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PERSPECTIVES

How social science should complement scientific discovery: lessons from nanoscience

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Abstract This article examines the state of social science of science, particularly nanoscience. It reviews what has been done and offers a series of constructive criticisms. It examines some of the problems associated with experts and expertise and itemizes challenges we confront dealing with them. It presages some of the social science research work that we may consider to embrace in the future.

Keywords Nanoscience · Nanotechnology · Social science · Societal and ethical implications of nanotechnology · SEIN · Experts · Expertise

Purportedly, some problems are wicked (incomprehensible and resistant to solution) (Churchman 1967; Rittel and Webber 1973) and sticky (resistant to change) (Heath and Heath 2007), two terms that describe big problems that are not resolvable by simple and traditional solutions. They are steeped in uncertainties and function at scales, both temporally and physically, that are far beyond traditional attention. Critics claim advanced technologies involve wicked and sticky issues and some even claim they can solve them as well. The hazard and risk profiles associated with advanced technologies are generally unknown, and regulating their integration into society demands high levels of trust in those marketing them. In addition, they are often associated with overclaims in terms of both their desirability and their drawbacks.

Scientific discovery can be an end, but for most of the world, it is a means; we evaluate contributions of science in terms of the benefits they produce for eco-kind either directly or indirectly. Those benefits are most often mediated by technology. Generally, social scientists study technological artifacts and phenomena and how they interact with publics of all sorts to determine beneficiality (the conjectures and suppositions underlying what we mean by "benefits").

When theoretical and bench scientists, hereafter referred simply as scientists, encounter a social science of science professional, they are added onto large grants, sometimes as window dressing and other times as assessment officers. When a social scientist is found on a research team, especially one funded by the federal government, that social scientist is probably working alone without a social scientist colleague. Exceptions occur when the grant was designing to specifically

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20th Anniversary Issue: From the editors

Nicola Pinna, Executive Editor, Mike Roco, Editor-in-Chief

This article has been drawn in part from a brief piece of mine submitted as part of a decadal survey of social and behavioral sciences (SBS), the National Academy of Sciences' Committee for the Decadal Survey of Social and Behavioral Sciences for Applications to National Security (http://sites.nationalacademies.org/dbasse/bbcss/dbasse_175673), and a Power Point presentation of mine on December 13, 2017, at the annual Grantees Meeting held at the Westin Arlington Gateway sponsored by the National Science Foundation.

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address a societal issue. A clear exception was the decision to fund two Centers for Nanotechnology in Society (examined briefly below).

Social scientists come with degrees in statistics, political science, and even communication. Generally, we are the last to speak at scientific and even science policy meetings after most of the scientists have gone home. Those that remain take a coffee break during these sessions and stretch their legs. In books, our chapters are included in peculiar locations, often at the end, if at all.

Introduction

While there have been many social scientists of science involved with nanoscience and nanotechnology in the last 30 years, there has not been much to report, whereby social science has made a significant impact on the theoretical and bench sciences. This article offers some insight into the roles played by social science in the social science of nanoscience, what we have learned, why we sometimes succeeded, and why we more often failed to accomplish very much at all. It is written from the perspective of a quarter century of experience as a social science of science practitioner, 5 years as a social science coordinating editor for this publication, and was written to celebrate occasions when social scientists attempted to contribute to the process of scientific inquiry and discovery. There are great scientists and there are mediocre ones; there are great social scientists and mediocre ones as well.

Setting standards to assess the roles played by social science in scientific discovery is critically important for self-evaluation of the cases instant and the future of the social science of science in general. Emerging science has become a term to describe what happens when traditional fields begin to work together to accomplish complex problems and goals that disciplines by themselves have failed to reach and resolve. When two or more sciences come together, there is interdisciplinary static energy when the paradigmatic disciplinary functions come in contact. Privilege, language, tools and instruments, methods and measurements, standards for defining success and reputation, etc. come in contact and can provoke discordance. This article hopes to dampen worries and resolve concerns when science and social science meet on the fields of discovery.

Before we evaluate the roles played by social scientists in the world of "emerging science and technology," especially nanoscience and nanotechnology, it may be prudent to set the context.

First, humanists and social scientists are lumped together in the disciplinary mélange featured by organizational schemes within colleges and universities. The traditional academic schema separate departments into different buildings and erects barriers of all sorts to the cross-disciplinary fertilization of ideas and interdisciplinary research projects. These barriers are both intentional and unintentional. For example, a university may claim to commit itself to interdisciplinarity while retaining decades-old policies and procedures over issues such as budgeting, hiring, and tenure that frustrate true cross-disciplinary activities.

Informally, social science in its broadest sense includes humanists, but there is a difference. Humanists study history and critical theory, and they often can avoid using statistics and numerical data to analyze their experiences and summarize their findings. "Social science, which is generally regarded as including psychology, sociology, anthropology, economics and political science, consists of the disciplined and systematic study of society and its institutions, and of how and why people behave as they do, both as individuals and in groups within society" (Halloran 2010). Social scientists claim to use more rigorous methods and data analysis to draw their conclusions. On a more epistemological level, humanists seem fascinated by exceptions while social scientists are attracted to trends. In the world of humanities and social science, lines have been drawn based on measurement and methods.

Second, social scientists have been excluded from bench science unless and until a bench science needs assessment. Without a doubt, the strongest contribution from a social scientist from the traditional view of bench science comes in the form of assessment. In this situation, a social scientist will design some tool or set of tools to demonstrate that a project is important to other stakeholders and may have perceived significance to others such that the project will be renewed and, maybe, refunded, or, at least, will not be canceled.

Some social scientists denigrate the works of their humanist brothers and sisters and some social scientists seem to feed off each other's foibles and failures as well, not unlike scientists. Put simply, they can be a wary bunch.

