Fondazione Giannino Bassetti

CONVERSATIONS ON INNOVATION, POWER, AND RESPONSIBILITY

Jeff Ubois

Foreword by Piero Bassetti

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FOREWORD

These *Conversations on Innovation, Power and Responsibility* have realised one of the fundamental intents of the Bassetti Foundation. Jeff Ubois' interviews contribute to the widest possible exploration and explication of a topic - the responsibility of innovation - which is the mission of our Foundation.

For ten years now, our foundation has been engaged in promoting a cultural policy for fostering responsible innovation. Our initial purpose, when commissioning this project, was to spread the mission of the foundation and to cultivate a network of contacts within the world of research and innovation on the American side of the Atlantic, in ways that could resonate with the mainly Italian experience of the Bassetti Foundation. At first, it seemed a difficult objective to achieve. This pamphlet capitalises on the results reaped in the following three years.

The link between innovation and responsibility lies in the complex scenarios of tomorrow which will include the consequences of today's innovation. Everyone agrees it is important to cultivate and foster innovation, but the cultures and politics of innovation devote scarce attention to prefiguring adequate models to tackle its consequences - good or bad. Such models cannot be merely economic scenarios but must involve political, social and cultural scenarios.

Amongst the possible critical points that will be of help for us to develop and refine better our mission, and to direct our

future steps, is the fact that in this collection many people talk about responsibility, but they do not mean the same thing. We still find that within the world of innovation, the concern about responsibility does not seem to be understood within a wider historical and political framework.

This pamphlet helps advancing precisely this state of things and I am proud to present it to our public.

Piero Bassetti,
President of the Giannino Bassetti Foundation

INTRODUCTION

Innovation is a special kind of power: it assumes different forms in different contexts, is shared and applied by diverse actors, and by continuously reshaping our environment, our institutions, and our values, it acts on us all.

In an ideal world, power brings responsibility. But the connections between innovation and responsibility have never been less clear. Responsibility for innovation is diffused among an ever-expanding number of actors, each of them caught between their own hopes for the future relevance of their work, and the impossibility of knowing the effects—good and bad—their work may have.

For more than ten years, the Giannino Bassetti Foundation of Milan, Italy has been exploring the nature of responsibility in innovation. Through conversations with innovators and politicians, public meetings and events, publications, and the creation of a network of individuals in government, industry, and academia, the Bassetti Foundation has engaged with this question at the personal, organizational, and societal level.

We have found that asking "what is responsibility in innovation?" invites discussion about critical issues now facing us individually and collectively. Rather than proposing some final answer, this paper explores how engaging with the question may clarify research priorities for innovators and funding organizations, bridge the gap between innovators and policy makers, and reframe debates that have been gridlocked.

Following are the results of several informal interviews with innovators in fields with disruptive potential (including genetics, nanotechnology, robotics, computer science, and design), describing their approaches to responsibility in innovation. The intent here is let innovators speak for themselves, to make their ideas broadly accessible, and to suggest future lines of inquiry.

About The Question

Innovation and responsibility exist in every political and scientific domain, from the most theoretical to the most prosaic, and at every level of social structure—from the individual and the small group, to the multinational, nation state, or disciplinary field. But clearly defining the terms “responsibility” and “innovation” is difficult; the meaning of both is in flux.

Innovation has been described as the ability to achieve the improbable[1]; as a reconciliation of contradictions[2]; as “the act that endows resources with a new capacity to create wealth”; as a process extending from initial concept to eventual changes in practice by individuals and institutions; and as the application of capital to scientific discovery[3]. Innovation has been typed in various ways—e.g., radical or gradual, linear or network-based—and differentiated from discovery and invention by a requirement for application in the practices of institutions and individuals.

For purposes of this discussion, it’s helpful to think of innovation as an arc that stretches between basic research, applied research,

commercial development, and general adoption. Although this linear model of innovation as a process with distinct stages leaves out various aspects of how new technologies eventually become broadly adopted, it is widely understood, and helps to structure discussions about responsibility.

Responsibility is harder to define. It may be a power and a limit; to "be responsible" may mean to cause; to have the power to choose between different actions (response-able); a duty or obligation; a goal for which one is accountable. As it relates to innovation, responsibility exists throughout the process of innovation, from initial concept to final application, from inventor to engineer to vendor to the end user, from investor or grant-maker to final buyer, from theorist to manufacturer.

Assessments of responsibility for particular innovations—whether defined as credit, blame, or agency—evolve over time, and may involve subjective or aesthetic judgments. Were the theoretical physicists of the 1920s and 1930s responsible for Hiroshima? That question may seem naïve (or tired), but after more than 60 years, our answers continue to evolve: in 2008, physicist Freeman Dyson announced he had changed his mind about the role played by atomic weapons in ending World War II based on new information recently released by the U.S. government, writing, "Until this year I used to say, perhaps. Now, because of new facts, I say no."[4]

To the extent that innovation shapes our individual and collective futures, all of us are stakeholders in the answers to questions about responsibility. So are there "recipes" and processes that can be applied across different domains? What kinds of societal ills might be attributable to a lack of responsibility in innovation (or cured by an increase in it)? Do recurring issues and approaches

exist across different disciplines? And do basic questions about responsibility reliably generate new insights?

The discussions summarized here indicate that dialog on the question "what is responsibility in innovation?" can illuminate the nature of technology and society, law and ethics, economics and power, and can serve as an organizing theme for a wide variety of ethical questions about technology.

