What's So Special about Nanotechnology and Nanoethics?

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ABSTRACT: Nanoethics is a contentious field for several reasons. Some believe it should not be recognized as a proper area of study, because they believe that nanotechnology itself is not a true category but rather an amalgamation of other sciences, such as chemistry, physics, and engineering. Critics also allege that nanoethics does not raise any new issues but rather revisits familiar ones such as privacy. This paper answers such criticisms and sets the context for the papers that follow in this nanoethics symposium.

Nanoethics, or the study of nanotechnology's ethical and social implications, is an emerging but controversial field. Outside of the industry and academia, most people are first introduced to nanotechnology through fictional works that posit scenarios—which scientists largely reject—of self-replicating "nanobots" running amok like a pandemic virus.[1] In the mainstream media, we are beginning to hear more reports about the risks nanotechnology poses on the environment, health and safety, with conflicting reports from within the industry.

Given this growing interest in nanoethics, as well as related confusion, this symposium of the *International Journal of Applied Ethics* is dedicated to a survey of some of its central issues. But before we dive into that symposium, we must first address a persistent meta-controversy surrounding the status of nanotechnology itself, which casts questions about the legitimacy of nanoethics as its own discipline.

Some people have complained that nanotechnology is not a real discipline in the first place, or at least not a clearly defined one, thereby making its ethics equally ill-defined. Others argue further that nanoethics is not entitled to its own discipline, because it does not raise any new questions that are not already considered by, say, bioethics or computer ethics. In this introduction, we will explain why nanoethics is a discipline in its own right as well as set some context for the papers that follow.

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1. WHAT IS NANOTECHNOLOGY?

First, we need to be clear on what nanotechnology is before we can appreciate the ethical and social questions that arise from it as well as the controversy surrounding it. Nanotechnology is hailed by the U.S. government and industry organizations as "The Next Industrial Revolution."[2] It is a new category of technology that involves the precise manipulation of materials at the molecular level or a scale of roughly 1 to 100 nanometers, with a nanometer equaling one-billionth of a meter. How small exactly is a nanometer? As one journalist had put it, "If a nanometer were somehow magnified to appear as long as the nose on your face, then a red blood cell would appear the size of the Empire State Building, a human hair would be about two or three miles wide, one of your fingers would span the continental United States, and a normal person would be about as tall as six or seven planet Earths piled atop one another."[3]

Working at the nanoscale, it turns out that ordinary materials can have extraordinary properties, about which we are still learning. At the nanoscale, quantum physics begins to play a key role in the behavior of materials, and the large surface-to-volume ratio of elements means that they are much more reactive. So, for instance, things that are brittle at the ordinary scale may possess super-strength at the nanoscale, and things that do not normally conduct electricity now might at the nanoscale, among other surprising changes to physical and chemical properties.

As a specific example of how properties change with scale, aluminum is used ubiquitously to make harmless soda cans, but in fine powder form, it can explode violently when in contact with air. But it is not only about the size: by precisely manipulating common elements at the nanoscale, scientists can fashion new materials. For example, carbon atoms bound together in a relatively loose configuration may create coal or graphite found in pencils; in a tighter configuration, carbon makes diamonds; and an even more precise configuration, it creates carbon nanotubes, one of the strongest materials known to man, estimated to be up to 100 times stronger than steel at one-sixth the weight.

Given these new properties, nanotechnology is predicted to enable such things as: smaller, faster processing chips that enable computers to be imbedded in our clothing or even in our bodies; medical advances for dramatically less-invasive surgeries and more-targeted drug delivery; lighter, stronger materials that make transportation safer and energy-efficient (e.g., enabling us to travel farther into space); new military capabilities such as energy weapons and lighter armor; and countless other innovations. Some even predict that nanotechnology will extend our lifespan by hundreds of years or more by enabling cellular repair, which might slow, halt, or reverse the aging process.[4] And because nanotechnology enables us to manipulate individual atoms—the very building blocks of nature—some have predicted that we will be able to create virtually anything we want in the future.[5]

Today, however, research is still continuing on the basic science, so we are years if not decades away from most of the fantastic nanotechnology products that have been predicted. Nevertheless, companies are beginning to productize more of their research to create commercially viable applications based on nanomaterials. These nanotechnology products are quickly entering the marketplace today, from stain-resistant pants to scratch-resistant paint to better sports equipment to more effective cosmetics and sunblock.

