in 2000, the USA launched the National Nanotechnology Initiative (NNI) across nearly all its research funding agencies in 2001. From its launch until 2017, these agencies expended a combined budget of 24 billion dollars (Sargent 2013: 16).³ Early estimates of the eventual market value of nano-based products were extraordinarily high, with some indicating a 1 trillion dollar value by 2015 (National Science Foundation 2001). Government policy literature emphasized comparative analysis of national research and market position in nanotechnology, with at least sixty countries having NNIs by 2010 (ETC 2010: iii). Meanwhile, claims about nanotechnology’s disruptive scientific, technological, and economic potential helped amplify concerns over its larger societal ramifications (Fisher and Mahajan 2006).

The twenty-first century Nanotechnology Research and Development Act (2003) (Public Law 108–153) legally extended the NNI from a presidential initiative to a congressionally authorized program. Using unprecedented language, the Act sought to ensure that ethical, legal, environmental, and social concerns were integrated directly into NSE and prescribed an ‘American Nanotechnology Preparedness Center’ (Bennett and Sarewitz 2006; Fisher 2019). In keeping with this prescription, the NSF allocated funding to support research, education, public outreach, and international collaboration related to NSE and society, ultimately resulting in a 2004 solicitation for a Center for Nanotechnology in Society.

Arizona State University (ASU) developed a grant proposal around Real-time technology assessment (RTTA; Guston and Sarewitz 2002) and in 2005 received funding of \$6.2 million for 5 years (NSF #0531194) to create CNS-ASU. At the time, ASU represented itself as a ‘metropolitan research university for the twenty-first century’, highlighting its ‘innovative interdisciplinary programs, and its direct social engagement’ (Crow 2002).⁴ This provided a flexible and future-oriented institutional environment for methodological experimentation in technology assessment and engaged social science. NSF renewed the grant for an additional 5 years at \$6.5 million (NSF #0937591) in 2010, and awarded supplements totaling almost \$800,000. The larger of the two centers focused on the societal aspects of nanotechnology (the other based at University of Santa Barbara), CNS-ASU was a multi-university research network with ASU as its center and largest node with important links at Georgia University of Technology, and University of Wisconsin, Madison, among others.⁵ Within its first 3 years, CNS-ASU articulated the influential concept of anticipatory governance (Barben et al. 2008; Guston 2014a,b) to direct its own research program and encourage similar work elsewhere.

3. The dual research and engagement mandate of CNS-ASU

University research centers traditionally focus on disciplinary or multi-disciplinary academic research, with science and engineering research centers also engaging in industrial partnerships (Gaughan and Corley 2010). The RTTA approach, in concert with the 2003 Act’s ‘preparedness’ mandate to engage broadly with and to integrate societal considerations into NSE research, implied that the CNS-ASU needed to circulate its research output neither solely within the social science disciplines nor purely in an academic mode. CNS-ASU’s mission and goals were thus to develop a combined focus on academic research and on productively engaging stakeholders from science, engineering, industry, government, education, and the general public. Research was not only about potential societal implications, but also about how publics, stakeholders, and NSE researchers might act and interact in light of such implications and in a more reflexive mode. This expanded scope of what it means to be a research center required CNS-ASU not only to engage in knowledge creation and dissemination, but also to be a facilitator of interdisciplinary and cross-sectoral knowledge and values exchange.

Intended to enhance the human capital of individual participants, partner institutions, and the broader community, the Center developed and implemented a conceptually coordinated suite of activities and initiatives to function as a university-based ‘boundary organization’ that would link science and decision making (Guston 2001; Parker and Crona 2012). In this pursuit, CNS-ASU operated under several crucial premises about the intersection of science, emerging technologies, society, and governance. These working assumptions addressed the combined value for both science and society of foresight and anticipation; public participation and engagement; and collaborative interdisciplinary integration of societal perspectives directly into laboratory research (Barben et al. 2008). The Center thus sought to engage in the simultaneous and synergistic building of capacity for understanding the conditions of anticipatory governance. These goals focused the Center not only on conducting societal research, but also on informing the ways in which stakeholders imagined, considered, and confronted emerging nanotechnologies in society.

Accordingly, CNS-ASU articulated its four-fold mission as follows: 1) research the societal implications of nanotechnology and emerging technologies; 2) train an interdisciplinary community of scholars with new insights into the societal dimensions of emerging technologies; 3) engage the public, policy-makers, business leaders, and researchers in dialogs about the goals and implications of emerging technologies; and 4) partner with cutting-edge laboratories to cultivate greater reflexivity in research, development, education, and policy.⁶ This mission was carried out through a combination of education, outreach, and research programming, primarily through the four methodological components of RTTA and two focused Thematic research clusters (TRCs). RTTA, as implemented by the Center, focused on 1) research and innovation systems analysis, 2) public opinion and values, 3) anticipation and deliberation, and 4) integration and reflexivity.⁷ RTTA was developed to reconceptualize traditional forms of technology assessment in a distributed and decentralized way, acknowledging reflexivity as a foundation for ongoing interactions between science and society, and seeking to provide means to manage the complex emergence of new science and technologies dynamically and equitably in conjunction with society. At the time, this study commenced, two TRCs explored 1) equity, equality, and responsibility and 2) urban design, materials, and the built environment (and two had been retired).

The activities of CNS-ASU can be organized within the four parts of its mission. With respect to research, CNS-ASU investigated the societal implications of nanotechnology and other emerging technologies through traditional social science research, publishing on the societal impacts of nanotechnology, and its RTTA components. RTTA 1 focused on analyzing the structure and trajectories of the nanotechnology enterprise, for instance, by compiling a comprehensive public dataset of NSE articles and performing extensive bibliometric analysis to map the increasingly complex research system funded by NSF and other investors in nanotechnology (Shapira et al. 2015; Wang and Shapira 2011). This research resulted in public goods that others adapted to better understand the history, evolution, and possible futures of nanotechnology. Societal implications were more explicitly examined in RTTA 2. Through RTTA 2 research, opinion surveys (with both the public and scientists) were developed that helped register and interpret public understandings of science, including attitudes of lay audiences (Anderson et al. 2013) and of scientists (Corley et al. 2016) toward emerging nanotechnologies. RTTA 3 conducted numerous scenario development and futuring workshops (e.g. Selin 2011), and RTTA 4 conducted numerous laboratory-based interdisciplinary collaborations (e.g. Fisher 2007) and policy studies (e.g. Rodriguez et al. 2013), producing insights into the visions and substance of societal implications of nanotechnology endeavors, as well as the ways various stakeholders understood such implications.