Related Concepts

Perspectives on Responsibility

If the question of responsibility in innovation is fundamental, then it should be found in other guises across a wide variety of disciplines. That turns out to be the case; law, economics, engineering, design, administration, and others all address facets of the problem. For example:

- Legal scholars sometimes frame the issue of responsibility in terms of liability, or proximate cause.[5] If innovation builds on the work of multiple actors, how is responsibility shared among them, and who is ultimately responsible when something goes wrong?

- Economists think in terms of externalization of costs,[6] risks, minimax, and moral hazard.[7] To the extent that innovation creates risks, how can they be measured and assigned, particularly when there is potential for irreversible consequences?

- Engineering and medical societies may operate under codes of ethics or practices that address responsibility.

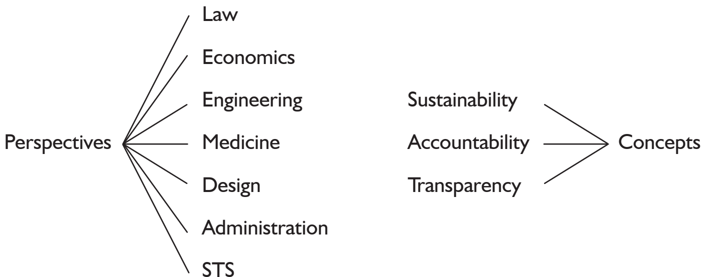
- Designers have searched for answers with “user centered” approaches, and argue that responsibility can rest with the end user.[8]

- University administrators may simply delegate the problem to their Institutional Review Board. To them, responsibility in innovation means avoiding liability, and secondarily, protecting human subjects of research. Responsibility rests with experts.[9]

- Researchers in the field of Science and Technology Studies (STS) have grappled with issues of agency and unintended consequences, public policy and innovation.[10]

Each of these approaches sheds light on questions of responsibility, but it is rare for more than one or two to be applied to any single circumstance.

Related Perspectives And Concepts



Perspectives on responsible innovation have been developed in many fields, and described in terms of several different concepts.

Concepts Similar to Responsibility

In addition, there are three related concepts—sustainability, accountability, and the Precautionary Principle—that are sometimes referenced in discussions related to responsibility.

Sustainability, the prospect for indefinite continuance, is now invoked as a useful value for everything from fisheries to libraries, from national healthcare systems to neighborhood non-profit organizations. The UN General Assembly's Brundtland Commission noted in 1987 that sustainability "implies meeting the needs of the present without compromising the ability of future generations to meet their own needs," and that sustainability "should become a central guiding principle of the United Nations, Governments and private institutions, organizations and enterprises …"[11]

"Sustainable innovation" is now the subject of numerous academic conferences, papers, books, and academic programs[12], and is becoming a part of the academic curriculum of engineering and business schools as a more refined set of concepts once grouped mostly under the term "green." The problem with "sustainability" is that as it becomes a universally accepted value, its meaning is becoming increasingly nebulous.

Like sustainability, accountability is subject to various definitions, ranging from liability to reporting functions (accountability is often paired with transparency) to enforcement.[13] The concept presupposes some type of authority; it may also imply an assumption of responsibility. As Andreas Schedler writes in *The Self-Restraining State*,

“Today, it is the fashionable term accountability that expresses the continuing concern for checks and oversight, for surveillance and institutional constraints on the exercise of power. All over the world (wherever the term is halfway translatable), international financial institutions, party leaders, grassroots activists, journalists, and political scientists have discovered the blessings and adhere to the cause of ‘public accountability.’”[14]

The Precautionary Principle, in all of its many different varieties, is another effort to engage with questions of responsibility, risk, policy, and law. Essentially, it argues that the burden of proof for the safety and desirability of a new technology rests with the innovator, and in the absence of such proof, restrictions on the technology are appropriate. For example, the February 2, 2000 European Commission Communication on the Precautionary Principle[15] notes that the precautionary principle applies “where scientific evidence is insufficient, inconclusive or uncertain and preliminary scientific evaluation indicates that there are reasonable grounds for concern that the potentially dangerous effects on the environment, human, animal or plant health may be inconsistent with the high level of protection chosen by the EU.”

In sum, discussions around responsibility in innovation should take into account different interpretations of responsibility, as well as concepts, policies, laws, and other governance mechanisms that touch on responsibility, as innovators are likely to be affected by one or more of them to varying degrees.

Choosing Subjects: Where Does Responsibility Matter Now?

Seen in retrospect, many predictions about the course of science and the impact of science on society seem naïve or misguided: moon colonies, power too cheap to meter, and flying cars never came to pass. Others have far exceeded expectations: air travel, birth control, and television have changed society far more profoundly than predicated.

But any effort to get upstream in the innovation process involves making predictions about which technologies are likely to have broad social effects. For the purposes of the following conversations, biotechnology, nanotechnology, robotics, and computer science stood out as among the most potentially transformative technologies of the next fifty years. That is not to downplay the significance of energy, aviation, or other fields; rather, the point is that by engaging in fields that already have proven to be changing society, and which seem likely to continue to do so, issues of responsibility may become more visible. In other words, because these fields generate widespread effects, issues of responsibility are more likely to be apparent.

In choosing respondents, the Bassetti Foundation looked for innovators who are building tools that reflect and embody intentionally chosen values, and for leaders of institutions with a taste for policy who were in touch with large networks of innovators.

