Ethics in Nano Education, but First the Ethics of Nano Education

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***Abstract*— Discussions of the ethics or societal implications of nanotechnology almost always focus on products (and occasionally manufacturing or experimental processes) which are nano-enabled and/or contain nanomaterials. These discussions are important, but they miss that (literally) the most visible part of nanotechnology involves the reorganization of education at all levels but especially in universities, museums, and community colleges. In general, institutions which have "nano" in their names have spent the 21st century advocating for more interdisciplinary, market-oriented, hands-on, publicly engaged forms of education. Both the benefits and the costs of these educational innovations should be at the center of discussions of the societal implications of nanotechnology. Education is the means by which cultures reproduce themselves; thus education is always sensitive and frequently contested. In this paper I survey the long history of activism and political debate which informs the educational innovations associated with nanotechnology, including the innovation of bringing ethics training into nano education. I argue that ethics does belong in nano education, but to understand why we first need to analyze the ethics of nano education.**

Keywords—societal issues, responsible research and innovation, public engagement, museums, interdisciplinarity, commercialization of academic research

I. Introduction: Becoming Nano (or Not)

About twenty years ago, I began a PhD project on the history of the scanning tunneling microscope and atomic force microscope. Almost all the early pioneers of those techniques were still working at that point, so much of my research involved going and talking to them. When I started conducting interviews for that project in 2000, most of the people I spoke to identified as electrical engineers, applied physicists, surface scientists, polymer chemists, etc. By 2002, however, I started to notice that some of the people I interviewed were beginning to refer to their work as "nanotechnology." Sometimes they used the term with a heavy dose of irony or cynicism, yet even so in the course of just two years "nano" had become a label that an increasing number of probe microscopists felt they needed to link to. This was especially true of the academic and government scientists and engineers I interviewed. At the time, corporate researchers seemed to have less need for the term. That said, many of the academic scientists and engineers in my study were people who had previously worked in industry. That was a common career trajectory among the early probe microscopists, and therefore a career trajectory that seemingly correlated with adoption of the "nano-" label.

I underwent a similar transition almost simultaneously. Because the US National Nanotechnology Initiative (NNI) targeted a percentage (what percentage depends somewhat on how you count, but roughly 4%) of federal nano research funding to go to the social sciences and humanities, an American "social studies of nanotechnology" community arose very quickly around 2003. Funders in other countries had set similar goals, so similar interdisciplinary communities composed of philosophers, historians, sociologists, anthropologists, economists, communications researchers, literature scholars, artists, museum professionals, and others also arose in the Netherlands, Germany, and elsewhere. In 2005 the US National Science Foundation ran a competition for a Center for Nanotechnology in Society, resulting in funding for two major centers, at Arizona State and UC Santa Barbara. I was a founding member of the Santa Barbara center and was affiliated with it through its ten-year run. Thus, having started my PhD not knowing anything about nanotechnology, by the time I started my first academic job in 2007 I was primarily known to my peers as an historian of nanotechnology.

I'm recounting my personal involvement with nanotechnology in parallel with that of my interviewees to give a sense of how the label "nanotechnology" and the organizations, funding streams, journals, etc. which bear that label have real impacts on individuals' education, research, careers, and self-conceptions. Certain questions and contacts presented themselves to me because I was associated with nanotechnology. I'm sure other questions and contacts were made invisible to me for the same reason. On the whole, I benefited quite a bit from the opportunities that came with nano. I gained smart, interesting colleagues and I was exposed to disciplines, methods, and topics I would never have sought out had I not been part of a nano center which was mandated by its funder to promote interdisciplinary communication and collaboration. However, we should be wary of survivor bias. Through hard work but also a significant amount of luck, I have managed to stay in academic positions despite a very tight job market. Many of my peers have not been as fortunate,

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despite working just as hard. I think it is quite possible that there were some people who left academia or their chosen field against their wishes because of changes in the academic system wrought by use of the nano label. These include people excluded from association with nano and its benefits, people who were associated with that label but for whom the negatives outweighed the positives, and people who were doing good work on a topic that could have been cast in the nano mold but who chose not to for whatever reason.