History

This is a very brief history of the social science of nanoscience. There are other expert commentaries and publications that cover the field of the social science of science. This field is usually called Science and Technology Studies (Jasanoff et al. 1995; Sismondo 2003; Felt et al. 2016). It has its own society called the Society for Social Studies of Science as well as its own journal since 1970, Social Studies of Science. Programs in science, technology, and society (STS) can be found on the campuses of Berkeley, Cornell, Duke, Michigan, MIT, NCSU, and elsewhere.

STS, as practiced in academia today, merges two broad streams of scholarship. The first consists of research on the nature and practices of science and technology (S&T). Studies in this genre approach S&T as social institutions possessing distinctive structures, commitments, practices, and discourses that vary across cultures and change over time. This line of work addresses questions like the following: is there a scientific method; what makes scientific facts credible; how do new disciplines emerge; and how does science relate to religion? The second stream concerns itself more with the impacts and control of science and technology, with particular focus on the risks that S&T may pose to peace, security, community, democracy, environmental sustainability, and human values. Driving this body of research are questions like the following: how should states set priorities for research funding; who should participate, and how, in technological decision-making; should life forms be patented; how should societies measure risks and set safety standards; and how should experts communicate the reasons for their judgments to the public? (Harvard Kennedy School 2013).

Some of the first work in this area was associated with biotechnology and the NIH Human Genome Initiative. It was called ELSI (Ethical, Legal, and Social Implications) and was established in 1990. An excellent review of ELSI was published in 2014 (McEwen et al. 2014). A similar and updated application to ELSI in translational genomics was reviewed a year later (Koenig 2015). Since that time and for many different reasons, private and government funding opportunities for bench science research have encouraged, if not required, social science work in fields ranging from ethics to policy studies.

Rice University under Vicki Colvin and Kristen Kulinowski introduced societal issues in terms of its Center for Biological and Environmental Nanotechnology (2001) focusing nearly exclusively on human health and safety, though over time it has added the environment to its concerns, especially under Pedro Alvarez. Decades later, the National Science Foundation (NSF) would fund the Center for the Environmental Implications of Nanotechnology (2008) between Andre Nel at UCLA and Mark Wiesner at Duke.

One of the first teams to become involved in the broader sense of the social science of nanoscience came from the University of South Carolina led by professor of philosophy Davis Baird. It involved me as a CoPI. After some negotiations, we received a start-up grant from the Social, Behavioral, and Economic Sciences (SBE) Directorate at the NSF (2002). For better or worse, the field called itself SEIN (Societal and Ethical Implications of Nanotechnology).

This was soon followed by a series of six- to seven-figure grants to study the public understanding of nanoscience as well as a life cycle analysis of nanoscience that took into consideration impacts that were more social in nature, such as equity and justice (2003, 2005, 2007). It soon became evident that SEIN had much more to do with human and environmental health than any one societal value. With only a small percentage of the funding for nanoscience going to societal issues, the readjustment of societal concerns to be primarily those affecting human safety and health and the overall ecosystem in which humanity resides, most social science reverted to public understanding and surveys with some isolated forays into ethics, intellectual property, and governance. Funding for this type of research grew to more than 5% of the National Nanotechnology Initiative (NNI) budget (a budget involving allocations from over two dozen government organizations). However, once the environmental and health (EHS) and outreach components were excluded, it is safe to say no more than 1% of the NNI budget funded societal research, such as justice, economics, policy studies, etc.

Some of the very early work seemed to have been provoked by naysayers who warned about human extermination as rambunctious nanobots havoc the planet in search of feedstock (Drexler 1986; Joy 2000). However, it wasn't long until the publications began taking on a soberer look. Prodded by a small group of non-governmental organizations, such as the ETC Group, Greenpeace, Environmental Defense, and, especially, Friend of the Earth, Australia, more and more articles began appearing in journals and chapters in edited volumes. However, again these publications were dominated by EHS concerns.

Thanks to funding in the social science of nanoscience, there have been many peer-review publications, edited books, and white papers on the social science of nanoscience published in the 1990s to the present providing some insight into the public understanding of nanoscience and nanotechnology. Journals that led the field of the social science of science were Public Understanding of Science, Science Communication, and the Journal of Nanoparticle Research. The Journal of Nanoparticle Research was one of a few scientific journals publishing materials in the social science of nanotechnology. On occasion, Nature, Nature Nanotechnology, and Science publishes an article or two addressing some aspect of societal nanotechnology.

In 2001, one of the first books on societal impacts of nanoscience was released (Roco and Bainbridge 2001). It was loaded with speculation. In response, theoretical and bench scientists wrote damning articles about the hyperbole and called for calmer and more sensible assessments. Of course, the media found value in taking extreme and sometimes fictional accounts and using them a whip-together readership. Soon thereafter, a handful of books discussing societal impacts to nanotechnology appeared in print, including my own in 2006 (Berube 2006).

More universities joined the list of programs receiving SEIN funding, such as Virginia, UCLA, Cornell, Wisconsin, Yale, UC Santa Barbara, and others. In 2005, the NSF decided to fund a Center to study Nanotechnology in Society (CNS). The lead institution in the field became Arizona State University, mostly under the direction of David Guston, currently the director of ASU's School for the Future of Innovation in Society. A partner program was funded at UC Santa Barbara under Barbara Herr Harthorn.

Smaller programs developed elsewhere, such as Washington, Northeastern, Georgia Tech, and North Carolina State but the lead remained with Guston and ASU (Guston 2010). The two CNS sites produced many publications and were responsible for some highly creative efforts.

Social science research has mostly involved surveys on the public understanding of nanoscience. One of the first was done by Cobb and Macoubrie (2004), but soon they were eclipsed with work coming out of Wisconsin from Dietram Scheufele and Dominique Brossard and Yale from Daniel Kahan. Some outreach activities based on modified consensus conferences and citizen juries would survey participants about a range of non-EHS subjects, such as human enhancement (Hamlett et al. 2012).