Following are some summaries of discussions with innovators who are grappling with issues of responsibility. They are drawn

from industry, academia, and non-profits, and from diverse fields, including nanotechnology, bioethics, design, and computer science—less with an eye towards ensuring a valid sample than from a desire to cast a wide net, and to search for patterns of responsibility that may exist in different fields and types of institutions.

GENETICS AND HEALTHCARE

Thomas Murray: Scenarios as a Tool for Thinking

Thomas Murray is President of The Hastings Center, an independent bioethics research institute based in Garrison, N.Y., and founded in 1969.

Interdisciplinary inquiry, broad public engagement, scenario-based thinking, training for the next generation of bioethicists, and public service and engagement with regulators at all levels characterize the Center's approach to bioethics.

"The founding insight for the Center was simply that the issues that medicine and the life sciences were presenting to society were vastly too complex for any one person, one profession or one discipline to fully comprehend," Murray explains. "And so the only way to get a relatively well-rounded understanding of even the nature of the problem, let alone solutions, was to bring together a variety of expertise and points of views, that together could create something greater than even the individuals working side by side."

But simply including more people in the discussion doesn't necessarily improve it. "Bioethics has now become a part of the political discourse, which means that it has become prey to all the sort of spinning and sound biting in that realm,

and that's an anathema to the Hasting Center," Murray says. "[Our] goal is to… deepen and enrich the public conversation and understanding about these issues."

Human enhancement is of particular interest. The "boundary between therapy and enhancement is much more difficult to stake out than many people may assume it is," Murray says. "Erythropoietin was developed and approved by the Food and Drug Administration for the treatment of chronic anemia. It took bicyclists a nanosecond to figure out that more red cells might be useful to them, as well."

Scenarios of various kinds have been a staple of ethics education for millennia. By accounting for multiple stakeholders and points of view, scenarios can illuminate choices about responsibility in innovation. Here's one:

"Imagine you've just been hired as a new lawyer fresh out of law school, and you're an associate in the firm of Harass, Devour and Milk. The general partner comes out and says welcome to the ten new associates. 'We want you to know that five years from now when we decide who becomes a partner, seven of you will be asked to leave, and in the meantime we'll be watching your work very closely…we would never require our employees to use cognitive enhancing drugs, [but] here will be an ample supply, free and available in the coffee room. We'll be watching you very carefully to see how well you work.'"

Scenarios like this make it possible to examine possible effects of new technologies in advance of their widespread adoption and use, and thus develop strategies to manage associated risks and opportunities.

Ignacio Chapela: Drawing a Boundary Around the Lab

How can innovators maintain a broader perspective about the implications of their work? What happens when their work becomes political? Is it possible to insulate the environment from the lab?

Ignacio Chapela is an assistant professor at the University of California Berkeley who specializes in mycology, microbial ecology, and in transgene migration. With colleague David Quist, Chapela discovered that illegally grown, genetically modified corn contaminated traditional heirloom corn in Oaxaca, Mexico. That discovery touched off a major controversy[16], and illuminates many of the issues related to responsibility in innovation that most concern the Bassetti Foundation.[17]

One of Chapela's primary areas of interest is introduction of transgenic organisms into the environment. "This is a revolution that has parallels only in the Great Colombian Exchange—what some people refer to as the discovery of the Americas," Chapela says. "From the biological point of view, that was really the breaking down of very important barriers that existed before, and it led us to a major reconfiguration of the biosphere, not to mention human society, politics, policy, economy, everything."

Chapela suggests several approaches that individuals, research groups, university administrators, and others can use to increase or improve responsibility, including:

- Preservation of intellectual diversity, especially in the sciences, where an orientation towards the humanities can provide context for new discoveries.

- Scrutinizing the role of money in innovation to better identify political agendas.

- Maintaining the boundary between the lab and the public space, to ensure freedom for research inside the lab, and to control the impacts outside it.

- Public involvement in discussions about moving new innovations out of the lab and into public space.

To sum up, Chapela suggests that innovators "focus on the process of innovation and to what extent is that process inclusive of, or responsive or sensitive to the public."

Arthur Caplan: Innovation as Politics

Few areas of innovation are more politically charged than healthcare. Yet subjecting the agenda of medical research to the chaos of modern politics doesn't necessarily improve the outcome.

Dr. Arthur Caplan is the Emmanuel and Robert Hart Professor of Bioethics, Chair of the Department of Medical Ethics and the Director of the Center for Bioethics at the University of Pennsylvania in Philadelphia. Caplan is

the author or editor of twenty-five books and over 500 papers in refereed journals of medicine, science, philosophy, bioethics and health policy.

Caplan points out that innovation in certain areas has less to do with responsibility than with power. "Stem cell research, for example, is pure politics at this point. It isn't connected to the issues, anymore. It's who can muster up the most lobbying power, the patient groups or the pro-life groups. And right now, the patient groups, I'd say, are winning despite a recent setback in this country."

A diversity of funding sources is also changing the dynamics of stem cell research. "The funding of embryonic stem cell research is proceeding in many states and with private money as well," Caplan says. "We're able to see where the science might be in a couple of years, so we're positioned to be an early warning system."

"I'm never happier than when one of our veterinary scientists comes over and says, 'You know, I'm doing this project on animals and we think we can do such and such with the animal, and obviously, if it was done with people, it would raise a big issue, so you guys should start thinking about that.' That's great when that happens, and that's the kind of scientist you want," Caplan says.

That early engagement offers the promise of responsibility. "The innovator has to be someone who signals potential issues and problems, [and] should be sophisticated enough to think about them," Caplan says. "We don't expect the innovator to solve the social challenges that a new technology would raise, but we do expect them to alert people."