CNS-ASU pursued the second, training, component of the mission through project-oriented graduate and undergraduate programs, inter school academic workshops, and through a variety of engagement exercises that made both the engaged and the engagers the target of the learning process. Through RTTA 3, CNS-ASU had formal and informal educators working within more than half a dozen science centers and universities throughout the USA. Center-affiliated faculty members taught undergraduate and graduate courses in responsible innovation, science and technology policy, and governing emerging technologies. CNS-ASU also organized an annual extracurricular program in 'science outside the lab' (Bernstein et al. 2016), an annual international winter school on anticipatory governance, a 'PhD plus' option in which doctoral students in science and engineering included a chapter on societal

dimensions in their dissertations, and opportunities for graduate students in the sciences and social sciences to engage in collaborative cross-training in NSE and society. In addition to this unusual training work for an 'interdisciplinary community,' CNS-ASU supported more traditional disciplinary training for social science doctoral students and early career researchers.

Addressing the third part of the Center's mission, CNS-ASU facilitated public dialogs and deliberations about social implications of emerging technologies with a variety of audiences. As part of RTTA 3, which focused on anticipation and deliberation, CNS-ASU conducted the National Citizens Technology Forum (Cobb 2011), developed Futurescape City Tours (Altamirano-Allende and Selin 2016), and produced similar small- and large-scale public events. One such event, *Emerge*, continues to use a combination of artistic media, technological props, and participatory activities to provoke members of the public to think about socio-technological futures (Selin 2015). Such events encouraged stakeholders to think about plausibility, imagination, risk, and the future as it applied to their own lives. Through the TRC research programs, CNS-ASU facilitated programming to help publics reflect on equity, equality, and responsibility related to emerging technologies. In one example, a card game called 'Nano Around the World' encouraged players to consider their values and needs when they made choices about new technologies, revealing that many existing and imagined nanotechnologies were not of use to large segments of the world's population, for example, poor populations in developing countries. 'Nano Around the World' represented just one element of a larger partnership with the NSF-funded Nanoscale Informal Science Education Network (NISE Net), which distributed the game freely to more than 200 science museums and shared it online to provide information on the societal features of NSE (Guston 2014a,b). NISE Net provided resources for CNS-ASU staff to train informal science educators on how to discuss societal issues surrounding NSE, including discussions beyond simple risk/benefit framings that became significant departures for informal educators. The NISE Net partnership was central to the ability of CNS-ASU to interact, directly or indirectly with millions of members of the public through annual NanoDays celebrations, exhibitions placed in museums and science centers, and participation in other community events.

Addressing the last portion of CNS-ASU's mission, the Center partnered with science and engineering laboratories and developed a program to enhance socio-technical integration in research, development, education, and policy. For instance, RTTA 4 regularly interviewed NSE researchers who interacted with the Center (Fisher et al. 2019). It also worked with more than two dozen laboratories around the world through the separately funded but associated Socio-Technical Integration Research (STIR) project (NSF award #0849101), by embedding humanities scholars and social scientists in labs located across a dozen nations on three continents to explore the possibility and utility of incorporating social and ethical reflection as a regular component of science and engineering research activities. The STIR project documented numerous instances of scientists and engineers 'modulating', that is, creatively altering their research practices to produce more socially responsive outcomes (e.g. Fisher 2007; Fisher et al. 2010; Fisher and Schuurbiens 2013; Flipse et al. 2013, 2014; Schuurbiens 2011). The STIR project and its results served as a proof of concept for the Center and for the integrative agenda of anticipatory governance (Guston 2014a,b) and went on to provide an empirical and methodological basis for approaches to responsible innovation (Fisher et al. 2015; Fisher and Rip 2013; Owen et al. 2013; von Schomberg 2012).

4. Measuring the dual research and engagement mandate of CNS-ASU: Engagement, learning, and impacts

Some previous research has articulated CNS-ASU's impact. A bibliometric study identified CNS-ASU as a central actor in societal research on NSE, acting as a hub, collaborator, and integrator of knowledge. This work on the academic impact of the Center demonstrates its extensive geographic reach in both co-authorship and citations (Youtie et al. 2019). Senior CNS-ASU faculty are 'the hub of the co-author network of researchers' in NSE and social issue research (Youtie et al. 2019), suggesting that extensive knowledge sharing occurred through the publication process. As stated, however, CNS-ASU also had a set of core functions that were meant to facilitate discussion, training, learning, and mutual responsiveness between publics, stakeholders, and the NSE research community, which had yet to be gauged and thus required additional assessment.

Identifying methods to measure impact and accurately assess resultant change from social science research can be challenging (Reale et al. 2017). To assess CNS-ASU as an engaged social science research center, we draw upon the lessons learned from Science and Technology (S&T) assessments. S&T assessments have investigated how the organization of a partnership or institution led to outcomes (Feller et al. 2002) or facilitated endeavors such as creativity (Heinze et al. 2009). Assessments of S&T research programs typically focus on easily identifiable outputs such as bibliometrics, patents, or other out-the-door measures (Bozeman and Sarewitz 2011; Bozeman et al. 2015). Assessments of human capital development are more difficult and less prevalent (Bozeman et al. 2001; 2015).

Some recent literature calls attention to how one evaluates the 'wider range of non-economic impacts, based on the expectation that science is important for society as a whole' (Joly and Matt 2017), particularly in the context of 'Grand Challenge' narratives now motivating research funding priorities.⁸ Publicly funded research is evaluated to demonstrate its societal impact to show return on publicly supported science (Feller 2017; Jones et al. 2017). Timing of the ex-post assessment can be particularly challenging. Done too soon, an assessment might not pick up the full spectrum of impacts. Completed too far away from the intervention, and too many impact pathways might become intertwined (Jones et al. 2017).