My point is that reorganizing research and education around the concept of nanotechnology, and sticking the nano label on fields, institutions, and ultimately on people has consequences. The course of people's lives has been changed by the institutions of nanotechnology, how people think has been changed, what people value has been changed. There are other institutions in contemporary society which have had much greater effects, and in the end we may well judge that the effects wrought by nano are almost entirely benign. But still, the *existence* of nano institutions has intellectual, moral, and personal consequences which go beyond societal implications of the *products* of those institutions. Ethical reflection on nanotechnology should therefore encompass the existence of nano as much as its products.

The current state of nanoethics, however, focuses more on the output of nano research than its existence. If you look at the journal *Nanoethics*, most articles discuss ethical or societal issues presented by some nano-enabled technology. Quite a few take an "anticipatory" approach by asking how regulation, governance, and design practices could be reformed to ensure that future nano-enabled technologies are more benign [1]. Likewise, if you go to the NNI's website, their discussion of Ethical, Legal, and Societal Issues (ELSI) focuses on "potential benefits and risks of research breakthroughs" [2]. Both the *Nanoethics* and NNI versions of nanoethics ask students and researchers to consider what the consequences of nano-enabled technologies might be, and encourages them to look outward to other stakeholders to anticipate and evaluate those consequences. These are the versions of nanoethics that have been incorporated into formal and informal nano education in museums, community colleges, and universities.

However, relatively few scholars – with exceptions such as Emily York – have considered the ethics *of* nano education, i.e., the issues involved in bringing the goals associated with nanotechnology into formal and informal education institutions in the first place [3]. Later, I will outline what those goals are, but for now the ones articulated by the NNI will suffice: "responsible development of nanotechnology"; "continuing a world-class R&D program; fostering the transfer of new nanotechnologies into products for commercial and public benefit; and educating the workforce, engaging the public, and sustaining an effective nanotechnology R&D infrastructure" [2]. Those are contested goals that require (sometimes significant) modification of the educational institutions which adopt them. Adoption of nano by educational institutions therefore merits ethical reflection and debate. In this article I present some historical reasons that debate has not really appeared; I give some examples of issues in the ethics of formal and informal nano education; and I outline why the viability of nano education requires discussion of these issues.

II. The Early Days of Nanoethics

I was present at some of the early discussions of nano-ELSI shortly after the founding of the National Nanotechnology Initiative (NNI) [4-6]. I've also seen archival documents relating to pre-NNI discussions among leading nanotechnologists (such as the Nobel laureate fullerene chemist Rick Smalley) and some of the people (such as the National Science Foundation's Mihail Roco) who helped found the NNI. In both the pre- and early post-NNI discussions, recent historical examples of public concerns about high-tech products were crucial in molding nano-ELSI research. Roco, Smalley, and their allies were worried that nanomaterials and nano-enabled technologies would stir public controversy in the same way as genetically-modified organisms (GMOs), nuclear power, and reproductive technologies had earlier. In the 1990s, the Human Genome Project had included an ELSI component and had seemingly avoided public outcry despite the long history of controversy over genetic technologies. Adopting ELSI for nano therefore seemed like a winning strategy.

One source of anxiety for early NNI proponents was the recent publication of two high-profile texts that they thought might turn the public against nano: Bill Joy's *Wired* essay "The Future Doesn't Need Us" and Michael Crichton's novel *Prey* [7, 8]. The former argued that nanotechnology and artificial intelligence research would soon yield sentient technologies which could do without humans; the latter portrays a sentient swarm of nano-agents that takes the natural next step of doing away with its human creators. Since both Joy and Crichton explicitly mentioned that they were inspired by the works of Eric Drexler, pro-NNI scientists and civil servants strategized ways to de-legitimate Drexler's views on nanotechnology.

One part of that strategy was using ELSI research to prevent Drexler's ideas from taking hold in the public imagination. As a result, Drexler was a frequent topic and occasional guest at early ELSI events. There is, indeed, much for humanists and social scientists to engage with in Drexler's work. He paints a vivid, readable picture of a world transformed by self-replicating nanoscale programmable automata: a world without limits to resources, human capacities, or even human life [9]. It is easy to see why he struck a chord with a wide audience, and also why the NNI's creators worried that the public would be spooked either by the dramatic changes Drexler envisioned or by the failure of the NNI's program to achieve the spectacular world he imagined.