Initially, research was undertaken using surveys and focus groups, both of which have significant predictive shortcomings. Researchers have found correlations between perspectives on nanotechnology and ideology, religion, and other societal variables. In addition, some researchers learned that cultural mindsets (Kahan et al. 2009) tend to be correlated with certain sensibilities about nanotechnology. For quite a while, we witnessed article after article corroborating these findings. But for very specific applications, the publics were and are less concerned about nanotechnologies than many other risks (Berube et al. 2011; Cummings et al. 2013).

Simultaneously, some researchers employed scraping methods, such as content analysis, to examine how media was covering nanotechnologies in the USA (Friedman and Egolf 2011; Donk et al. 2011) and abroad (Stevens 2005; Donk et al. 2011). Other social scientists studied correlative effects between nanoscience and research funding (Li et al. 2008), scholarly production (Youtie et al. 2008), and patent generation (Meyers 2001) trends within and between countries. Still others studied legal issues linked to nanotechnology (Lacour 2012) as well as policy implications, though most of that research was EHS related as well, an exception is noted for what appeared over time in multiple editions of *Nanotechnology Law and Business*. In terms of specific applications and its interplay with health and safety, food (Yawson and Kuzma 2010; Donk et al. 2011; Brown and Kuzma 2013) and sunscreens (Friends of the Earth 2007; Nohynek et al. 2007; Berube 2008) dominated much of the discussion.

Other social science experts took very different ethnographic perspectives focusing instead on interactions in the labs (Börner et al. 2010) as well as policy development (Shapira and Youtie 2011). Others studied ethics (Mnyusiwalla et al. 2003; Schummer and Baird 2006; Nordmann and Rip 2009; Corley et al. 2016), history (Berube 2006), and even rhetoric (Berube 2004; Selin 2007). Indeed, some researchers began to study how social science and natural science expertise worked at odds or cooperatively in these environments with some of the most productive work coming out of Guston's CNS. Since nanoscience was fundamentally cross-disciplinary, there were some unique opportunities to see how scientists worked with other scientists.

Finally, another group concerned themselves with governance issues (Lin 2006; Linkov et al. 2009; Bosso 2016) to determine how to move regulation as an ongoing process rather than a consequence of planning shortcomings. Largely their work was associated with EHS issues.

What have we learned about nanoscience and nanotechnologies from the small group of social scientists who work in this field? Initially, we learned the public knew very little about nanotechnology. We saw the application of psychometrics and cultural theory that has led us to conclude different categories of publics think differently about nanotechnologies.

Stakeholders and flawed experts

Mostly, the primary consumers of advanced technologies are governments, industries, and publics (this term is used to reflect that many different publics that make up the "rhetorical" public). The roles of publics in consuming advanced technologies involve but are not limited to electing and communicating with representatives in the government who support budgets in turn funding research and development as well as purchasing, boycotting, and protesting the sale of products derived from advanced technologies. In addition, as members of the public sphere, publics are in a partnership with others, such as business and industry, to participate in a grand ecosystem common that helps define what is and is not public property and is and is not public interest.

Public participation in advanced technologies can be viewed as a public good. As advanced technologies become more integrated into society both as consumables and as platforms for other technologies, publics are left to defer to others especially experts, and policy makers who may be expert, but more than not they are no better informed than the publics in understanding advanced technologies.

Nanoscience and nanotechnology, as science and technology, retain a complicated risk profile (Berube 2008). Experts of all sorts testify as to nanotechnology's public benefits as well as public costs and their testimony covers the breadth of concerns from ultra-conservative fears and reservations to bright-eyed hyperbolic claims of nearly indescribable benefits. Trying to determine how understood advanced technologies are by publics is under the purveyance of social scientists that have spent their careers studying trends.

While the publics have their own ways to discern interest and attention, there have been many examples where expert predictions have proved to be notoriously incorrect (Berube and Cummings 2016). We need to understand public needs and concerns and use the full realm of methodologies of the social sciences to determine what they may happen to be.

Challenges

Fundamental paradigmatic barriers may prevent members from one discipline from incorporating knowledge systems from one discipline into another. These barriers are associated with power, static, and noise found in forced association on multiple disciplines in some research initiatives.

A recent publication from Berkeley anthropologist Paul Rabinow who worked with SynBerk (synthetic biology) and anecdotes from colleagues in the social implications of nanotechnology field suggest that interactions between the bench science and engineering community and especially the qualitative social science community have not been as fruitful as anticipated (Rabinow and Stavrianakis 2013).

While there may be instances where maliciousness might explain some of the negative interactions, largely what we are seeing is a systematic disconnect between how scientists and engineers make knowledge and how social scientists make knowledge. What has happened has been the generation of a population of marginal experts who know very little about what interdisciplinary colleagues are doing? Experts who are most problematic are marginal experts who not only do not understand the field of their colleagues but also are least preparing to recognize their own deficiencies.[1]

Consequently, the challenge for mixed disciplinary research and development activities seems to be to find a model that can do more than merely expose one group

[1] Mea culpa. I find I am always second-guessing myself. I am not a formally trained scientist and never have claimed to be. I read as much as I can about the science and technology because I enjoy it. I am asked to review communication on science and technology as part of my duties at NCSU and in the many grants about which I have been associated. While some researchers try to learn about the science about which their scientist colleagues are engaged, many simply do not. How this impacts communication between scientists and social scientists remains an important concern and a rich field of study.

of experts to another group of experts' principles and practices and expect transference to occur sufficiently to affect the others' field. While practitioners in societal research might claim their efforts are more than mere exposure, the exercises remain limited in both populations involved as well as the extent of the exposure. Models for transfer need to be iterative and longitudinal in nature. The communication needs between actors in the mixed disciplinary work must be sustained and fluid where weaknesses are addressed quickly and self-interest is minimized.

Experts and expertise

There is a recurring and seemingly increasing problem with experts. In the process of triaging, the data sets for a life cycle analysis (LCA) project (Berube 2013a); we were underimpressed with the studies that have been used to set risk profiles to nanoparticles. This finding was much like observations made nearly a half decade ago (Berube 2008) that some critics of applied nanotechnology were using risk profile shifts to enhance their arguments. They tend to select egregious applications that never get to market, or a special exposure scenario reinforced by a toxicological protocol that meet their argumentative challenge rather than an application or exposure that best described the instantiation at hand, for example, excessive installation or other exposure scenarios to very large quantities of nanomaterials.