In fact, Procter & Gamble, as one example of a leading consumer goods company, announced earlier this year that it is looking to incorporate nanotechnology into its products.[6] Other notable companies made similar statements recently as well, such as BASF's plan to invest U.S. $221 million in nanotechnology research and development over just the next three years.[7]

2. IS NANOTECHNOLOGY ITS OWN DISCIPLINE?

Despite massive spending in nanotechnology by corporations and countries—the U.S. government alone is expected to invest over U.S. $1.2 billion in 2007 through its National Nanotechnology Initiative (NNI)—there is still a debate over whether "nanotechnology" is a legitimate field.

At first glance, this controversy seems strange, given that so much is being invested in nanotechnology worldwide. If nanotechnology were not a real field, then why does it command so much attention and money? Many people, however, believe nanotechnology to be merely a convergence or amalgamation of several existing disciplines, such as chemistry, biology, physics, material science, engineering, information technology, and so on, which has some truth to it.

As an example of biology inspiring engineering, scientists are creating artificial noses with nano-sized sensors which can accurately "sniff" out smells that are otherwise imperceptible to humans.[8] Similar work has been done to create artificial compound eyes,[9] borrowing from nature's design of insect eyes, as well as artificial skin[10] using nanomaterials to mimic the sensitivity of touch. And entire research centers have been created to explore this rich field, including Georgia Tech's Center for Biologically Inspired Designs (CBID) and UC Berkeley's Center for Interdisciplinary Bio-Inspiration in Education and Research (CIBER).

But does drawing from other scientific areas preclude nanotechnology from being a field in its own right? Consider the similar and ongoing debate in philosophy of science whether chemistry, biology, and other established sciences can be reduced to simply physics. One line of thought is that these other fields operate the way they do given the laws of physics that govern how atoms, molecules, and their dependent structures interact with each other and the world. But no matter which side of the debate we take here, no one on either side actually suggests that chemistry and biology, for example, do not constitute their own disciplines; so it would be inconsistent to insist that nanotechnology—even if it substantially borrows from other fields—cannot be meaningfully discussed or investigated as a field of its own. As with these other scientific fields, nanotechnology seems to bring something unique to the discussion that merits recognition as its own field; or in other words, it is greater than the sum of its parts. At the least, it appears to be the first to integrate otherwise-distinct fields in this one area.

Another source of the controversy about nanotechnology's ontological status comes from various opinions on when the field was first created. Many point to Richard Feynman in 1959 as the founding father of nanotechnology; others to Norio Taniguchi in 1974; and sill others to K. Eric Drexler in 1986. But, as the following quote from physicist Richard A. L. Jones shows, a growing sentiment in the field points to a much more recent, and unlikely, person:

> Perhaps a better candidate to be considered nanotechnology's father figure is President Clinton, whose support of the U.S.A's National Nanotechnology Initiative converted overnight many industrious physicists, chemists and materials scientists into nanotechnologists. In this cynical (though popular) view, the idea of nanotechnology did not emerge naturally from its parent disciplines, but was imposed on the scientific community from outside.[11]

3. IS NANOETHICS ITS OWN DISCIPLINE?

The preceding quote suggests that nanotechnology is a political construct or a marketing buzzword invented to resuscitate old disciplines that appear to be losing ground, particularly in the U.S. where the decline of science graduates has been well documented. But no matter what the answer is here, we can already now understand some of the controversy surrounding whether nanoethics is a field in its own right: if nanotechnology is just a fancy term for a range of other fields, then ethical and social questions arising from nanotechnology would seem to be the same kind of questions already raised in these other fields.