Drexler himself said little about nano education; at least, any form of nano education that the NNI would recognize. Yet his ideas do tell us something about nano education. First, Drexler himself graduated from a highly interdisciplinary, personalized degree program at MIT in the 1970s that can be seen as a precursor of the interdisciplinary education the NNI today encourages. Second, there is anecdotal evidence that the generation of nanoscientists currently aged 35-55 was indeed inspired by Drexler's writings, even if their current ideas about nanotechnology bear little resemblance to his.

Despite that potential for common ground, however, NNI proponents pushed back on Drexler, in particular through the "Drexler-Smalley debate," conducted in the pages of *Scientific American* and *Chemical & Engineering News* from 2001 to

2003 [10]. There, Smalley criticized Drexler for "scaring our children" with stories of "gray goo," i.e. self-replicating nanobots capable of digesting everything in their path and turning the world into a solid mass of nanobots. Notably, everything in that debate hinged on the outputs of nanotechnology research: are nanobots possible, and if so are they scary? At no point did Drexler or Smalley talk about why one would reorganize research around the concept of nanotechnology, what aims might accompany that reorganization, or what the societal consequences of that reorganization might be.

Early workshops convened under the NNI's auspices that attempted to grapple with nano's ethical, legal, and societal implications also focused almost exclusively on nanomaterials and nano-enabled technologies. In particular, the scientists, engineers, and policymakers in attendance were concerned that engineered nanoparticles such as quantum dots or carbon nanotubes might have (or be perceived to have) toxic effects if ingested or inhaled by humans and/or if released into the environment. This was sometimes presented as putting nano on a "wow-to-yuck" trajectory similar to that of asbestos – a seemingly analogous material which was disastrously oversold only to turn out to have lethal effects [11]. As a result, there has been a significant amount of toxicology research on nanomaterials, the interim results of which have inevitably become fodder for successive ELSI events. Are nanotubes toxic? Would members of the public perceive them as potentially dangerous? Would they perceive the benefits as outweighing the risks or *vice versa* [12]? In part to prevent potential risks from causing a public backlash against nano, museum professionals and practicing scientists and engineers developed a number of creative means of engaging the public – e.g., Science Cafés and annual Nano Days at research centers – in the hopes that a public familiar with nano would be a public that trusted researchers not to poison them [13].

To be clear, I wholeheartedly support nanotoxicology research as well as efforts to communicate about all nanotechnology research through museum exhibits, Nano Days, science cafes, etc. That said, some ELSI researchers argued from the beginning that these efforts rather missed the lessons of past episodes of controversy. GMO foods were banned in European markets not because the European public believed that such foods were toxic; rather, European publics were inclined to listen to claims about the toxicity of GMOs because those publics already associated GMOs with corporations, trade deals, and modes of agriculture they didn't like [14]. That is, negative press about a product is much more likely to lead to public unease if the public already distrusts the institutions associated with the products. Trusted institutions are usually met with forgiveness; the public is often willing to attribute bad news about a product to growing pains. But once public trust in an institution is poisoned, good news about its products has little effect. Indeed, good news about the output of a field of scientific research can actually *decrease* trust, at least among members of the public who have a prior distrust of the institutions of research in that field [15].

III. Nano Education and Public Engagement

Thus, nano-ELSI researchers advocated from the start that scientists and engineers be as open and transparent as possible and involve members of the public in nanotechnology research in a meaningful way in part to generate trust in institutions. A number of concrete methodologies, such as consensus conferences, have been developed to help scientists and non-scientists better understand each other and to foster a sense that they have cooperatively anticipated the consequences of nano-enabled technologies. More generally, Responsible Research and Innovation (RRI) has emerged as an umbrella field for a variety of efforts to help researchers become more engaged with and responsive to the public. Most of the leading early voices in RRI participated in nano-ELSI research; to some extent RRI can be seen as a way of taking techniques developed for nanotechnology and applying them to successive "emerging technologies" as (or before) they become visible to the public. Indeed, a number of institutions associated with RRI, such as the *Journal of Responsible Innovation* and the Society for the Study of New and Emerging Technologies (S.NET – formerly the Society for the Study of Nanoscience and Emerging Technologies), grew out of nano-ELSI. Notably, the European Union adopted RRI as a framework relating to nano research but has since broadened its reach to emerging areas such as synthetic biology, artificial intelligence, geoengineering, etc. [16].