David Magnus and Mildred Cho: True Fictions

Increasingly, scientists whose work touches on political issues are finding themselves engaged in policy discussions, willingly or not. Improving the quality of those discussions is one of the aims of the Stanford Center for Biomedical Ethics (SCBE).

David Magnus, Ph.D. is Director of the SCBE, an Associate Professor of Pediatrics, Medicine, and Philosophy, and co-Chair of the Ethics Committee for the Stanford Health Center. He is also Director of the Scholarly Concentration in Biomedical Ethics and Medical Humanities in the School of Medicine.

Mildred Cho, Ph.D., Associate Director of the SCBE, is also Associate Professor of Pediatrics. Her major areas of interest are the ethical and social issues raised by new technologies such as genetic testing, gene therapy, pharmacogenetics, and gene patents. She also studies how academic industry ties affect the conduct of biomedical research.

In a wide-ranging interview, Drs. Magnus and Cho reflected on pre-natal sex selection, genetic testing, public/private partnerships, open access publishing, and research funding. They also offered some fascinating examples of public education via television entertainment, cross-disciplinary studies, and the relative times scales of the research community, government, and the media in coping with innovation.

“The more prominent political debates over stem cell research, evolution, global warming, and the use of the

science in making political decisions has galvanized scientists and made them aware of the fact that their research does get used out in the political world, and that they can't just stand on the sidelines and say, 'Well, that's how they're using my research. That's not my problem,' right? And so, that has dragged unwillingly, maybe, some researchers into the … to sort of facing the downstream uses of their research," Cho says.

As at the Hastings Center, and at the Center for Bioethics at the University of Pennsylvania, part of the goal for the Stanford Center is to become involved with innovations early. "Innovation isn't just a single thing. Every time you look at something that counts as a major innovation, it's usually, itself, a product of a whole series of things that made it possible for this step to be taken, and that's actually one of the reasons why there's often such a disconnect between public responses and scientists' responses," Magnus says. "We're seeing a shift in which we're trying to develop methods for being involved right from the beginning, so that as science goes down the path, we're right there … because often, the reality is by the time you've hit that part where everybody's commenting, it's really too late."

Both Magnus and Cho are actively engaged with the media around bioethics issues. "One of the biggest problems, especially with the rise of all these 24-hour news channels, is there's a tendency to conflate being balanced with having two positions," Magnus says. "So if 99.9 percent of neurologists say Terry Schiavo's in a persistent vegetative state, and five neurologists say she's not, then let's have a debate and have one of the five guys on every single show."

The Stanford Center has also engaged with entertainment media about ethical issues; it turns out that the scenarios possible in dramatic programs can actually be more nuanced than the news. "I used to work with the TV show 'ER,'" Magnus says. "For many years, they provided me plots to episodes in advance, and I would have students write essays on the ethical issues on the show, so they could go up on the web as soon as the episode aired."

NANOTECHNOLOGY

Christine Peterson: Nanotechnology and Enhancement

Exercising responsibility is often a matter of engaging with colleagues; at the same time, responsibility for the use of many controversial technologies, such as human enhancement, will prove difficult to control, and are likely to remain in the hands of individuals with sufficient economic power.

Christine Peterson writes, lectures, and briefs the media on coming powerful technologies, especially nanotechnology. She is Founder and Vice President, Public Policy, of Foresight Institute, the leading nanotech public interest group. Foresight educates the public, technical community, and policymakers on nanotechnology and its long-term effects. She serves on the Advisory Board of the International Council on Nanotechnology, the Editorial Advisory Board of NASA's Nanotech Briefs, and on California's Blue Ribbon Task Force on Nanotechnology.

Peterson offers a variety of approaches to enhancing responsibility in innovation, including participation in professional societies, understanding the special distinctions between disciplines, and analyzing the ethos of software developers. She also notes that whistle blowing, public participation, and prohibitions are unlikely to be effective remedies.

“My guess is that the professional societies in almost any technical field have probably played a role of enabling individuals to find allies in a kind of safe, protected way, exerting pressure on academia, on industry in positive ways, at least to balance the huge pressure of profits. And most of these professional societies have ethical codes.”

Stepping into a completely oppositional role is likely to be less effective than remaining engaged with professional societies. “Whistle blowing doesn’t work ... let’s say you’re in a lab, and you feel that carbon nanotubes are not being handled in a safe fashion,” Peterson says. “You can either go to the media with that, which is probably going to cost you your career. Or you can participate in the International Council on Nanotechnology [ICON], which just produced the first study of industry practices.”

Efforts to increase public participation often suffer from a selection bias. “There is increasing pressure to have public participation, but most of the people who organize these events … have an anti-technology agenda, and they may not even know it,” Peterson says. “If you’re going to do public participation … somehow you have to get the bias out of the process. You can get ‘the public’ to say anything, depending on how you pick them and what you tell them up front and what you ask them.”

It’s important to face inevitabilities and economic realities about politically charged innovations. “One thing that comes up is human enhancement,” Peterson says. “People who are trying to stop it are wasting their time. If people want to be enhanced, they’ll go to another country and get enhanced.”

"What's not going to work anywhere is to try to tell rich people they don't get what they want with their money. If people privately want to have plastic surgery, we permit that," Peterson says. And the same will be true with other enhancements.