Indeed, one critic, professor Soren Holm, asks:

> It is difficult to specify exactly what could make an area of technology so special that it needs its own ethics, but a minimal requirement must be that it either raises ethical issues that are not raised by other kinds of technologies, or that it raises ethical issues of a different (i.e., larger) magnitude than other technologies. Is this the case for nanotechnology?[12]

Philip Ball, science writer for *Nature*, elaborates on this point:

> Questions about safety, equity, military involvement and openness are ones that pertain to many other areas of science and technology [and not just nanotechnology]. It would be a grave and possibly dangerous distortion if nanotechnology were to come to be seen as a discipline that raises unprecedented ethical and moral issues. In this respect, I think it genuinely does differ from some aspects of biotechnological research, which broach entirely new moral questions.

These are fair and forgivable concerns, and current research in nanoethics might even support this position. For instance, in shrinking down devices, nanotechnology is expected to create a new class of surveillance devices that are virtually invisible and undetectable, thereby raising privacy questions; however, these questions do not appear to be new—some skeptics would claim—but simply an extension of the current debate about privacy. Nanotechnology is also predicted to play a critical role in developing human-enhancing technologies, such as cybernetic body parts or an exoskeleton that gives us superhuman strength or infrared vision; however, society has already been discussing the ethics of such technologies with respect to biotechnology and cognitive sciences. In the more distant future, some people envision nanotechnology's role in extending the human lifespan to the point of near immortality; but the question of whether we want or should live longer, or forever—as well as its political, economic and social impacts—does not seem dependent on nanotechnology *per se*.

On the other hand, some issues are emerging that appear unique to nanotechnology, namely the new environmental, health, and safety (EHS) risks arising from nanomaterials. For instance, research studies suggest that some nanoparticles are directly harmful to animals, and because they can be taken up by cells, they might enter our food chain to unknown effects on human health.[13] Other research asks whether carbon nanotubes will be the next asbestos, since both have the same whisker-like shape that makes it so difficult to purge from our lungs if inhaled.[14] And the flip side of creating super-strong materials such as carbon nanotubes is their fate at the end of a product life-cycle: will these materials persist indefinitely in our landfills, as is the case with Styrofoam or nuclear waste?[15]

One new ethical issue is perhaps not enough to confirm nanoethics as a field in its own right. And in fact, we could perhaps reduce even this apparently unique issue to belong to another discipline, such as engineering or environmental ethics that questions the wisdom of creating products that do not decompose. But there are other good reasons for believing nanoethics to be a distinct field, especially if we believe that nanotechnology itself is a distinct field.

First, nanoethics also commands a significant amount of attention and money, though far less than the amount poured into nanotechnology. In the U.S., the NNI currently sets aside approximately $43 million for the "identification and quantification of the broad implications of nanotechnology for society, including social, economic, workforce, educational, ethical, and legal implications."[16] So it would certainly be strange that there would be so much invested by various government agencies, universities, publishers, and other organizations globally, if nanoethics were not a distinct or intelligible field. Of course, there is a possibility that all these organizations and scholars have been fooled because nanotechnology and its ethics allegedly do not exist, but that appears more unlikely than correctly identifying nanotechnology as a meaningful area of its own.

Second, it is unclear why we should accept the litmus test that, to be a true discipline, nanoethics must either raise new ethical issues or larger ethical issues than other technologies. Looking again at chemistry, for example, whether or not we can properly categorize it as a subset of physics, there is no existential dilemma about its status as a legitimate category; no one is proposing to do away with the name or reorganize the university chemistry lab under the physics department. Therefore, it is unclear why such a dilemma would exist with nanoethics, even if nanoethics can be wholly contained within another field or set of fields.

Third, to the extent that nanotechnology is a convergence of many disciplines in the first place, it should be no surprise that nanoethics is a convergence of many ethical areas as well. So, even if a new area of ethics requires raising new or larger issues, that standard may no longer apply with the discovery or creation of nanotechnology, which uniquely draws from other disciplines like no other discipline before it.

Rather than an argument that nanotechnology is not a real discipline because it does not truly break new ground, nanotechnology seems to represent a new height in our understanding about the world. We are finally able to integrate our learning from a wide range of fields to create profoundly useful applications, which happen to belong to the category of nanotechnology. So, just as, for example, architecture can be regarded as a convergence of aesthetic design and engineering, so too can nanotechnology and nanoethics be considered a "real" discipline even if it is a convergence of other fields. Again, the whole of nanotechnology is arguably greater than the sum of its parts, because of the new synergies or interplay between the various parts.