There is reasonable consensus as to the main tenets of RRI: to be "responsible," research and innovation should be (1) anticipatory; (2) reflexive; (3) inclusive; and (4) responsive [17]. I.e., scientists and engineers and those they engage should reflect on the possible future consequences of research; should question their own positions and privileges and how those inform their views on research; should attempt to involve a broad cross-section of those who have a stake in research; and should be open to the shaping of research by that inclusive group of stakeholders. How one actually puts RRI into practice, however, is less clear. That said, a number of new practices – such as asking stakeholders to collectively shape science fiction "scenarios" imagining the consequences of current research – have been developed in line with these RRI tenets [18]. At a few academic institutions, these practices have become an ordinary part of nano research and training. RRI's future is unclear – it has been preceded by a string of similar buzzwords, and could easily be replaced by yet another. But while it's here it is generating interesting developments.

The two strands of nano-ELSI which I've described above (Nano Days and RRI) represent the ends of a spectrum along which most attempts to incorporate ethical and societal issues into nano education fall. At one end of the spectrum, some programs take a rather traditional approach – borrowed from medical and engineering education – of requiring students to take an ethics course oriented to the ethical implications of the outputs of nano research and development. Such courses ask things like "what are the risks posed by nanoparticles in human bodies or in the environment, and how can we use ethical principles to evaluate those risks?" As in bioethics and engineering ethics courses, students learn a few different philosophical schools of ethics and then work through some case studies. At the other end of the spectrum are courses, for example at University College London or Arizona State, which present nano in an RRI framework. Students learn how nano is embedded in society, why that means they should practice in an anticipatory, reflexive, inclusive, and responsive manner, and then are exposed to some of the different techniques for fostering RRI. Many nano and society courses – e.g., at Brown [19], University of Virginia, or one I was involved with at Rice University – fall somewhere between these poles.

Courses which incorporate ethical and societal issues into nano education are valuable, wherever they fall on this spectrum. However, both poles fall short in that they don't confront the ethics of nano education itself. As a result, attempts to make nano research and nano education more responsible have in fact ignored precisely those areas of social life where nano is most visible to the public and has had the most social consequential, and potentially controversial, effects thus far: i.e., institutions of education, both formal (e.g., community colleges and universities) and informal (e.g., museums).

Consider where ordinary citizens encounter the pre-fix "nano." As a point of fact, most citizens, even of countries which do a great deal of nano research, *haven't* heard of nano, (or believe they haven't) [20]. Even if you have heard of nano, opportunities to knowingly encounter it in person are rather rare. Government agencies are happy to let the public know they are working on nano, but the places where they do so – e.g., the National Laboratories – are not ones that many people have contact with. Companies such as Intel do a great deal of nanotechnology research, but tend not to publicize their involvement with nano as such. When you buy a laptop, you're told that it has "Intel Inside" but not that it has nano inside. Indeed, the semiconductor industry's reluctance to use the nano label means that even many ELSI researchers seem not to understand that the semiconductor industry is one of the largest and most politically influential nano industries.

Universities and science museums, however, loudly proclaim their connection to nano, and do so to quite large audiences. If you have a child attending a university, they might tell you about the nano course they are taking or nano research they are doing. If you have been physically present on a university campus, you've probably seen "Nanotechnology" in the name of a building you've passed. If you are an alum of a university, there's a good chance you've seen nano mentioned in communications directed at your alma mater's graduates [21]. Nano today is part of academic branding.

The same is true for institutions of informal nano education. The museums and other organizations participating in the Nanoscale Informal Science Education Network claim to reach 11 million people per year [22]. That network, incidentally, became the National Informal STEM Education Network in 2016 – another good example of how institutional changes made to support nanotechnology are now being applied to ever broader domains. Now, I'm an enthusiastic visitor to science museums and I applaud the NSF for supporting the NISE Net, but I also recognize that reorganizing "informal STEM education" around the nano label is not an apolitical move. NISE Net and its partners do a good job of bringing discussion of societal issues into informal nano education, but don't – as far as I know – confront the societal issues arising *from* informal nano education.