Peterson suggests that a closer look at the software developers might provide some clues about responsible cultures of innovation. "If you really want to know how to create a sense of responsibility, look at the software development community," she says. "They see their work as political. They see it as ethics-based. They think of the ethical consequences of their decisions. They're very politicized and very aware. So, why is that? Why is that true in software and not so much true in other areas?"

Whether that is due to the academic and countercultural roots of the microcomputer industry, the communicative nature of computer systems, or desire to affect the world so prevalent among innovators generally is difficult to establish. However, finding ways to assess the political sensitivities (or lack of them) in different communities of innovation could be a fruitful way of enhancing responsibility in innovation.

Lawrence Gasman: NanoMarkets

All too often, policy discussions about innovation are based on incomplete understanding of the underlying science. Given that policy makers must anticipate the future, how can they account for the tendency to exaggerate hopes and fears of new technologies?

Lawrence Gasman is the co-founder of NanoMarkets, LLC and author of the recent book, *Nanotechnology Applications and Markets*, which examines the market for nanotechnology in the healthcare, energy, and information technology sectors. The book also provides a generalized approach to forecasting the impact of nanotechnology on particular companies and industries.

Gasman sees a number of issues in nanotechnology that will force the creation of new policies:

- Memory enhancements. Gasman suggests that enhancements of human memory based on nanotechnology are only fifteen years away. These have the potential to deeply alter the nature of human experience.

- New forms of industrial pollution. “Certain kinds of particles at the nano level are undoubtedly dangerous and need to be controlled. If some firm is pumping huge quantities of nanoparticles that are dangerous, they deserve to suffer some consequences for that.”

- Cloning. Conceived in broad terms, nanotechnology touches on genetic issues, and may play a role in cloning. “It is happening with pets now, and somebody somewhere is going to start doing it with people.”

Technological uncertainties and other difficulties in the forecasting make intelligent policies hard to formulate. Gasman notes that despite hopes expressed in the 1960s,

nuclear power and space colonies have not come to pass. "Some technologies just don't happen. When I was a young teenager, I would say that 95 percent of the population believed that by now, we would have colonies on the moon and Mars. That's a forecast that spectacularly failed," Gasman says. "One of the reasons the Mars colonies didn't happen is they involved unbelievable quantities of money … but [nanotechnology] doesn't."

The diversity of claims and possibilities for nanotechnology make regulation more challenging. "It was certainly a popular idea that by now, because of nuclear power, energy would be too cheap to meter," Gasman says. "They obviously made predictions that were probably unrealistic in the first place, but also, they ended up being so controlled that nobody could make any money with nuclear power in this country. The nanotechnology stuff is not unitary. It's going off in lots of different directions."

Yet innovators who do understand the science may not be in the best position to assess social effects. "It's the social consequences more than the business consequences that are really hard to work out, yet the innovators are not particularly interested in the social consequences, and wouldn't be the people I would choose to think these things, either," Gasman says. "Some of the innovators in this field are the last people in the world I'd give any credence to in their social predictions or their desires. But, on the other hand, a lot of the people who talk about nanotechnology from a social point of view are often completely ignorant about what's actually going on."

ROBOTICS AND COMPUTING

Ronald Arkin: Embedding Values in Machines

Certain forms of technological progress seem almost inevitable. For technologies that are widely believed to be life enhancing, this is usually seen as a good thing. But what about technologies of war? Given the long historical trend towards technologies that kill more people faster, how should innovators engage with technologies with potentially lethal effects?

Dr. Ronald Arkin (http://www.cc.gatech.edu/aimosaic/faculty/arkin/) is a Professor in the College of Computing at the Georgia Institute of Technology, and Director of the Mobile Robot Laboratory. [18]

Arkin has thought deeply about the ethical aspects of robotics, especially those used in war; embedding ethical codes in technical systems; and how practitioners can effectively engage their colleagues in discussions about the ethical aspects of research and engineering.

"The deepest issue right now that I'm confronted with is seeing what I view as the almost inevitable march toward autonomous systems in the battlefield," Arkin says. "How do we build the safeguards into the technology, which is to me the real responsibility question, to make sure that if it is created, it will be created and used as it was intended… I

am not creating new ethical rules for warfare. I am trying to implement existing technology to ensure that this technology abides by the existing rules of warfare."

One of Arkin's "aha" moments came when viewing a video from Iraq. "I recognized that I might want to start taking some responsibility for the kinds of things that are happening after some recent discussions with my military colleagues [of] some video that I found personally disturbing," Arkin says. "It involved lethality; I'm not adverse to lethality under the normal ethical conditions of warfare … but I saw something that verged on what I might have interpreted as a violation of the Geneva Convention."[19]

Arkin has avoided offering prescriptions, and instead has focused on encouraging independent thinking. "What I was concerned with principally is not to go around and tell people 'you're doing things wrong,' but to try and encourage introspection by my colleagues, to recognize that this stuff is not just the joy of making things happen, but is potentially life-changing, society-changing, and world-changing in many, many different dimensions," he says.

Part of that has been a decision to avoid classified research, and to retain the freedom to publish. "I was happy to work with them [the military], as long as I didn't have any restrictions on publishing my research," Arkin says. "That's not to say I'm disdainful of those folks in my community who do classified research, far from it. They just have a different commitment than I do."

There are possible upsides to robot soldiers. "My contention is again, that ultimately robots can do better in the battlefields than human soldiers can. That's not perfect, but better — if

you look at the recent reports on mental health and ethical behavior [in Iraq] it's a relatively low bar to do better," Arkin says. "People will not turn in people that are guilty of war crimes, and a percentage of soldiers are ready, willing and able to treat non-combatant civilians with lack of respect, to abuse them both verbally and physically."