Fourth, nanoethics does seem to raise new ethical issues insofar as it adds a new dimension or "flavor" to current ethical debates. For instance, though privacy may be a relatively old debate, the possibility of creating near-invisible and undetectable devices did not meaningfully exist prior to nanotechnology; so nanotechnology brings a new urgency and reality to the issue of privacy. Further, nanotechnology may help shift the privacy debate in an entirely new direction: whereas worries about unauthorized or unwanted surveillance have traditionally focused on a few agencies, notably governmental organizations, the possibility of cheap, ubiquitous tracking devices—emerging now with radio frequency identity chip (RFID) technology, as one paper in this symposium will discuss, and later to a greater extent with nanotechnology—"decentralizes" surveillance and changes the terms of the debate.

Nanotechnology likewise is putting a new spotlight on, and elevating other ethical issues, such as related to human enhancement or longevity. Even something as apparently tangential as the ethics of space exploration and settlements—or space ethics—now overlaps with nanoethics, because only with nanotechnology does the possibility of extended space flights and terraforming (i.e., the ability to create a hospitable atmosphere and environment on another planet or moon) become plausible.

4. ISSUES IN NANOETHICS

If nanoethics is its own discipline, then what are its issues? Again, controversy surrounds even this question. If we are conservative and only acknowledge those issues that will likely or possibly arise from current lines of research in nanotechnology—which is primarily focused on the discovery and applications of new nanomaterials—then nanoethics certainly covers some of the issues mentioned above: EHS impacts, privacy, human enhancement, as well as global security (since the military is a major driver of nanotechnology research to such a degree that some fear a new arms race).[17] Other relevant issues may include research ethics (if some research seems too dangerous to publish or pursue, e.g., splitting the atom, human cloning, or replicating viruses capable of pandemics), intellectual property (if today's patent-grab and processes stifle innovation), and humanitarianism (why we are not doing more to solve poverty, hunger, energy, clean water, and other problems through nanotechnology).

But more imaginative people, such as Drexler, postulate a more advanced form of nanotechnology in our future—sometimes called molecular manufacturing—by which we can position individual molecules with exact precision. The difference between how we create nanomaterials today (e.g., carbon nanotubes) with precisely-positioned molecules, and molecular manufacturing is the difference between engineering and chemistry. Carbon nanotubes rely on bulk chemical processes and reactions at high temperatures to create the desired configuration of carbon atoms, which is similar in principle to the usual chemistry experiments in which various elements and compounds are thrown together in bulk and shaken up to predictably create a batch of new compounds.[18] In contrast, molecular manufacturing is envisioned to be more like a construction job, grabbing single atoms and deliberately attaching them to others to form the desired structure. This high degree of precision, without messy chemical reactions, would in theory enable us to create practically any possible object.

This line of thought is instantiated by a detailed speculative design for a "nanofactory" that might be a portable or desktop device—a black box of sorts—that can create virtually any object we want, from cakes to computers. To oversimplify things, raw materials, say dirt and water, might go in one end, and a raw steak or perhaps an unmanned fighter jet might come out the other. While this may sound like science fiction, the theory behind it seems sound: if we can precisely manipulate molecules, and physical objects are only made up of molecules, then why wouldn't we be able create any physical object we want?

If this still sounds far-fetched, consider the similarities with today's 3-D printers that can print out plastic or ceramic objects one thin layer at a time. No longer limited to producing only manufacturing prototypes and machine parts, 3-D printers recently broke new ground in printing out fully functional and fashionable footwear, among an expanding and impressive array of print-on-demand products.[19] The nanofactory operates by the same concept, except with much more precision and a mix of different materials.

So if advanced nanotechnology is in our possible future, then it raises truly unique and serious questions—and following the litmus test considered earlier, it may strongly support nanoethics as a distinct discipline. Molecular manufacturing appears to have the potential to wreak havoc on our economic system where millions might lose their jobs overnight in manufacturing and other industries and perhaps eliminate the need for global trade. If people and terrorists can easily create weapons with personal nanofactories, that may threaten global security and the lives of millions or billions of others. Some of the more fantastic issues are also related to advanced forms of nanotechnology, if not directly to molecular manufacturing, such as longevity or immortality, space settlements, and artificial intelligence.