Here's an example of the kind of issue I mean: while NISE Net content does promote fundamental research, any content which orients its audience to nano*technology* inherently puts a premium on novel technological artifacts that are rooted in nano research. However, many of the countries which sponsor nano research currently face a political dilemma: they need investment in maintaining old infrastructure and building new *low-tech* infrastructure in order to improve their economies and mitigate climate change, yet there is little political will to invest in infrastructure because politicians and much of the public have been captured by innovation discourse [23]. By presenting content on nanotechnology, museums choose to participate in an innovation agenda rather than a maintenance or low-tech infrastructure agenda. That's a political and ethical choice which should be reflected upon. I.e., there should be a discussion of the ethics *of* informal nano education *before* discussion of ethics *in* informal nano education.

IV. The Ethics of formal Nano Education

On the formal education side, the ethical and societal questions raised by nano education *per se* are probably most evident with regard to community colleges. As Amy Slaton and Mary Ebeling have documented, community colleges have been using the promise of vast numbers of jobs in "nanotechnology-based manufacturing" to entice students since the late 1990s [24]. The Pennsylvania Nanofabrication Manufacturing Technology Partnership (PaNMT), for instance, was formed in 1998 and today claims that there are twenty-six Pennsylvania colleges and universities offering about thirty different associate degrees in nanomanufacturing. These degrees exist because enough students have been convinced to pay at least five-figure tuitions in hopes of landing one of the seven million nanotechnology jobs in the US that the NNI promised would materialize by 2015 [25].

Slaton and Ebeling argue that an associate degree in nanomanufacturing is not an advantageous or even relevant qualification for anywhere near that many jobs. Moreover, the few jobs for which such a degree might be relevant are geographically concentrated in regions far from most institutions offering nanomanufacturing associate degrees. It's likely students are enrolling in these degree programs in the belief that nano jobs are as widely distributed (and therefore locally available) as the jobs connected to associate degrees in, say, medical care, construction, automotive repair, culinary arts, or bookkeeping. In fact, though, most graduates would have to leave their home regions to find one of the few jobs for which an associate degree in nanomanufacturing would be relevant. Such associate degree programs often claim to cover "global and ethical engineering issues." That's salutary, but if Slaton and Ebeling are correct then it seems rather obvious that questions of ethics should've been raised *before* the founding of these degree programs, rather than covered *in* their curricula.

At the university level, meanwhile, the ethical and societal issues involved in nano education are perhaps less evident, but still ought to demand reflection. Obviously, there is a great deal of variation in how the United States' 334 research universities

(R1, R2, and R3) implement nano education, not to mention variation in how the concept is applied internationally. Still, from my own personal experience I've seen the following aims uniformly accompany the introduction of the nano label into a university center, institute, department, or degree program.

- Interdisciplinarity
- Public outreach
- Commercialization (or "tech transfer" or "translational research")
- Public-private partnerships
- STEM education and STEM diversity
- Hands-on pedagogy (or "design-oriented" or other terms indicating that undergraduates will build *stuff* while, or perhaps before, they receive a grounding in basic theory)

Less anecdotally, Hyungsub Choi and I have shown that objectives such as interdisciplinarity and cooperation with industry have long histories in US universities, and that the introduction of new research banners (e.g., materials science in the 1960s, nano in the 1990s and 2000s) have repeatedly been used as vehicles for moving these aims into universities [26]. No doubt many readers would come up with a slightly different list, but I think it likely that most readers who have participated in setting up an academic nano institution will have heard these phrases (or their cognates) many times.