Back to LCA for a moment, we could find no LCA platform entertaining variables such as justice, sustainability, and prosperity. They were profoundly incomplete when it came to societal issues. Second, the data we needed was seemingly unavailable and generating the data was inconceivably expensive and exhausting. As such, current LCA algorithms stumble along, doing their best, pumping out results neither valid nor reliable. As such, the assessments would turn to expert opinion for data or risk speculation culled from years of experience with nanomaterials. Given the choice of using a database made by the expert community or the induction made by an expert, there is very little evidence one is much worse than the other is, as we shall see below.

There has never been a greater need for experts. In our overly complex and uncertain world, we need information about a plethora of subjects about which we know very little. Presumably, experts are a category of stakeholders that are more trustworthy than others are, especially when those others involve stakeholders with a stake in the outcome of our assessment. Experts are trained and when they confront uncertainties, they draw from their training to supplement and contextualize the experimental data rather than to depend on it. Experts are more than conduits of information and regurgitators of databases. They are knowledgeable forecasters and may be more reliable than are some of our databases (Ayyub 2001).

There will always be people calling themselves experts in and outside of nanoscience, self-described and self-appointed as well as those who are socially sanctioned and called experts by other. It allows people who like to categorize to salute people who agree with them as knowledgeable or who seem to be interested and presumably competent in some often-esoteric finite set of knowledge. Of course, experts perform expert functions in a variety of settings, like testifying in a trial proceeding or serving on the editorial staff of professional journals. This article is less about them than it is about what they purport to have: expertise.

If there is a continuum along which we can situate expertise, it runs from non-experts to experts. Non-experts have opinions and attitudes, but they are underinformed and unlikely to be evidenced from data. Experts draw from experiences in a data-rich environment. They seldom make claims they cannot evidence and when they speculate they identify what they say as speculation and usually detail the grounds upon which the speculation is based. Between non-experts and experts is a peculiar world populated by people who represent themselves as experts when they have little right to do so.

Experts are rare, and they are valuable. Employing expertise from actual experts is seldom free unless the expert feels compelled to offer his services pro bono. Fools and charlatans as well as miscreants and monsters populate this "gray" area between non-experts and experts, when they impersonate experts to represent their own best interests and not those of others, oftentimes, when the public interest crosses with their own it is serendipitous.

Experts are rare in the media. When the budgets for expensive network news divisions on television were slashed to make network and cable news cost-efficient, we lost researched news stories, to reporting rumors from "leaks" and "inside sources" or to featuring opposing experts yelling at each other, performing rather than reporting. Often the same set of "experts" appear all over the television screen from one program to another providing ideologically biased diatribes. Experts may be rarer on the internet where likes have replaced peer review.

State of expertise

Initially, there is simply too much data (Weinberger 2011). Having spent many months on a grant working on data triage involving a large database on threats from terrorism, it became clear the tools we use to triage data are clumsy and prejudiced. Despite best intentions and efforts, what generally happens is that new research appears on the horizon that challenges orthodoxy and often it assumes primacy over what we may have known? Learning about unknown knowns, known unknowns, and unknown unknowns skews our analyses. Since most generated data from published research has a short half-life, we tend to have analyses that are nothing better than historical artifacts.

"The amount of technical information is doubling every two years. For students starting a 4-year degree, this means that half of what they learn in their first year of study will be outdated by their third year of study" (Dickerson 2017). Terms like "info-xication" (Chamorro-Premuzic 2014) and "infobesity" (Rogers et al. 2013), and other clever terminology dominate the world Toffler warned us about 45 years ago. We are a world in shock! (Toffler 1970).

Nanoscience has been plagued with expertise issues, especially the field of nanotoxicology. As an emergent health science with its attendant uncertainties, we see article after article published in renowned journals that draw nearly contradictory conclusions about the health and safety risk signature of a nanoparticle. For the naive researcher, this can be wholly disconcerting. Nanoscience and any associated emerging scientific subdiscipline will confront phenomena such as aforementioned for many years until data and its generation pass through iterative standardization. It seems we may have many years to go before we reach that condition in the nanosciences.

It has been challenging to develop criteria to separate experts from less than expert. Experts are expected to survive the process of peer review and introduce new ideas into the thinking commons. Traditionally, they write and publish articles and books. They survive critical review and their ideas move from ideas to knowledge. Traditionally, we use an informal algorithm inserting weights like citation records, awards, reviews, etc. to glean experts from less than expert. However, a series of reports and articles have surfaced that seriously challenge the concept of expertise in terms of research and publication records, the sine qua non of expertise.

Researching the world of expertise can be depressingly halting, if not downright paranoiac, for an academic. For example, Dunning (2011) and others drew conclusions such as people who claim to be experts often are not, the same "less than expert" claim to know more than they do, real experts assume non-experts are smarter than they are and underestimate their own expertness, and real experts are often uninterested or too busy to be bothered with policy, whether it is policy at the workbench or in the halls of Congress. Trying to get a bench scientist to leave his laboratory to address an audience composed of people who are not in the bench scientist's discipline is difficult to do. They tend to be very busy and generally uncomfortable speaking to audiences unfamiliar with their work and their discipline. In addition, this phenomenon tends to frustrate and isolate interdisciplinarians from engaging bench scientists. Those experts who volunteer to speak are sometimes untrained to do so or tell science stories near the very edge of their expertness given their amount of free time often highly rare for a hard-nosed bench scientist. While there are exceptions, they tend to be remarkable.

Here is some of the data issues. Unfortunately, there is only space herein to examine only three sets of effects: over-solicitation, fraud and retraction, and the decline effect. Though there are more, they need to wait for another article and please keep in mind neither the sciences nor the social sciences are not immune from these biases, including nanoscience.