Traditional impact assessment methodologies focused on economic and scientific impacts, but not wider social impacts (Joly and Matt 2017; cf. Bozeman and Sarewitz 2005). In contrast to this, we note that Guanand et al. (2017) develop an ordinal rating scale to assess the political impact of research, which includes exploring the relationship between research and global political impact, as well as use of knowledge in public debates and policy making. Similarly, Bozeman and Rogers (2002) develop the Churn model, which emphasizes uptake of research by other disciplines and members of a knowledge value collective. Bach and Wolff (2017) develop the Bureau d'Economie Théorique et Appliquée (BETA), and later the BETA-Evaluation of Research Infrastructures in Open innovation and research systems (EvaRIO), evaluation method. Through this method, Bach and Wolff (2017) clearly articulate the importance of focusing on specific groups of participants in research to investigate their learning and experience. The BETA approach operates at the 'micro-level' by interviewing participants to figure out how their participation enables different types of learning. The BETA approach takes an important step by evaluating the *indirect effects* of research on participants. The BETA-EvaRIO continues this focus but recognizes that some assessments, such as of research

infrastructure projects, require an understanding of long-term impacts, have heterogeneous actors, and focus on the interacting organizations instead of projects *per se*, particularly the *indirect effects* upon these research infrastructure utilizing entities. While our assessment also seeks to understand science and technology knowledge, relationships and networks, and capacity building—which is characterized as an indirect effect in Back and Wolff (2017)—we look at these as *direct effects* of engaged social science research. The focus of the research center we evaluate was to study how thoughtful awareness (reflexivity) of the *indirect effects* of scientific research can be encouraged in the scientific community or research entities. We, therefore, organize assessment differently by necessity.

While inspired by S&T research assessment, our methods provide a useful addition to traditional output measurements by asking stakeholders about changes in social and human capital, including learning, knowledge application, and changes in institutional behavior. This assessment seeks to gain an understanding of how CNS-ASU participants applied their understanding of key theoretical and methodological concepts across disciplines and sectors as part of a 'preparedness' mandate, by which societal concerns and values were brought into NSE research agendas.

This research assesses CNS-ASU in relation to its stated four-part mission, which includes process-oriented functions that extend beyond disciplinary knowledge creation to engagement and learning of those within and outside of CNS-ASU. We examine the results of our survey with the CNS-ASU mission to identify whether or not the Center responded to the unique policy mandate of the Act. This approach will also illuminate the effectiveness of a university-based boundary organization. Studying the Center participants' experiences, learning, and knowledge application contextualizes the impact of its activities on a variety of groups, from natural and social science academic researchers and students, policy actors, public educators, and business leaders.

CNS-ASU sought to pioneer the type of socio-technical assessments and best practices that it espoused. Its influence is thought to be a function not only of its research outputs, but of a combination of process-oriented sets of collaboration, education, and outreach activities that involve discussion, inquiry, and education. To identify the impact of its activities, we developed a survey instrument to measure self-reported learning of concepts and skills, as well as to investigate impacts on individuals and institutions. We intended this survey to illuminate the engaged social science approach by which CNS-ASU researchers worked with their collaborators. To measure impact and reach, the instrument included questions about the professional roles of survey participants; it then asked about their familiarity with particular learning objectives and included opportunities for respondents to provide open-ended answers to questions about their CNS-ASU experience.

A sample of 794 participants in CNS-ASU activities with current email addresses was identified from administrative record keeping for the initial seven years of the Center's funded work.⁹ A survey on impacts and outcomes of CNS-ASU was distributed using Qualtrics software. Respondents had a period of 4.5 weeks to reply, after which a portion of the remaining non-respondents (those with identifiable US mailing addresses) were sent a printed survey with a return envelope. The survey was developed using Dillman's Tailored Design Method (Dillman et al. 2009), emphasizing survey response as a social exchange within a community (rather than a cost/benefit economic exchange). The survey was designed to provide respondents a full range of expression, given that CNS-ASU participants

Anticipatory governance - anticipating possible future scenarios for technology development, engaging the public in considering these, and integrating societal concerns into the development and governance of new technologies.

Real-time technology assessment - steering innovation toward socially desirable goals by examining it and intervening as the research is being conducted.

Public values mapping - identifying the expected civic values of public policy (determined from public opinion, government policy statements), tracking their implementation in science policy, their evolution in practice and their social outcomes.

Futures thinking - using a various methods to imagine possible outcomes of a technology, using scenarios to consider effects upon stakeholders and how they will act.

Responsible innovation - considering the social and ethical implications of innovation during the design process and adjusting design accordingly.

Socio-technical integration - incorporating alternative experts, methods, and perspectives into science and engineering research programs, for example, embedding a humanist in a laboratory.

Figure 1. Concepts promoted by the center that survey participants were asked to identify.

were diverse in their engagement and backgrounds. In this way, self-reported impact statements help to better discern attributable impacts from the Center. Participants included graduate and undergraduate students, post-doctoral researchers, adjunct and tenure-track, and tenured faculty from numerous academic disciplines, spanning the Humanities, Arts, and Social Sciences (defined as ‘interdisciplinary-close’) and the various science and engineering disciplines (defined as ‘interdisciplinary-far’). A variety of participants were also external to university research and teaching communities (defined as ‘cross-sectoral’), including informal science educators, business and industry representatives, civil society and policy agents, and the general public. Questions addressed concept familiarity, skills and method use, self-reported learning about societal and technical issues of nanotechnology, working with publics, and CNS impacts and outcomes knowledge. Concept awareness questions included ‘anticipatory governance’, ‘real time technology assessment’, ‘public values mapping’, ‘futures thinking’, ‘responsible innovation’, and ‘socio-technical integration’ (see Fig. 1). Familiarity and use of skills and methods questions included ‘data mining’, ‘ethnography’, ‘public engagement’, ‘interdisciplinary collaboration’, and ‘cross-sectoral collaboration’. For both skill and conceptual learning questions, definitions were provided to help participants respond accurately about their familiarity. Survey respondents who indicated familiarity with these concepts and skills were further asked about how much CNS-ASU influenced their understanding of these concepts and in which ways they used these concepts, whether in their professional life/work, research, teaching, public communication work, or some other way.