However, because these issues are tied to advanced forms of nanotechnology—the plausibility or likelihood of which is in question with mainstream scientists—critics may believe that it is inappropriate or well premature to consider such issues now. But we do not need to resolve that question here in order to take seriously the ethical and social issues advanced nanotechnology might raise. Even if advanced nanotechnology is a remote possibility, its scenarios appear so disruptive that they merit consideration. A simple cost-benefit analysis might justify spending $5 million over the next decade to study and perhaps mitigate a scenario that has a 1 percent possibility of causing $1 billion of economic disruption, which has an expected negative utility or value of $10 million. (These figures are purely hypothetical but appear to be in a plausible range.)

As an analogy, if decoding the human genome had just a small likelihood of, say, leading to employment or insurance discrimination based on a person's genetic makeup, we would still expect that scenario to be important enough to warrant an investigation. Or more abstractly, if a political course had even a bare possibility of leading to a devastating war, costing the lives of millions, it seems that we are morally obligated to seriously consider that possibility, no matter how remote.

With nanotechnology, so much is still unknown that scientists are really not in a position to accurately forecast what is likely or not and by when. Some believe molecular manufacturing is inevitable; others disagree. But if history is any guide, most of our mid- and long-terms predictions about technology have been proven overly optimistic or pessimistic (e.g., flying cars, robotic maids, and the end of privacy). Many things we have today were once believed to be impossible or impractical—such as gas streetlights, residential electricity, telephones, highways, radio, airplanes, rockets, and even today's ubiquitous personal computer—so perhaps the prudent course is to treat most of these possibilities as reasonable until proven otherwise.

Even near-term challenges in technology—such as how to shrink the smallest computer processor even further—seem difficult if not intractable to us right now, but somehow we find a way to sustain Moore's Law, which posits a doubling of processing power every eighteen months and which some predict will soon fail to hold.[20] Technology is moving rapidly indeed and may be limited now only by our imagination, so it is not implausible to think any technical challenges associated with molecular manufacturing might be eventually solved.

Indeed, in just the last few months, scientists have announced creating a blueprint for an "invisibility cloak"—essentially a heavy blanket created with nanomaterials that can bend, instead of reflect or diffuse, light and other electromagnetic waves around the object cloaked, just as water might flow around a rock in the middle of a stream.[21] (This, too, seems to give rise to ethical issues associated only with nanotechnology, namely privacy and security, if we are still interested in identifying unique issues.) But as recently as early 2006, such innovations would have been thought as merely science fiction, consigned to fantasy worlds such as Harry Potter's. Again, throughout history and even now, ideas that have been dismissed as unworkable somehow become reality, despite their technical challenges, so it is not irrational to treat molecular manufacturing as a real possibility absent compelling evidence to the contrary.

Furthermore, no matter how speculative some of these scenarios seem to be, they provide a useful platform to test our moral principles as at least "thought experiments," which is a common, accepted, and invaluable practice in ethics. For instance, no one thinks that anyone would plausibly be kidnapped and surgically connected to a famous violinist—the premature detachment of whom would lead to the violinist's death—but this hypothetical example isolates and tests out intuitions in Judith Jarvis Thomson's discussion about the moral permissibility of abortion.[22]

Also, few actually question the wisdom of sending spiders into outer space on the grounds that spiders do not exist and may never exist in space (unless we introduce them into space); yet this is useful to study the relationship between gravity and a spider's ability to orient itself and spin webs by isolating gravity as a variable. As it applies to nanotechnology, even if cybernetic people never exist, the possibility of human enhancement provides a platform to explore intuitions related to human dignity, personal identity, and other concepts.

Given all this controversy, it should also be no surprise that the questions in nanoethics seem ill-defined as compared to, say, ethical questions in decoding the human genome, as some critics have pointed out.[23] Nanotechnology itself is fractured into different approaches or philosophies, each of which raises it own questions; so, until there is a consensus on what nanotechnology is and will be, it will be difficult to gain a consensus on a plausible set of issues for nanoethics. Moreover, the overlap of nanotechnology with other disciplines—and the overlap of nanoethics with bioethics and other areas—contributes to this challenge.