First, there is over-solicitation. It may be time to reexamine expertise as a conceptual phenomenon. Our technical publications have not done a creditable job as gatekeepers. For example, Kastenakes reported that over half of scientific journals accepted fake research papers. Even our conferences are not able in some instances to screen out a gobbledygook paper (Ball 2005). Explosively proliferating profit mills for pseudo-academic works are increasing and encouraged via predatory online journals that will print anything for a fee. According to Colorado's Jeffrey Beall, there are 4000 predatory journals representing nearly a quarter of all open-access journals (Kolata 2013).

Recently, a presumably peer-reviewed counterfeit cancer study was accepted by 70% of 106 journals with only PLOS One noting flaws in the bogus study before rejecting it (Vergano 2013). Springer and IEEE removed more than 120 papers from their subscription services after they were revealed as computer-generated nonsense (van Noorden 2014).

Second, there are *fraud*, *retraction*, and the *persistence of contradicted claims*. While there is honest error such as errors in sample or data, scientific mistakes, and disputes over attribution, there are intentional misconducts: data fabrication, violating ethical protocols, duplicate submissions, and plagiarism. Beyond that, we have some gray areas involving unverifiable information and irreproducibility. Cerejo (2013) reported a major negative shift in the reasons for retraction over the last 30 years. Beyond claims involving better tracking and increasing vigilance affected in some part by digital publication, there seems to be few developments to secure scholarship. While a Journal of Medical Ethics study found only about 25% of retraction were due to fraud in 2000–2010, a PNAS study by Fang et al. (2012) linked two thirds of retraction since 1977 to fraud. Since 2001, the number of retractions has leapt more than 15-fold, data compiled for The Wall Street Journal by Thomson Reuters reveal. Just 22 retraction notices appeared in 2001, but 139 in 2006 and 339 last year. Through 7 months of this year, there have been 210, according to Thomson Reuters Web of Science, an index of 11,600 peer-reviewed journals worldwide (Naik 2011). Furthermore, most of these retractions are due to fraud or expected fraud and not error (Fang et al. 2012). According to MIT's Maxwell Krohn, co-creator of the SCIgen program, there is an academic underground where everyone seems to benefit, but they are wasting time and adding nothing to science (Sample 2014).

A completely new form of fraud surfaced in 2012. Retraction Watch discussed the practice of editors allowing authors to suggest their own reviewers, which resulted Hyong-In Moon reviewing his own work by corresponding via created e-mail addresses that an author could control (Oransky 2012). Recently, SAGE retracted 60 articles involving a peer-review citation ring (Oransky 2014) involving the creation of multiple submission ad reviewer accounts. SAGE reported 130 fake accounts seemed to have been involved in the ring (Newman 2014).

What effect does retraction have on literature accuracy? First, it is important to note that nearly a third of retracted papers are not noted as retracted (Steen 2011). Second, it is equally important to note that retracted papers are often cited in future publications by different experts perpetuating the questionable results and extrapolated implications. Third, the time it takes for a retraction has increased significantly between 2000 and 2009 (Steen 2011). In addition, most importantly, retraction does not seem to have the same effect on different populations. While climate deniers were aghast about the East Anglia ClimateGate incident, Wakefield not only had his article on the association between autism and inoculations retracted but he lost his medical license and the issue remains controversial. While the Tribecca film festival in 2016 removed Vaxxed: From Cover-Up to Catastrophe, the Wakefield directed propaganda documentary lauding a purported Center for Disease Control whistleblower reifying many of Wakefield and his followers unsupported claims (Oransky 2016).

Finally, there is decline effect. This effect surfaced when Jonathan Schooler wrote a brief article in Nature (Schooler 2011) in which he defined this phenomenon as the *diminution of results* as studies are replicated, part self-correction, regression to the mean. "Replication is viewed as grunt work. Honors and achievement in science go to those who publish new, startling results, not to those who confirm—or is confirmed—old ones" (Adler 2014). This problem is hardly unique to the social sciences. Amgen reported that in search of new drugs, they selected 53 promising basic-research papers from leading medical journals and attempted to reproduce the original findings with the same experiments. They failed nine times out of ten (Adler 2014).

As such, we have the associated *single study effect*. Duke's Nina Strohminger complains "…we live in an age that glorifies the single study. It's a folly perpetuated not just by scientists, but by academic journals, the media, granting agencies—we're all complicit in this hunger for fast, definitive answers" (Adler 2014). Of course, the fastest way may be to skip the research altogether and just make up the results. However, if that is too much like the Wild West, you can peek at your data and stop when you have gotten the results you want.

These biases lead to an underappreciation of negative results. One of the few journals publishing negative results, BioMedicine's Journal of Negative Results, has closed its doors in September 2017. Databases are drawn from publications that reflect overclaims rather than conservative findings. Grant officers and academic councils reward outrageous claims as well. More narrowly defined databases and subject-specific repositories to improve the record of unpublished research before we can know how well the current scientific process, based on peer review and experimental replication, succeeds in distinguishing grounded truth from unwarranted fallacy.

Some recommendations

What should be on the social science of nanoscience agenda in the first quarter of the twenty-first century? There are at least five priorities for the social science of nanoscience and nanotechnology.

First, we need to understand why publics cognize nanotechnologies the way they do. Rather than understand "what" publics feel, we need to move to "why" publics feel the way they do about nanotechnology. This involves the functions of attitudes and beliefs and their interaction that may help us predict behavior (Fishbein and Ajzen 2015). Largely, these are experimental designs (Webster and Sell 2005) rather than surveys. Collecting data is the currency of experimental design in the natural sciences and contemporary social science research as well. Broad conclusions about communities and subcultures of publics provided little useful information for managers of science and technology in government and industry. It might be time for government and industry to commit itself to developing data-based expertise in communicating risks of all sorts to publics. This effort would encourage experimental research in communicating risks before crises are upon us. Risk communication is much less expensive, in pecuniary and a host of other terms, than crisis communication.