Influenced by an evaluation of the Citizen’s Panel on Telecommunications and the Future of Democracy (Guston 1999), the final section of the survey inquired about knowledge of specific impacts or changes resultant from the work of CNS-ASU. These questions were arranged in a continuum from actual impacts (to an authoritative decision, institutional behavior, or individual behavior) to changes in general thinking about nano and other emerging technologies (vocabularies, the way issues of nano were discussed, or changes in general awareness of nanotechnology). The survey concluded with questions about specific learning objectives, such as

the social and technical aspects of nanotechnology, the process of working with publics to consider policy, and the role and relevant life experience of other participants engaged with CNS-ASU. This final question was intended to test reflexive knowledge necessary to engage successfully with others in the research system, namely learning through social connections made at CNS-ASU training and outreach activities. The information was analyzed using SPSS 21 statistical software. Because questions were structured with piping logic, all results are here presented with both the valid total of responses (those who provided an answer) and the total number of responses expected for the question, given no missing data.¹⁰

5. Results

The survey response rate was 50.1 per cent ($N = 794$), with respondents coming from varied backgrounds and depths of participation in CNS-ASU. Most respondents were academics, including undergraduate students (5.8%), graduate students (31.1%), post-doctoral students (10.0%), faculty members (29.1%), and visiting scholars (10.9%). Respondents also included science/engineering researcher/practitioners (7.0%), support and administrative staff (7.0%), business and industry professionals (4.9%), science educators (K-12) (1.2%), informal science educators (6.1%), government and policy professionals (5.8%), and non-governmental organization professionals (2.9%). Some respondents indicated only occasional or brief participation, with a one-time outreach activity occurring for less than a day (10.8%), brief involvement lasting a day to a few weeks (18.2%), or infrequent involvement over a longer period of time (27.5%). Others indicated frequent and enduring involvement lasting up to a year (14.8%) or more than a year (28.7%).¹¹ Results below are grouped thematically to assess knowledge dissemination, capacity building, and change facilitation.

5.1 Knowledge dissemination

As previously described, CNS-ASU had a respectable publication record and was considered relevant within its own research field, demonstrable from the Center’s reputation and through bibliometric analysis. Here, however, we look at response to the Center’s training

Table 1. Response distribution. How much would you say you learned during your interaction with CNS-ASU about the following?

Amount (rows) and type (columns) of learning during interaction	Learned about societal aspects of nano- or other emerging technologies	Learned about the scientific or technical aspects of nano- or other emerging technologies <i>n</i>
	<i>n</i> (%) ^a	<i>n</i> (%)
Valid		
Learned none (1)	17 (4.3)	28 (7.2)
Learned little (2)	50 (12.8)	119 (30.5)
Learned some (3)	146 (37.3)	151 (38.7)
Learned a lot (4)	178 (45.5)	92 (23.6)
Valid total	391 (100.0)	390 (100.0)
Missing	49	50
Grand total	440	440

^aValid percentages exclude missing responses.

Table 2. Statistics. How much would you say you learned during your interaction with CNS-ASU about the following?

Statistics	The societal aspects of nano- or other emerging technologies	The scientific or technical aspects of nano- or other emerging technologies
N		
Valid	391	390
Missing	49	50
Mean ^a	3.24	2.79
Median	3	3
Std. deviation	0.837	0.886

^aAmount of learning values: None (1), Little (2), Some (3), A lot (4).

and outreach activities. Survey results suggest that learning occurred through CNS-ASU activities. Most survey respondents (82.8%) reported learning ‘a lot’ or ‘some’ about the societal aspects of nano- or other emerging technologies (Table 1). CNS-ASU participants also learned about the technical aspects of nanotechnology and other emerging technologies: 62.3 per cent of respondents indicated that they learned ‘a lot’ or ‘some’ about scientific or technical aspects of emerging technologies (Tables 1 and 2). Interestingly, this result included, although at a slightly lower rate, NSE professionals, thus demonstrating linkage in the work of CNS-ASU between societal and technical/scientific issues.¹² Discussion of NSE societal issues also increased participant knowledge of the scientific and technical aspects of nano or other emerging technologies. Facilitating interdisciplinary discussion and debate also brings together NSE experts from different fields who learn from one another, from the questions raised, and from the social scientists.

Learning was measured by identifying how much CNS-ASU influenced participants’ understanding of key concepts and methodologies central to the mission and goals of the Center. This approach sifted out participant concept/skill knowledge that was not specific to CNS-ASU program work. A majority of respondents indicated they were influenced ‘very little’ or ‘not at all’ by CNS-ASU in data mining and ethnography, skills that are taught in the training programs of specific disciplines. For broader skills/methods not generally taught within other disciplines, several participants indicated being ‘very much’ or ‘entirely’ influenced by CNS-ASU in their understanding of public

engagement (27.6%), cross-sector collaboration (17.1%), and interdisciplinary collaboration (22.9%) (Tables 3 and 4).

Most respondents (56.3%) indicating familiarity with anticipatory governance were ‘entirely’ or ‘very much’ influenced by CNS-ASU in their use or understanding of the concept. This influence permeated into the professional life/work and research of participants. Of these participants who indicated they used the concepts, nearly 50 per cent indicated using anticipatory governance in their professional life/work and 64.2 per cent using it in their research. Additionally, 35.4 per cent of respondents used anticipatory governance in their teaching and 33.6 per cent in their public communication work.

Forty-eight per cent of respondents felt that their use or understanding of RTTA was ‘very much’ or ‘entirely’ influenced by CNS-ASU. Respondents used RTTA 46.8 per cent of the time in their professional and work life and 61.5 per cent in their research. Very few respondents who indicated concept familiarity reported that they were ‘not at all’ influenced by CNS-ASU for anticipatory governance (5.2%), sociotechnical integration (8.2%), and futures thinking (8.8%) (Tables 5 and 6).