5. NANOETHICS: A SYMPOSIUM

That said, it is still important to look at both near-term and speculative issues in nanoethics, for reasons previously stated. In this symposium of *International Journal of Applied Philosophy*, we will present papers on some of the most exciting ethical debates emerging from developments in nanotechnology.

First, a core concept in the current controversy about nanotechnology's EHS risks, as well as other debates, is the so-called precautionary principle. This principle advises that we err on the side of caution and proceed slowly if an action might plausibly lead to devastating consequences—as many see in at least some applications of nanotechnology. Yet there is disagreement on how strong this principle is and whether it even makes sense or is reasonable. Our first paper, "The Precautionary Principle in Nanotechnology" by John Weckert and James Moor, defends this principle from key criticisms.

Relatedly, some organizations are calling for increased regulations and even a moratorium on nanotechnology research, as a way to mitigate EHS risks or to buy more time until we can sufficiently address those risks. This debate underscores the lack of specific regulations to govern nanotechnology beyond existing laws that were not designed with nanotechnology in mind. Our second paper, "Introducing Standards of Care in the Commercialization of Nanotechnology" by Vivian Weil, offers a framework for nanotechnology researchers and stakeholders to proceed responsibly.

Beyond EHS concerns in nanotechnology, one of the more pressing and near-term issues in nanoethics will be centered on privacy. One of the immediate impacts nanotechnology can make is to miniaturize devices through the use of smaller electronic components, for example. But this feature feeds worries that nanotechnology, as other new technologies are now also doing, will create surveillance and eavesdropping systems that will be even more difficult to detect. Our third paper, "Nanotechnology and Privacy: the Instructive Case of RFID" by Jeroen van den Hoven, draws lessons from today's radio frequency identity chips (RFID)—an emerging technology that promises to make businesses more efficient and productive, but also holds serious privacy implications—to help guide our thinking about a similar class of devices that nanotechnology is predicted to create in the near future.

As a mid-term issue, nanotechnology is expected to play a crucial role in human enhancement, or the augmenting of human capabilities—such as strength, sight, hearing, memory, and longevity—through technology. While some embrace the notion of becoming more than human or see technology as a way to realize our full potential as humans, others fear that possibility will turn us less than human or pervert the notion of human dignity. Our fourth paper, "Altering the Body: Nanotechnology and Human Nature" by Robin Zebrowski, criticizes a central belief held by opponents of human enhancement that there is some "standard body" from which we should not diverge.

And at a more distant point in our future, nanotechnology is expected to accelerate work in artificial intelligence, with innovations such as increased processing speed, increased memory, quantum computing, and more. Our fifth and final paper, "Nano-Enabled AI: Some Philosophical Issues" by J. Storrs Hall, discusses the possibility of intentionality in formal systems as well as machines as moral agents.

Again, some of these sound like familiar issues, but in the context of nanotechnology, we now have an expanded and increasingly plausible platform to discuss these matters. For instance, with nanotechnology, the possibility of "intelligent" machines now seems less fantastic and more real, making our thinking about its implications less frivolous and more relevant to the real world.

These papers also certainly do not address every relevant issue in, say, privacy or human enhancement, but they give a sense of the depth and diversity of ethical and social issues in nanotechnology. Other issues in nanoethics include such areas as research ethics, environment, nanomedicine, intellectual property laws, global equity, economics, politics, national security, education, life extension, and space exploration.[24]

Finally, the papers in the present symposium do not necessarily reflect the viewpoints of the editors or publisher, but only of their authors, whom we thank for their contribution. We also would like to thank IJAP's Editor-In-Chief, Elliot Cohen, for proposing this symposium and inviting us to edit the collection, one of the first of its kind. As nanoethics gains momentum, we hope to see more industry experts, academics, and the broader public engaged in this critical field—helping to guide science and humanity to a better future.

Endnotes

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24. For more about nanoethics and these issues, please see: *Nanoethics: Examining the Societal Impact of Nanotechnology* (forthcoming, Wiley), ed. Fritz Allhoff, Patrick Lin, James Moor, John Weckert.