Second, the interaction between governance and publics needs to be understood in cross-national settings (Rothlauf 2015). Paths of interaction between regulators, researchers, and consumers need to be modeled to enable the construction of predictive and evaluative algorithms. We need to understand the cross-national macroeconomics of advanced technologies and the roles played by government and industry in research and development (Romig et al. 2007). The promotion of science and technology remains controversial yet with the extensive delay in return on investment, some common investment in new technologies may be inevitable. It is time to begin to gather data on how productive funded research has been in moving nanotechnology forward.

Third, it would be useful to comprehend how different players interact in laboratory and commercial settings by continuing to embed social sciences and the public into places scientists and engineers work (Guston 2010). This organic work may provide information that we can use to address a whole gamut of wicked and sticky problems we may come to confront. In addition, databased social science has evolved over the last half-century to a point where marketing of a technology can be done with some assurance of confidence. Marketing does not mean mindless or conspicuous consumption. While much is marketed that does not have a true societal benefit, a lot is marketed which does.

Fourth, it might be important to attend to if not reexamine what we know about media as the internet and its social/digital nature continue to mature (Internet Society 2017). Ask ourselves, where do we get expertise these days? All the research concludes digital media, though some of the time the primary source is traditional media, like newspapers, now found on line. Digital media includes a broad swath of potential information sources. There are news feeds and accumulators that organize the news you have requested to be packaged and delivered to your platform of choice. Information availed to publics about advanced technologies, including nanotechnology, are found in online public forums rather than in traditional media settings. This trend will continue as media moves from its traditional print and video formats to multifarious digital formats. There are a seemingly infinite number of online webpages created by anyone with internet access and a domain name. There remain some blogs by the highly opinioned and vidblogs for those who with the wherewithal to produce them. We have YouTube and its offspring that include capsulations of ideas and comments of varying quality in video format, sometimes with commercials, and often with annoying musical accompaniments. Twitter allows you to provoke and run. Finally, we have social media: though the list is nearly endless as well, it remains dominated by Facebook and LinkedIn. If Facebook were a nation, its size would rank it third.

Fifth, it is ironic that Drexler who provoked so much controversy also presaged an important opportunity: foresight. Guston and Sarewitz (2002) touted real-time technology assessment. We found ourselves entrenched in trying to produce a way for real-time life cycle assessment. The way around problems with expertise and experts might be forecasting. We may be able to employ forecasting protocols to avoid the biases with a broad array of forecasting tools (Ayyub 2001; Tetlock and Gardner 2015).

Closing thoughts

What have we learned? We fail as social scientists when we participate as the conscience of the scientists. They are aware of their failures and we must be with our own. Haranguing them does not help. We fail when all we do is generate user data and even worse concatenate public opinions, which reflect very little understanding from the public. They tend to rise to the occasion responding to surveys with what they think the survey team wants to hear all the while unwilling to admit their own ignorance. We fail when we package databases that are more often than not very dissimilar and unreplicated, and when we categorize public sensitivities under broad ill-defined demographic features. We fail when we allow ourselves to be used as window-dressing amplifying the idea social science works well the scientist. We fail were we take on a title without adequate support for release time, support staff, and experiments.

We more often succeed when we are integrated into the projects and serve as an equal partner in program management and decision-making. We succeed when we are able to spend quality time in experimental communities testing the precepts of theories like "team science." We succeed when we integrate completely new ways of evaluating risk assessment into the algorithms science uses to evaluate what it does.

Unfortunately, success takes time, energy, and money. The stakeholder community cannot wait for us to change protocols and priorities. The event horizon of emerging technology, especially nanotechnology, is upon us. We will need to take what we have learned and do our best. However, taking what we know may not be the best that we can do. There has never been a more important moment to engage social science to help solve the problem of facts in the twenty-first century though ever the social scientist must stay vigilant over its own weaknesses and failures.

Grants can be onerous. They are made worse when the role you play is window-dressing. Having written on the subject (Berube 2013b) and been the social scientist on many different nanoscience and nanotechnology grants, choose to participate in a grant if and only if you are given respectful space and influence. As a social scientist, integrate yourself into the science community. Try to learn what dedicated scientists in the field are up to, read what they publish, spend time with them and ask them questions, and try to make certain that the organizational structure of your team includes you in the top tiers of management.

While some may argue that social science is underfunded in federal and private grant support, others have insisted it is waste of money. On balance, the expense of a social science research project is minute when compared to the investments made in science and technologies. However, without this research we guess what we should do. A more empirical approach might be both more amenable to our scientific colleagues in the sciences as well as policymakers who design how the future should be built. Before we invest fortunes in technologies the publics may not want or need, it is our duty as scholars to understand as well as we can the susceptibilities and sensibilities of scientists and the public.

If we return to the first line of this piece, we may want to conjecture whether the future will be populated with issues that may be wicked and sticky or not. With the advent of technological convergence and deep ecosystem analysis of the profound changes ushered in by globalization, it seems easy solutions to easy problems may be a historical artifact. Complexity has begun to dominate the lives we live and how we interact with technologies of all sorts including nanotechnologies. Maybe it is time to develop new toolsets.