5.1.1 Capacity-building

Survey results revealed CNS-ASU’s ability to build capacities for being aware of and addressing societal impacts of NSE. When asked about learning the process of working with publics to consider policy related to emerging technologies, over a third reported learning ‘some’ and another third reported learning ‘a lot’ (Tables 7 and 8). For example, one respondent reported a potential change in public engagement practice based on this type of learning by stating, ‘I have also been able to relay this information to colleagues in a way that has allowed us to explore changes in our training approaches for staff (who have direct interactions with the public) about having conversations with the public on the impact of science on people’s lives and the impact of people on science’. This suggests that CNS-ASU was effective in facilitating processes that can build capacity for participants to engage with others about policy and emerging technologies. When questioned about the knowledge, role, relevant life experience, contacts, and social organizations of the other participants of CNS-ASU training and outreach activities, more than 30 per cent of participants remarked that they learned ‘a lot’, while 40.5 per cent indicated they learned ‘some’. Response to this question was used as an approximation of ‘reflexivity’, that is, to what extent did participants feel that they were learning about their own or other related parts of the larger interacting community of NSE researchers, stakeholders, and affected publics with whom CNS-ASU was tasked to work. Science policy relevant knowledge can only be effectively applied when multiple actors in the research system have an awareness of their own roles and that of others with whom they will work, to be able to enact practical changes in the overall system.

The capacity to engage on the societal issues of nanotechnology was facilitated by specific changes in language use. Survey respondents indicated altered discourse about nanotechnology and emerging technologies. Of 293 survey respondents indicating knowledge of CNS-ASU impacts, many noted changes related to use of vocabularies (64.2%), or the ways in which nanotechnology was discussed (69.6%) (Table 9).

5.1.2 Social catalysis

Results suggest that CNS-ASU served as a catalyst for individual and collective forms of changed behavior. The survey measured

Table 3. Response distribution

Amount influenced by CNS-ASU	Data mining	Ethnography	Public engagement	Interdisciplinary collaboration	Cross sector collaboration
	<i>n</i> (%) ^a	<i>n</i> (%)	<i>n</i> (%)	<i>n</i> (%)	<i>n</i> (%)
Valid					
Not at all (1)	82 (39.8)	67 (35.3)	34 (11.9)	54 (15.9)	36 (17.1)
Very little (2)	54 (26.2)	59 (31.1)	59 (20.6)	77 (22.6)	43 (20.5)
Partly (3)	32 (15.5)	48 (25.3)	114 (39.9)	131 (38.5)	95 (45.2)
Very much (4)	24 (11.7)	11 (5.8)	68 (23.8)	69 (20.3)	32 (15.2)
Entirely (5)	14 (6.8)	5 (2.6)	11 (3.8)	9 (2.6)	4 (1.9)
Valid total	206 (100.0)	190 (100.0)	286 (100.0)	340 (100.0)	210 ()
Missing	35	26	30	36	29
Grand total	241	226	316	376	239

^aValid percentages are only of those who answered the question. The grand total depicts the total number of participants who could have responded to the question. In this instance, the grand totals are lower because to respond to the question about a skill or method, they had to report familiarity with the skill or method first.

On a scale of 1–5, with 1 being ‘not at all influenced’ and 5 being ‘entirely influenced,’ please say how much you feel your use or understanding of this skill or method has been affected by your involvement with CNS-ASU.

Table 4. Statistics

Statistics, <i>N</i>	Data mining	Ethnography	Public engagement	Interdisciplinary collaboration	Cross sector collaboration
Valid	206	190	286	340	210
Missing/no response	234	250	154	100	230
Mean ^a	2.19	2.09	2.87	2.71	2.64
Median	2	2	3	3	3
Std. deviation	1.265	1.035	1.03	1.044	0.998

^aAmount of influence values: Not at all (1), Very little (2), Partly (3), Very much (4), Entirely (5).

On a scale of 1–5, with 1 being ‘not at all influenced’ and 5 being ‘entirely influenced,’ please say how much you feel your use or understanding of this skill or method has been affected by your involvement with CNS-ASU.

Table 5. Response distribution

	Anticipatory governance	Futures thinking	Public values mapping	RTTA	Responsible innovation	Sociotechnical integration
	<i>n</i> (%) ^a	<i>n</i> (%) ^a	<i>n</i> (%) ^a	<i>n</i> (%) ^a	<i>n</i> (%) ^a	<i>n</i> (%) ^a
Valid						
Not at all (1)	14 (5.2)	21 (8.8)	17 (10.4)	17 (7.6)	31 (11.4)	18 (8.2)
Very little (2)	29 (10.7)	43 (18.1)	32 (19.5)	32 (14.3)	40 (14.8)	30 (13.6)
Partly (3)	75 (27.8)	93 (39.1)	64 (39.0)	67 (30.0)	109 (40.2)	81 (36.8)
Very much (4)	89 (33.0)	61 (25.6)	27 (16.5)	61 (27.4)	65 (24.0)	59 (26.8)
Entirely (5)	63 (23.3)	20 (8.4)	24 (14.6)	46 (20.6)	26 (9.6)	32 (14.5)
Valid total	270 (100.0)	238 (100.0)	164 (100.0)	223 (100.0)	271 (100.0)	220 (100.0)
Missing	32	44	45	31	42	36
Grand total	302	282	209	254	313	256

^aValid percentages are only of those who answered the question. The grand total depicts the total number of participants who could have responded to the question. In this instance, the grand totals are lower, because to respond to the question about a concept, respondents first had to report concept familiarity.

On a Scale of 1–5, with 1 being ‘not at all influenced’ and 5 being ‘entirely influenced,’ please say how much you feel your use or understanding of this concept has been affected by your involvement with CNS-ASU.

reported knowledge of changes to authoritative, institutional, and individual decisions, and changes of practices within institutions and individuals. When asked directly about these levels of decision-making, participants identified whether a change occurred and then provided qualitative examples of these changes. These changes occurred at various locations around the world, in different institutional contexts, and in some instances, resulted in codified changes (Table 9).

Twenty-six respondents indicated that CNS-ASU influenced an authoritative decision. One respondent provided the following

example of such a decision about nanotechnology within an informal science educational organization: ‘an authoritative decision was made to include Societal and Ethical Implications as a core message in our programming and all materials we provide to partner institutions. Additionally, we had started regularly using the phrase “Risks and benefits” and then ultimately changed to “Societal and Ethical Implications.”’ In this example, CNS-ASU’s engagement within a network of stakeholders interested in nanoscale informal science education was perceived to have an impact on the programming, language, and direction of this organization.