Robots will also change the perceptions of war. "If you have these robots in the battlefield, this is right on the front line, so to speak, and they have video that you could transmit back into the living rooms of America, and that could have significant impact upon reducing war."

Finally, robots may change the emotional lives of users, and thus, relationships between humans. "We are deliberately creating an affective state in people to bond with these artifacts in ways that some people might consider unethical," Arkin says. "I have found papers by colleagues of mine in the philosophy community who have indicated that this promotes detachment from reality, especially among the aged, and other things as well too, that may not be appropriate."

Jeff Jonas: Applying the UN Declaration of Human Rights

More directly and obviously than many forms of innovation, software embodies the values of those who create it. This is particularly true of software used to monitor human behavior: in the extreme, it can be a tool that saves lives, or one that enables political repression. Software development therefore provides many examples of responsibility in innovation.

As a leading innovator in the field of data analysis, Jeff Jonas has thought deeply about the social and political implications related to technological advances in surveillance, the loss of privacy, and the use of computerized monitoring systems by governments and corporations. Through engagement with others outside the usual ambit of software developers, Jonas has developed approaches to assessing the possible long-term consequences of his work, as well as new technical approaches to sharing and anonymizing data.

Now a Distinguished Engineer at IBM, Jonas founded Systems Research and Development (SRD) in 1983 as a custom software house. SRD built many different kinds of systems, including a marketing data warehouse that collects information daily from over 4,200 data sources. This warehouse resulted in a database that tracks the transactional patterns of over 80 million people. Another system developed by SRD was designed to reveal relationships between individuals and organizations that would otherwise remain unnoticed. Initially created to help the Las Vegas gaming industry better understand who they were doing business with, only to later be applied to help companies and governments detect corruption from within, it was adapted for national security applications prior to the attacks of September 11. SRD was acquired by IBM in 2005.

In "Designing for Human Rights" (see http://jeffjonas.typepad.com/jeff_jonas/2006/02/responsible_inn.html), Jonas explores the relationship between human rights, and the systems used to collect and store data about large numbers of people, particularly for law enforcement.

"I took the Universal Declaration of Human Rights[20], which in Article 9 roughly says, 'Thou shall not arbitrarily detain, arrest, exile, torture, etc.' And the operative word there is arbitrary," Jonas says. "I posited a system that could possibly be used to arrest, torture, interrogate, and exile people—for law enforcement, intelligence, defense—or that could also affect people's credit and their ability to pick their own school, and it turns out that if you want to build a system that can uphold the Universal Declaration of Human Rights, you have to know who said it [the data recorded in the system], and when they said it."

Without a mechanism for error checking and correction, decisions made based on the system would be arbitrary. "There are several properties: provenance, attribution, pedigree—essentially 'source attribution,'" Jonas explains. "And if you don't have source attribution, you cannot have a system that's non-arbitrary—you cannot guarantee it will uphold the Universal Declaration of Human Rights."

Jonas suggests that technologies might be assessed in these terms, and given—or not—a "Universal Declaration of Human Rights compliance stamp."

"You probably can't stop people from doing R&D to see what's possible. But then how is it going to be deployed, what are its controls, what's the oversight and accountability? And on and on, a series of checkpoints about how it's going to be used," Jonas says. "Until you pair the technology up with the use, you can't even begin to assess its spectrum of good to evil. You have to go right to a use case and right to a governance model, and then you can start determining where it is going to sit on the spectrum of good versus evil."

Marc Smith: Invention, Mitigation, Accounting and Externalities

If responsibility is about effects, then systems of measurement and observation are key to any understanding of responsible innovation.

Dr. Marc Smith (http://www.connectedaction.net) is formerly a Senior Research Sociologist leading the Community Technologies Group at Microsoft Research in Redmond, Washington. His group focused on computer-mediated collective action, and he now studies and designs enhancements for social cyberspaces for Telligent Systems Inc. In particular, he is interested in the emergence of social organizations like communities in online conversation and annotation environments. The goal is to identify the resources groups need in order to cooperate productively.

Smith is the co-editor of *Communities in Cyberspace*, which explores identity, social order and control, community structures, dynamics, and collective action in cyberspace, and has developed software called Netscan that measures and maps social spaces in the Internet, starting with the Usenet. A related effort, Project AURA, allows users to associate conversations (and more) with physical objects using mobile wireless devices and web services.

Responsibility in innovation often comes after the fact. "The history of the technology is seize new power—then mitigate, mitigate, mitigate all the pathologies," Smith says. "How long was it from the Model T Ford to safety belts?"

Responsibility can be improved through measurement of effects. "May I suggest that your best method for mitigation is documentation of negative externalities?" Smith says. "You can 'govern' innovation when the language and the data to document negative consequences are more available, freely available, easily used. Then you have a technology regulation and negative externality problem, and that I think is one that is more tractable."

Part of that is stakeholder identification. Smith argues that it is easy to identify stakeholders, at least after the fact, because, "They're at the top of the legal documents that are served to you. That's how you identify the stakeholders, the ones that actually get the job done, make themselves known, tell you that you're creating negative externalities for them, and insist that you [provide] remedy."

But it's also important to recognize the initial position of most innovators. "Innovation typically comes from the people who are most squeezed out of the sweet solution space," Smith says. "You don't innovate unless you have to… Innovation is the behavior, I think, of marginal actors in an ecological landscape."