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Compliance with ethical standards

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References

Adler J (2014) The reformation: can social scientists save themselves. Pacific Standard. May/June. http://www.psmag.com/navigation/health-and-behavior/can-social-scientists-save-themselves-humanbehavior-78858/. Accessed 7 Oct 2014

Ayyub B (2001) Elicitations of expert opinions for uncertainty and risks. CRC Press, NY

Ball P (2005) Computer conference welcomes gobbledygook paper. Nature 424:946

Berube D (2004) The rhetoric of nanotechnology. In: Baird D, Nordmann A, Schummer J (eds) Discovering the nanoscale. IOS Press, Amsterdam, pp 173–192

Berube D (2006) Nano-hype: the truth behind the nanotechnology buzz. Prometheus Books, Amherst

Berube D (2008) Rhetorical gamesmanship in the nano debates over sunscreens and nanoparticles. J Nanopart Res 10:23–37 & Reply from David Berube. Journal of Nanoparticle Research. 2008. 10:265-266

Berube D (2013a) Socialis commodis and life cycle analysis: a critical examination of uncertainty. In: Savage N, Gorman M, Street A (eds) Emerging Technologies: Socio-Behavioral Life Cycle Approaches. Pan Stanford Publishing, Singapore, pp 139–163

Berube D (2013b) The grant landscape for communication scholars. Spectra 49(4):22–25

Berube D, Cummings C (2016) Convergence in ethical implications and communication of emerging technologies. In: Roco M, Bainbridge W (eds) Handbook of science and technology convergence. Springer International Publishing, Switzerland, pp 755–766

Berube D, Cummings C, Frith J, Binder A, Oldendick R (2011) Comparing nanoparticle risk perceptions to other known EHS risks. J Nanopart Res 13(8):3089–3099

Börner K, Contractor N, Falk-Krzesinski H, Fiore S, Hall K, Keyton J, Spring H, Stokols D, Trochim W, Uzzi B (2010) A multilevel systems perspective for the science of team science. Sci Transl Med 2:49 http://stm.sciencemag.org/content/2/49/49cm24.short. Accessed December 31, 2017

Bosso C (2016) Settling into the midstream? Lessons for governance from the decade of nanotechnology. J Nanopart Res 18:163. https://doi.org/10.1007/s11051-016-3451-9

Brown J, Kuzma J (2013) Hungry for information: public attitudes toward food nanotechnology and labeling. Rev Pol Res 30(5):512–548

Cerejo C (2013) What are the most common reasons for retraction? Editage Insights. 16 October

Chamorro-Premuzic T (2014) How the web distorts reality and impairs our judgement skills. The Guardian. Retrieved 15 June 2016

Churchman CW (1967) Wicked problems. Manag Sci 14(4):B141–B142

Cobb MD, Macoubrie J (2004) Public perceptions about nanotechnology: risks, benefits and trust. J Nanopart Res 6(4):395–405

Corley EA, Kim Y, Scheufele DA (2016) Scientists' ethical obligations and social responsibility for nanotechnology research. Sci Eng Ethics 22(1):111–132

Cummings C, Berube D, Lavelle M (2013) Influences of individual-level characteristics on risk perceptions to various categories of environmental health and safety risks. J Risk Res 16(10):1277–1295

Dickerson D (2017) Are we keeping pace as leaders? April 21. https://dougdickerson.wordpress.com/2017/04/21/are-we-keeping-pace-as-leaders/. Accessed 13 Nov 2017

Donk A, Metag J, Kohring M, Marcinkowski F (2011) Framing emerging technologies: risk perceptions of nanotechnology in the German Press. Sci Commun 24(1):5–29

Drexler KE (1986) Engines of creation: the coming era of nanotechnology. Doubleday, NY

Dunning D (2011) The Dunning-Kruger effect: on being ignorant of one's own ignorance. Adv Exp Soc Psychol 44:247–296

Fang FC, Steen RG, Casadevall A (2012) Misconduct accounts for the majority of retracted papers. PNAS 109(42):17028–17033

Felt U, Fouché R, Miller C, Smith-Doer L (2016) The handbook of science and technology studies, Fourth edn. MIT Press, NY

Fishbein M, Ajzen I (2015) Predicting and changing behavior: the reasoned action approach. Psychology Press, Oxfordshire

Friedman S, Egolf B (2011) A longitudinal study of newspaper and wire service coverage of nanotechnology risks. Risk Anal 31(11):1701–1717

Friends of the Earth (2007) Nanotechnology & sunscreens: a consumer guide for avoiding nanosunscreens. Available http://www.foe.org/nano_sunscreens_guide/Nano_Sunscreens.pdf. Cited 29 Sept 2007

Guston D (2010) Societal Dimensions Research in the National Nanotechnology Initiative. CSPO Report # 10–02. http://cspo.org/legacy/library/100701F7WL_lib_CSPOReportGuston.pdf. Accessed 13 Dec 2017

Guston D, Sarewitz D (2002) Real-time technology assessment. Technol Sci 24(1–2):93109

Halloran J (2010) 1.2 What is scientific about social science? https://www.le.ac.uk/oerresources/media/ms7500/mod1unit2/page_03.htm. Accessed 18 Dec 2017

Hamlett P, Cobb M, Guston D (2012) National citizens' technology forum: nanotechnologies and human enhancement. Springer, Dordrecht

Harvard Kennedy School (2013) What is STS? http://sts.hks.harvard.edu/about/whatissts.html. Accessed 18 Dec 2017

Heath C, Heath D (2007) Made to stick: why some ideas survive and others die. Random House, New York

Internet Society (2017) Internet society global interim report 2017: paths to our digital future. Internet Society, Reston

Jasanoff S, Markle G, Peterson J, Pinch T (eds) (1995) Handbook of science and technology studies. Sage Publications, Thousand Oaks

Joy B (2000) Why the future doesn't need us. Wired

Kahan D, Braman D, Slovic P, Gastil J, Cohen G (2009) Cultural cognition of the risks and benefits of nanotechnology. Nat Nanotechnol 4:87–90

Koenig B (2015) Symposium: should we offer genomic research results to a participant's family, including after the participant's death? The journal of law. Med Ethics 43:3

Kolata G (2013) Scientific articles accepted (Personal checks, too). The New York Times. April 7. http://www.nytimes.com/2013/04/08/health/for-scientists-an-exploding-world-of-pseudoacademia.html?pagewanted=all&_r=0. Accessed 7 Oct 2014

Lacour S (2012) Emerging questions for emerging technologies: is there a law for the nano? In: Brayner R, Fiévet F, Coradin T (eds) Nanomaterials: a danger or a promise? A chemical and biological perspective. Springer, Dordrecht, pp 357–378