Table 6. Statistics

Statistics, N	Anticipatory governance	Futures thinking	Public values mapping	RTTA	Responsible innovation	Sociotechnical integration
Valid	270	238	164	223	271	220
Missing/no response	170	202	276	217	169	220
Mean ^a	3.59	3.07	3.05	3.39	3.06	3.26
Median	4	3	3	3	3	3
Std. deviation	1.114	1.061	1.168	1.184	1.109	1.119

^aAmount of influence values: Not at all (1), Very little (2), Partly (3), Very much (4), Entirely (5).

On a Scale of 1–5, with 1 being ‘not at all influenced’ and 5 being ‘entirely influenced,’ please say how much you feel your use or understanding of this concept has been affected by your involvement with CNS-ASU.

Table 7. Response distribution

Learning	The process of working with publics to consider policy related to nano- or other emerging technologies	The knowledge, role, relevant life experience, contacts, social organization, etc. of the other participants of CNS-ASU training and outreach activities
	<i>n</i> (%) ^a	<i>n</i> (%) ^a
Valid		
None (1)	31 (8.0)	35 (9.0)
Little (2)	67 (17.3)	75 (19.3)
Some (3)	151 (38.9)	157 (40.5)
A Lot (4)	139 (35.8)	121 (31.2)
Valid total	388 (100.0)	388 (100.0)
Missing	52	52
Grand total	440	440
		–
		–

How much would you say you learned during your interaction with CNS-ASU about the following?

^aValid percentages exclude missing responses.

Table 8. Statistics

Statistics, N	The process of working with publics to consider policy related to nano- or other emerging technologies	The knowledge, role, relevant life experience, contacts, social organization, etc. of the other participants of CNS-ASU training and outreach activities
Valid	388	388
Missing	52	52
Mean ^a	3.03	2.94
Median	3	3
Std. deviation	0.923	0.93

How much would you say you learned during your interaction with CNS-ASU about the following?

^aAmount of learning values: None (1), Little (2), Some (3), A lot (4).

Eighty-seven respondents found that CNS-ASU contributed to an institutional change. These respondents held different roles at the time of their interaction with CNS-ASU, such as students, faculty, science educators, engineering researcher/practitioners, and/or government/policy work professionals. This result might suggest that institutional changes occurred in different organizational contexts.

Table 9. Has the work of CNS-ASU contributed to any of the types of impacts or changes listed below (within a public or private institution)?

	<i>n</i> (%)
Responses	
An authoritative decision	26 (8.9)
Institutional behavior	87 (29.7)
Individual behavior	124 (42.3)
Vocabularies used to discuss nano	188 (64.2)
The way issues of nano are discussed	204 (69.6)
General awareness of nano	201 (68.6)
Valid total	293 (100.0)
Missing	147
Total	440

Check a box only if you are aware of a specific impact or change in that type. I am aware of a specific impact or change in

^aPercentages are of the people who responded to the question about impacts. Missing responses in this instance might include those who did not answer the question or of those who found no impact.

Participants at universities mentioned various institutional changes that they witnessed and attributed to CNS-ASU. As an example, one university was perceived to have “imported” the sociotechnical integration into the research and graduate education in their philosophy of science and technology & STS [Science and Technology Studies] programs’. Another respondent stated that their research safety organization’s association with CNS-ASU ‘led to better dissemination of health & safety information to researchers and support staff to heighten awareness of potential hazards’. Specifically, the organization made a formal change in their Chemical Hygiene Plan, an official training document which ‘now has an appendix with guidance specific to various types of nanomaterials’.

The institutional change responses also reflected the locational breadth of CNS-ASU’s impact. Those reporting an institutional change included participants from across the USA, as well as other countries, such as the Netherlands, Germany, and Scotland. Respondents noted that local and city changes were influenced by CNS-ASU. As an example, CNS-ASU influenced ‘Planning and decision making culture in the City of [redacted] administration’. Another respondent stated, ‘In my opinion, the CNS-ASU program had an impact on [a nano public engagement organization] program in Europe’. Participants also mentioned changes in Japan and examples that suggested influence at the national level. These results suggest national and international relevance of the science policy dialogues through CNS-ASU.

Many respondents noted that CNS-ASU changed their individual behavior. Specifically, one respondent stated, ‘I think my

Table 10. CNS-ASU four-part center and mission assessment

Mission statement	Results
Research the societal implications of nanotechnology and emerging technologies	<ul style="list-style-type: none"> • Not directly measured by the survey, but supported in Youtie et al. (2019) • Respondents reported: • recognizing research concepts of CNS-ASU, learning about the societal implications of nanotechnology and emerging technologies
Train an interdisciplinary community of scholars with new insights into the societal dimensions of emerging technologies	<ul style="list-style-type: none"> • Respondents indicated familiarity with key concepts and, to a lesser extent, methodologies related to societal dimensions of emerging technologies • Respondents indicated that the way they talked about nanotechnology/emerging technologies changed • Individual and institutional changes were made based on what respondents learned from participation in CNS-ASU activities
Engage the public, policy-makers, business leaders and researchers in dialogues about the goals and implications of emerging technologies	<ul style="list-style-type: none"> • Responses represented a breadth of stakeholders participating in CNS-ASU activities • Respondents indicated that they: volunteered and engaged with the public, learned from each other
Partner with cutting-edge laboratories to cultivate greater reflexiveness in research, development, education and policy.	<ul style="list-style-type: none"> • Survey respondents shared that: STIR provided influential experiences • They learned about key concepts tied to reflexivity and partnerships, including responsible innovation, socio-technical integration, and interdisciplinary collaboration • Survey respondents indicated reflexive learning about their peers

interactions with CNS have affected my career choices more than my scientific research and training'. Others remarked that they saw changes in themselves and others, and that these changes would have reverberating effects. For instance, 'The work of CNS-ASU has changed my personal behavior, as well as several graduate engineering colleagues, in our approach to research and problem framing. Specifically, I am convinced that it is insufficient to proceed with engineering research without explicit identification and integration of broader concerns'.