Mikko Ahonen: Open Innovation … and Radiation Safety

Mikko Ahonen is a researcher in the Department of Computer Science at the University of Tampere (http://www.uta.fi/hyper/henkilokunta/ahonen_en.php). His work touches the concerns of the Bassetti Foundation at a systemic level,

through studies in open innovation, creativity, and the diffusion of inno-vation, and through his work on the risks associated with mobile technology.

With respect to open innovation, Ahonen is not prescriptive. While open innovation makes it easier for stakeholders to learn about innovations that may affect them, it also diffuses the responsibility for those innovations.

If "you are encouraged to reveal your innovations, to speed up your innovation [process] or to speed up the diffusion of your innovation, what would happen to this responsibility?" Ahonen asks. "Okay, things will speed up, but where's the control? Is there control needed? Are we sharing risks somehow here?"

Innovation market places such as Cambrian House ("Home of Crowdsourcings," http://www.cambrianhouse.com/); CrowdSpirit ("Electronic Products Crowdsourcing," http://www.crowdspirit.com/); Fellow Force ("World's Portal for Open Innovation," http://www.fellowforce.com/); and Innocentive ("Where the toughest problems meet the brightest minds," http://www.innocentive.com/) face similar issues, Ahonen suggests.

With the open innovation process comes a diversity of funding sources, and typically, a mix of public and private monies. Recipients of public funds are (or should be) under ethical obligations to society as a whole. "Return to taxpayers is not only an ethical question, it's also about politics," Ahonen says. "You need to think about both sides, the public, government, and taxpayers, but also the company and its needs. To me and my colleagues, the BBC has been

an example of good behavior in many areas, like its opening of its archives."

As a long-term researcher in the telecommunications industry, Ahonen is also paying close attention to the issue of risks posed by radiation. In a recent discussion, Ahonen posed the question, "When will the doctors in Nordic countries wake up?" and quoted Dr. Robert O. Becker—twice nominated for the Nobel Prize—who noted, "I have no doubt in my mind that at the present time, the greatest polluting element in the earth's environment is the proliferation of electromagnetic fields. I consider that to be far greater on a global scale, than warming, and the increase in chemical elements in the environment."

Given the amount of money at stake, unbiased researchers are likely to face an uphill battle getting their results heard about this issue.

DESIGN

Roberto Verganti: Varieties of Design Innovation

Radical innovations, incremental innovations, innovations created ahead of market demand, or because of it, all create different types of responsibility. This is particularly observable in the world of design.

Dr. Roberto Verganti is in the Technology and Operations Management unit at the Harvard Business School, and Professor of Management of Innovation at the Politecnico di Milano, Italy. His research explores the management of innovation, particularly design driven innovation in rapidly changing environments.

Verganti places different types of design innovation along a continuum ranging from incremental approaches (such as user-centered design) to more radical, "design-push" innovations that change the meaning associated with products and services. With user-centered design, the emphasis is on eliciting the preferences of current and potential users, which tends to give designers a sense that responsibility rests with users, not themselves. Design-push innovations may bring disruptive changes, but don't typically rely on user input upfront.

"Design is making sense of things. My model is that you can improve the technology and the performance of a product, but you can also change its meaning," Verganti explains.

"Changes in meaning can bring as much disruption in society as technological change."

Examples of design-push innovations that have resulted in changes in meaning include the Nintendo Wii (which made video games physically demanding), the Apple iPod (which let users show their affection for music), household items that act as transitional objects, and television "reality shows."

While designers typically do want credit for their innovations (which aids responsibility), Verganti argues that responsibility rests with politicians, not engineers, scientists, and designers. "Coming back to Truman and the Bomb, was it President Truman or the engineers who were responsible? In my opinion, responsibility rests with the politicians… instead of training engineers to understand the politics of innovation, we need to train politicians about technology, which is not very easy."

Of course leaving decisions about innovation in the hands of politicians may mean leaving decisions about innovation up to powerful incumbents, who have a stake in resisting new innovations.

Michael Twidale: IRBs, Design, Empowerment, Accountability, Sustainability

If there is any single mechanism designed to monitor and ensure responsibility in innovation in academic settings, it is the Institutional Review Board (IRB).

Originally designed to protect the rights and welfare of human subjects of medical and psychological tests, at their best, IRBs can bring an important ethical dimension to science. But today, many scholars believe that IRBs have devolved into cumbersome bureaucracies that frustrate legitimate research for no good reason.

Dr. Michael Twidale is an associate professor at the Graduate School of Library and Information Science at the University of Illinois at Urbana-Champaign. His interests include "computer-supported cooperative working and learning; collaborative technologies in digital libraries and museums; user interface design and evaluation; user error analysis; visualization of information and algorithms; and the development of interfaces to support the articulation of plans, goals, and beliefs."

His critique of Institutional Review Boards (IRBs) is wide ranging, and based on an examination of their assumptions, their effects, and suggestions for more effectively achieving the good intentions behind the IRB process.

"IRBs were created from the best of motives, motives that I, as a very vociferous critic of the whole IRB process, fully support. I don't want to ditch those principles," Twidale says. "There should be very strong rigorous ethical guidelines, but when they are bureaucratized to the extent that you can't even talk to people, or you worry about whether you're allowed to talk to people, then something has gone wrong."