Often, nano institutions incorporating these aims contain an ELSI component which invites humanists and social scientists such as myself to participate – for which I'm immensely grateful (see the acknowledgements below). But in my experience and my historical research I've seen that by the time ELSI is brought in, these aims are baked into the cake and therefore not fully open for debate. For instance, I've never seen a discussion of how to organize academic nano research in which the mandate to promote interdisciplinarity was seriously debated. Such discussions sometimes acknowledge that interdisciplinary research can be hard to do and evaluate. More humane administrators note that the challenges of interdisciplinarity fall hardest on young people since their tenure cases are more fraught than their monodisciplinary colleagues'. But I have never seen those challenges treated as anything other than bumps to be smoothed out with creative thinking. The possibility of rejecting interdisciplinarity, or even of reflecting on it as an ethical choice, is rarely available. Yet historians and sociologists have shown that interdisciplinarity always has a politics which should elicit reflection and debate *before* instituting an interdisciplinary curriculum for nano education [27, 28].

V. The Stakes and Stakeholders

Likewise, the other academic nano aims I've listed are usually accompanied by agendas in which there are winners and losers and the possibility exists for both intended and unintended consequences. Thus, these are the kinds of aims that should merit an anticipatory, reflexive, inclusive, responsive discussion before, during, and after their implementation. Some of the phrases in my list are self-evidently prone to controversy. For instance, much ink has been spilt attacking and defending the commercialization of academic research (and, occasionally, taking a middle path) [29-31]. With other aims, though, it may be harder to see what's controversial.

Public outreach, in particular, sounds unobjectionable. Yet historians and sociologists have criticized the mandate for public outreach from two, perhaps contradictory, directions. On the one hand, it can be seen as a strategy for "selling" the public on science and inculcating deference to scientific authority [32]. On the other hand, forcing scientists to explain themselves to the public disciplines them to avoid research topics the public finds unexciting or controversial and instead mold their research to give the market what it wants [33].

The ambiguities of public outreach indicate that reflection and inclusive debate on the organization of nano education is necessary, but also that it will be extremely difficult. It is through education, after all, the cultures reproduce themselves; whoever controls education controls which version of their culture is reproduced. Education is therefore inherently political. In many of the countries that lead in nano research, consensus is breaking down and politics are becoming more polarized. That polarization confronts education and research at least as much as other societal domains. When nano is used as a way to import the aims listed above into an academic institution, that institution risks losing public trust on all sides of the growing political divide.

Consider the not terribly hypothetical example of an academic nano center that includes the phrases I've listed above in its mission statement. Political conservatives may well object to the center's emphasis on fostering diversity in STEM fields and its heavy reliance on public funds. Those on the left, meanwhile, may well distrust the center for its emphasis on commercialization and its willingness to help private firms profit from publicly-funded research. People with arts backgrounds may decry the ideology of "STEM," which bears at least some responsibility for recent declines in teaching positions in arts and humanities in high schools and universities. People with science backgrounds, meanwhile, may well complain about having to do public outreach and having to de-emphasize fundamental disciplinary concepts (while prioritizing hands-on design) in their curricula. There's something for almost everyone to like *and* to dislike in these aims. That means that the grounds exist for almost everyone to trust *or* distrust our hypothetical nano center.

Applying the principles of RRI, or some other form of public engagement, can ensure that stakeholders and the general public opt for trust rather than distrust. But for engagement to work, it should begin *before* a center like this one is founded with these aims. Waiting until the center is in operation to ask what might be the societal consequences of research on nanoparticles or ultrafast circuits or synthetic biology puts the cart before the horse. As Brian Wynne puts it, "for all the fashion-following language of upstream public engagement, they remain rooted in attention only to downstream impacts, and not to making upstream driving purposes, about the *human ends* of knowledge, not only its instrumental consequences, more accountable and humane;" public engagement practices "exacerbate public alienation and distrust if, as they usually do, they impose their own definitions of what counts as an ethical issue" [34]. The privatization of public knowledge, the promotion of innovation over maintenance, the undermining of traditional disciplines – these are all ethical issues presented by nano education which the institutions of nano education almost never "count" as such.

There are many good reasons for nanotechnology to be a visible and important part of the work of museums and universities. There are many good reasons to reorganize academic research and graduate and undergraduate training around nanoscale phenomena rather than (or in addition to) organizing research and training through the traditional disciplines. I would hope that research and training that is organized around nanoscale phenomena and nano-enabled technologies incorporates RRI principles and practices. But incorporating ethical reflection and public engagement *in* academic nano research and education will only succeed on its own terms if it is preceded and accompanied by reflection on and public discussion of the ethics *of* academic nano research and education.

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