Not all survey feedback showed positive impacts gained from interactions with CNS-ASU. One respondent remarked that they learned very little from CNS-ASU and that the 'concepts, skills, methods are hardly unique to CNS-ASU'. Another respondent had difficulty articulating impact given their previous familiarity with nano, stating 'Not sure I have changed my thinking. I may have known a lot about nano to begin'. Both comments suggest that some CNS-ASU participants already had expert knowledge or interest in the work, making it difficult to discern additive impact.

6. Discussion

We use survey results to understand to what extent CNS-ASU effectively implemented the 'preparedness' policy mandate, and where applicable, discern something about how it accomplished this task. To do this, we connected survey results to CNS-ASU's four-part mission, which derives from early conceptions of what an NSE preparedness center might be and, more generally, the political discourse surrounding the 21st Century Nanotechnology and Development Act. By cross-referencing survey responses against the four-part mission, we measure engaged social science and demonstrate the extent of results accordingly.

Since the survey instrument was specifically constructed to measure learning and detect influence on discourse, knowledge, and institutional practices by attending to participant experience, few of its findings speak directly to the first component of the mission—research. By focusing on the influence of concepts on a broad diversity of disciplinary and cross-sectoral participants, the survey presumes

the research output and instead attempts to measure to what extent the research was framed in a way that could be relevant across disciplines and professional fields. In this, we find that respondents indicated awareness of CNS-ASU concepts and reported learning about the societal aspects of NSE. Although the survey results cannot speak specifically to the quality or types of outcomes, they can (and in this case, do) indicate that the research component of the mission received exposure by those engaged with the Center. Closely related, CNS-ASU appears to have translated its research and facilitated discussions so that those engaged with the Center indicated learning about the societal implications of nanotechnology and emerging technologies. Furthermore, as discussed above, parallel assessment work using citation, co-author, and bibliometric analysis show strength in the CNS-ASU research output ([Youtie et al. 2019](#)).

The second component of the mission is directly measured in the survey. Results suggest that CNS-ASU trained an interdisciplinary community of scholars with insights into the societal dimensions of emerging technologies. CNS-ASU engaged different types of scholars, from undergraduates to faculty, including informal and K-12 science educators. Respondents indicated that they learned and used concepts associated with the Center. Skills taught in the training programs of specific disciplines were not shown as strength of CNS-ASU, while broader skills and methods not often taught specifically within other programs (public engagement) demonstrated slightly better results. Respondents indicated learning concepts and methods related to emerging technologies, and some continued to use what they learned outside of their point of engagement with the Center. As one respondent remarked, 'We're using CNS ideas at [a North American public comprehensive university] in our efforts to reform engineering education and practice'. By educating and training others, CNS-ASU extended its impact past its direct engagements.

Third, CNS-ASU engaged the public, policy-makers, business leaders, and researchers in dialogues about the goals and implications of emerging technologies. Results show that CNS-ASU worked not only with stakeholders in traditional university science and social science communities, but also with science policy stakeholders spanning education, business, science, and policy sectors. CNS-ASU,

through educational and outreach activities, also helped introduce broader societal perspectives into communities interested in nanotechnology and emerging technologies. These communities include those who were directly involved in CNS-ASU activities, as well as those whom participants subsequently influenced. For example, a respondent remarked, ‘Volunteering at public outreach at the [redacted] science center, I was able to see changes in the perception and ideology of parents who were interested in learning more about nanotechnology in their life’. CNS-ASU events helped build a community that talked about societal dimensions of emerging technologies, where survey respondents indicated learning from each other through CNS-ASU activities.

The final part of the CNS-ASU mission, partnering with cutting-edge laboratories to cultivate greater reflexivity in research, development, education, and policy, was mostly addressed in the survey through the concepts tied to the STIR project. Some respondents directly cited the success of interdisciplinary and collaborative activities that involved partnerships with laboratories. One respondent shared that the STIR activities ‘impacted students involved in the study in terms of their thinking about societal implications’. Similarly, another described that ‘at one point we had a graduate student spend time in our lab and ask nanotechnology related questions. It made us think a little more about the social implications of our nanotechnology research’. Respondents also reported learning about core concepts tied to reflexivity in collaborative partnerships, including interdisciplinary collaboration, socio-technical integration, and responsible innovation. These responses might not directly indicate the quantity or quality of partnerships cultivated, but they suggest that participants learned foundational concepts that support efforts to enhance individual and institutional reflexivity in science research, development, education, and policy. Self-reported learning about ‘the knowledge, role, relevant life experience, contacts, and social organizations of the other participants of CNS-ASU training and outreach activities’, was directly captured in the survey. These responses were a proxy measurement for reflexivity (since all respondents were in some way participants of CNS-ASU training and outreach activities, their response is a comment on their learning about their own situation within the larger NSE research economy).

By aligning the components in the Center’s mission with results from the survey, we see that CNS-ASU engaged with numerous and diverse stakeholders on emerging technologies. Learning and reflexivity occurred and registered across a broad disciplinary and cross-sectoral span. The geographic spread of the Center’s knowledge dissemination is also sufficiently wide-ranging, with indication of both USA and international influence. Similarly, actual impact is shown when participants from a broad array of backgrounds and regions report using their learning in their professional life and in the facilitation of further public engagement activities. In this way, CNS-ASU responded to the issues formulated in the political discourse from which it was born.

The survey results suggest that CNS-ASU, focused on engaged social science research, became a center where education, engagement, and public outreach could occur around the relationship between NSE and society. Such results are in line with the original language of the 21st Century Nanotechnology Research and Development Act. The Center shared knowledge, built capacities within, and facilitated changes in people and institutions, creating places where social concerns were taken into consideration alongside, and integrated into, NSE considerations. While asking about participant experience by survey might not allow us to quantify engaged social science in a precise way, it demonstrated that engaged social science is happening and shows some of its extent.

There are numerous ways to conduct additional follow-up analyses. The long-term impacts of the research center could be addressed in a follow-up study, as well as identification of other types of societal impacts, such as public value impacts (Bozeman and Sarewitz 2011; Joly et al. 2015). Widening the respondent pool for future survey research could more accurately and thoroughly measure such social impacts, given that those who might benefit from CNS-ASU’s work might not be those in direct contact with the Center (Georghiou and Roessner 2000). As an example, if CNS-ASU increased knowledge of concepts and methods in CNS-ASU participants, it would be worthwhile to know if those participants used that gained knowledge to impact others. Additional investigations could use a variety of social impact tools to identify whether or not reported actions actually resulted in better social outcomes (Reale et al. 2017). In this way, it would be worthwhile to know if reported institutional changes resulted in better social outcomes. Such a study would more fully capture the reach of the engaged aspects of CNS-ASU.