Li X, Hu D, Dang Y, Chen H, Roco M, Larson C, Chan J (2008) Nano mapper: an Internet knowledge mapping system for nanotechnology development. J Nanopart Res 11(3):529–552

Lin A (2006) Size matters: regulating nanotechnology. Harvard Environmental Law Review. 31. UC Davis Legal Studies Research Paper No. 90. Available at SSRN: https://ssrn.com/abstract=934635

Linkov I, Satterstrom F, Monica J, Foss S, Davis T (2009) Nano risk governance: current developments and future perspectives. Nanotechnol Law Bus:203–220

McEwen JE, Boyer JT, Sun KY, Rothenberg KH, Lockhart NC, Guyer MS (2014) The Ethical, Legal, and Social Implications Program of the National Human Genome Research Institute: reflections on an ongoing experiment. Annu Rev Genomics Hum Genet 15:481–505
Meyers MS (2001) Patent citation analysis in a novel field of technology: an exploration of nanoscience and nano-technology. Scientometrics 51(1):163–183
Mnyusiwalla A, Daar A, Singer P (2003) Mind the gap: science and ethics in nanotechnology. Nanotechnology 14(3):R9–R13
Naik G (2011) Mistakes in scientific studies surge. The Wall Street Journal. August 10. http://online.wsj.com/news/articles/SB10001424052702303627104576411850666582080. Accessed 19 June 2014
Newman L (2014) A journal is retracting 60 papers because of peer review fraud. Future Tense: The Citizen's Guide to the Future
Nohynek G, Lademann J, Ribaud C, Roberts M (2007) Grey goo on the skin? Nanotechnology, cosmetic and sunscreen safety. Crit Rev Toxicol 37(3):251–277
Nordmann A, Rip A (2009) Mind the gap revisited. Nat Nanotechnol 4:273–274
Oransky I (2012) Retraction count grows to 35 for scientist who faked emails to do his own peer review. Retraction Watch. September 17. http://retractionwatch.com/category/by-author/hyung-inmoon/. Accessed 7 Oct 2014
Oransky I (2014) SAGE Publications busts "peer review and citation ring," 60 papers retracted. Retraction Watch. July 8. http://retractionwatch.com/2014/07/08/sage-publications-busts-peer-reviewand-citation-ring-60-papers-retracted/. Accessed 7 Oct 2014
Oransky (2016) Tribecca Film Festival pulls Wakefield vaccine film from schedule. Retraction Watch. March 26. http://retractionwatch.com/2016/03/26/tribeca-film-festival-pulls-wakefield-vaccine-filmfrom-schedule/. Accessed 28 Mar 2016
Rabinow P, Stavrianakis A (2013) Demands of the day: on the logic of anthropological inquiry. University of Chicago Press, Chicago
Rittel HWJ, Webber MM (1973) Dilemmas in a general theory of planning. Policy Sci 4(2):155–169
Roco M, Bainbridge WS (eds) (2001) Societal implications of nanoscience and nanotechnology. Washington, DC: NSF. http://www.wtec.org/loyola/nano/NSET.Societal.Implications/nanosi.pdf. Accessed 31 Dec 2017
Rogers P, Puryear R, Root J (2013) Infobesity: the enemy of good decisions. http://www.bain.com/publications/articles/infobesity-the-enemy-of-good-decisions.aspx. Accessed 13 Nov 2017
Romig A, Baker A, Johannes J, Zipperian T, Eijkel K, Kirchhoff B, Mann H, Rao C, Walsh S (2007) An introduction to nanotechnology policy: opportunities and constraints for emerging and established economies. Technol Forecast Soc Chang 74(9):1634–1642
Rothlauf J (2015) A global view on intercultural management: challenges in a globalized world. Walter de Gruyter GmbH & Co KG, Berlin
Sample I (2014) How computer-generated fake papers are flooding academia. The Guardian. February 24. http://www.theguardian.com/technology/shortcuts/2014/feb/26/how-computer-generated-fakepapers-flooding-academia. Accessed 7 Oct 2014
Schooler J (2011) Unpublished results hide the decline effect. Nature 470(4):437
Schummer J, Baird D (2006) Nanotechnology challenges: implications for philosophy, ethics and society. World Scientific, Singapore
Selin C (2007) Expectations and emergency of nanotechnology. Sci Technol Hum Values 32(2):196–220
Shapira P, Youtie J (2011) Introduction to the symposium issue: nanotechnology innovation and policy—current strategies and future trajectories. J Technol Transf 36(6):581–586
Sismondo S (2003) An introduction to science and technology studies. Blackwell, Oxford
Steen RG (2011) Retraction in the scientific literature: is the incidence of research fraud increasing? J Med Ethics 249–253
Stevens L (2005) News narratives about nano S&T in major U.S. and non-U.S. newspapers. Sci Commun 27(2):175–199
Tetlock P, Gardner D (2015) Superforecasting: the art and science of prediction. Broadway Books, NY
Toffler A (1970) Future shock. Random House, NY
van Noorden R (2014) Publishers withdraw more than 120 gibberish papers. Nature News. http://www.nature.com/news/publishers-withdraw-more-than-120-gibberish-papers-1.14763. February 24. Accessed 7 Oct 2014
Vergano D (2013) Fake cancer study spotlights bogus science journals. National Geographic Daily News. October 3. http://news.nationalgeographic.com/news/2013/10/131003-bohannon-sciencespoof-open-access-peer-review-cancer/. Accessed 7 Oct 2014
Webster M Jr, Sell J (2005) Laboratory Experiments in Social Science. In: Laboratory experiments in the social sciences. Academic Press, London
Weinberger D (2011) Too big to know: rethinking knowledge now that the facts aren't the facts, experts are everywhere, and the smartest person in the room is the room. Basic Books, NY
Yawson R, Kuzma J (2010) Systems mapping of consumer acceptance of agrifood nanotechnology. J Consum Policy 33(4):299–322
Youtie J, Shapira P, Porter A (2008) Nanotechnology publications and citations by leading countries and blocs. J Nanopart Res 10(6):981–986