In comparison to existing evaluations studies, the focus of this analysis is engaged social science, rather than technological, econometric, and bibliometric outputs. Whereas some science and technology assessments might consider the indirect impacts of scientific research (capacity, knowledge, and network building), such indirect impacts were the focal points that CNS-ASU tried to expose, build, and leverage at the core of their engaged social science work.

However, Bach and Wolff’s (2017) attention to the different entities associated with a research infrastructure (differentiating operators, suppliers, and users) would benefit our work. While nuanced collection of data allows us to differentiate between ‘insiders’ and ‘outsiders’ (for example, the label variables ‘interdisciplinary-close’, ‘interdisciplinary-far’, and ‘cross-sectoral’), for consonance with the purpose of the Center we never address recipients in a way that differentiates between ‘insiders’ and ‘outsiders’. Our survey instrument encouraged all participants to identify as members of CNS-ASU or, more exactly, with the purpose of increasing their own reflexivity.

Seus and Buhner (2017) use an experimental control in the design of evaluation to see if participant outcomes in a research program were better than nonparticipants. Having a similar comparison might also have helped further determine whether or not CNS-ASU contributed to the learning of participants and if the impacts can be attributed to the activities that participants engaged in through CNS-ASU. That said, CNS-ASU made a self-conscious decision at an early stage not to utilize an experimental control but rather to conduct its annual assessments in the form of in-depth interviews and to focus these almost exclusively on NSE researchers in consideration of the novel ‘integration mandate’ of the 21st Century Nanotechnology Research and Development Act of 2003 (Fisher 2019). The research reported on here thus represents a significant expansion of the Center’s assessment activities to encompass all and not only NSE participants. Given the heterogeneity of CNS-ASU participants in terms of length, type, and intensity of engagement, as well as their own backgrounds, this research relied on self-reported outcomes.

7. Conclusion

CNS-ASU was founded during a robust public policy discussion about nanotechnology and its societal implications. Being able to systematically identify impacts of the Center is critical to understanding whether or not a social science research center can respond

effectively to such complex public policy issues (such as integrating societal considerations into NSE) by conducting engaged social science. Because of the unique aspirations of CNS-ASU, standard assessments focusing on research productivity could not comprehensively measure its effectiveness. This study should be read as a complement to the co-authorship analysis by Youtie et al. (2019) to understand research networks. Indeed, much of the experimental mode of social science emphasizing engagement, dialogue and reflexivity would not register at all in traditional research assessment. Being able to analyze engaged social science impacts outside of publication analyses is important to understand how knowledge was mobilized to influence organizational practice and social behavior. A different type of center assessment was therefore used. A survey was crafted to be able to gauge to what extent the Center effectively fulfilled the more experimental and innovative aspects of its mission. While not all participants communicated that their involvement in CNS-ASU resulted in substantive impacts, the overall results indicate that CNS-ASU constructed relevant knowledge, built capacity to be responsive to such knowledge, and in many cases acted as catalyst for individual and institutional changes.

The lack of comparable studies make a more thorough assessment difficult. For example, could we expect similar results from a comparable research investment? Nevertheless, this study does demonstrate that CNS-ASU is proof-of-concept for the policy discourse upon which it was founded and that methods of assessment can be constructed for engaged social science. These findings are important because if there is public policy value in engaged social science, then such value should be demonstrable through systematic inquiry. Policy makers, funding agencies, and research institutes can make informed resource and organizational decisions to address socially complex science policy challenges. CNS-ASU activities appear to have resulted in changes in daily individual behavioral, institutional, and some authoritative decisions, indicating that Center activities do not just impact cursory topical learning confined within the walls of academic work. Instead, such CNS-ASU activities appear to have utility in informing the way multiple types of stakeholders think, speak, and act regarding nanotechnology and other emerging technologies. The case-study discussed here demonstrates the merits of *engaged social science* research where social science contributes not only to traditional knowledge production, but also to the capacity of individual researchers and research communities for greater reflexivity and responsiveness, ultimately for the sake of more socially robust national research systems.

Notes

1. The initial grant was issued for five years; the Center received a five-year renewal and a one-year no-cost extension. The data analysed here were collected during year 7 of CNS-ASU.
2. This number represents only the peer-reviewed journal articles and book chapters resulting from support of the Center, excluding working papers, books, theses, and other reporting categories of published materials.
3. As Sargent notes, 'The NNI budget is an aggregation of the nanotechnology components of the individual budgets of NNI-participating agencies' (2013). It was not extra money appropriated by Congress.
4. ASU would later adopt a charter that would formally characterize ASU's institutional behaviors, 'advancing research and discovery of public value' and 'assuming fundamental responsibility for the economic, social, cultural and overall health of the communities it serves'.

5. Academic participants at year 7 in the CNS-ASU network can be linked to approximately 125 universities throughout four continents (North America and to a lesser extent Europe, Asia, and South America, respectively).
6. <http://cns.asu.edu/about> (accessed August 15 2017).
7. The implementation of RTTA differed slight from its original conception. For example, analogical case studies (applied historical analysis) were not funded at CNS-ASU, since NSF funded historical research through other grantees.
8. Much of this literature is reviewed and further developed in a special issue of the *Journal of Technology Transfer*. See Joly and Matt (2017).
9. The entire population was slightly larger, at approximately 900, but contact details were not complete.
10. In this way, no assumptions are made about why someone chose to not respond to a question.
11. Some respondents existed in more than one category and therefore results total more than 100%. Respondents could also select an 'Other' category.
12. NSE professionals measured in the 'interdisciplinary-far' group responded on a scale of 1 to 4 with a mean score of 2.47 learning where 2 indicates 'a little' and 3 indicates 'some'. The 'interdisciplinary-far' group constituted 28% of the respondents. This indicates that learning about one's own discipline can happen through interdisciplinary (and cross-sectoral) interactions.

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