One problem is that the legalistic mindset is insufficient to address ethical questions about research. "IRBs are not as an ethical mechanism, but a legal mechanism. It's basically 'how

do we craft the consent form so that [subjects] can't sue us,'" Twidale says. "We're now in a very legalistic setting, where the IRB is talking to the lawyers, saying, 'what shall we do?' and it's safest for the lawyers to deny everything, and to say the IRB process applies to all research, except when it inconveniences the rich and powerful—when of course it doesn't apply."

Another problem is in how IRBs conceive of research. "The whole of the IRB approach assumes a certain mode of research, a carefully designed controlled experiment, as typically done in medicine," Twidale explains.

"Traditionally … you plan an experiment very carefully, then you go into your lab, you conduct the experiment, and then experiment is over. Then you analyze the results, and you sort of fit it into a larger theory and publish it," Twidale says. "Whereas, what I'm saying is, 'no, I live my research. Every working hour I am conducting research on human subjects. I am subjecting you to the stimulus of my voice and I'm measuring the feedback …' IRBs can't cope with that."

A third problem is in some of the unintended effects of IRBs. "It pushes research offshore, and this is starting to turn into a major competitive disadvantage for the United States," Twidale says. "This is becoming such a bureaucratic mess that people are saying, well why should I move to the United States to be fettered?"

Elevating concepts of ethics and blanket permissions, accountability, sustainability, and empowerment could help IRBs achieve their ends more effectively. "The solution is some sort of umbrella permission based on acceptance of certain ethical principles," Twidale says.

"I would design in my software technologies what is sometimes called technology of accountability," Twidale says. "You can override what it is the system says should be done here, but you sign off on it, so that when your boss said, why, why on earth did you do that, you should have a very good reason for it, because you've broken the rules."

Rather than persistence through time, "sustainability for me means having lots and lots of feedback loops, so I can find out things all the time as I go along," Twidale says. "I don't believe in the lone genius theory of innovation. I believe in involving lots of people in innovation, that's the participatory design approach."

"One ethical issue I see a lot in my work, and that is the idea of empowerment, and designing better computer interfaces that can convey complex ideas," Twidale says. "And that is something which can be incorporated into the public understanding of science, but also it allows people to contribute back."

The combination of engaged sustainability with empowerment might also help bridge the gap between scientists and policy makers. "One of the big problems in how science is portrayed is this concept that science knows the right answer. And that's clearly not the case—I mean even with global warming. Some politicians just want to know, 'well, is it happening or not?' And they can't cope with the answer, which is that we don't really know, but we're 95 percent sure," Twidale says. "Some will pause at that point and say, 'well, I'll hold out until it's 100 percent.' Earth will be fried to a crisp before that time. We need to convey the way that research is done and all that's missing, that uncertainty."

A SUMMING UP

A number of consistent themes come through in these discussions.

The first is that while innovation is relatively easy for most people to comprehend (or at least, most people have a mental model of it), responsibility comes in many forms that are much harder to gauge. Still, innovators themselves tended to have working definitions.

Several (including Chapela, Murray, and Ahonen) noted that only by remaining engaged outside their field—by making an active, ongoing effort to do so—can innovators be said to be responsible. Specialization can therefore lead to deterioration in the capacity for responsibility. Other discussions led to alternative definitions of responsibility. For example, responsibility might be defined the sum total of our downstream effects; considered in terms of research focus, that is, as wise allocation of limited intellectual, economic or environmental resources; as engagement with others in an active search for other stakeholders outside one's normal sphere; or a refusal to yield to particular political, religious, and economic powers.

Using something of Michael Twidale's "design by negation" approach, it's possible to approach responsibility in another way—that is, choosing to work on or to fund technologies with minimal payoffs or high social costs may be irresponsible. Indiscriminate acceptance of research funding from sources without clearly defined, consistent policies around downstream

effects of innovation and responsibility around it might be seen as “irresponsibility in innovation.”

A second theme that emerged during discussions was the possibility for approaches to responsible innovation that are not unique to particular fields, but which translate remarkably well from field to field. In addition to universal questions of value (e.g., who might be negatively affected by a particular innovation?), some specific practices to enhance responsibility can be identified. For example, researchers in most fields can consult the UN Declaration of Human Rights and think about the potential impact of their research; seek out interested parties in different fields; work to educate policymakers; and engage in public dialog.

The similarity across fields can be analyzed more closely by examining the mechanisms for responsibility that exist in different fields. Several authors have described different multistage models of innovation[21], but consider a simplified example involving stages of basic research, applied research, commercialization, and broad adoption. Responsibilities at each stage and in each field may be universal, or quite specific, as shown in Table 1.

Responsibilities in Different Stages and Fields of Innovation

	Discovery / Basic Research / Question	Applied Research / Funding	Commercialization / Engagement	Widespread Adoption / Legal Control / Governance
"Universals"	Do researchers retain the right to publish their findings? Are researchers engaged with others outside their field?	What restrictions are placed on innovators by their funders?	Is an organization willing to look beyond narrow cocerns of legal liability to more general approaches, such as the Precautionary Principle?	Are there mechanisms to respond when unanticipated consequences surface? Is there a commitment to mitigate negative externalities?
Genetics / Bioscience	Funding Enhancement Containment	Open access publishing Cotrolling release of GMOs into the wild	FDA approvals	Advertising guidelines; public discourse
Robotics / Computer Science	Defense funding Classified vs non-classfied research	UN Declaration	Safety	
Nanotechnology	Relinquishment?	Funding surveillance technology		Liability for nanoparticles
Design	RBs	User-centered design	Product safety	Packaging, environmental impact

A comparison of concepts across domains and in different stages of innovation, intended to be suggestive, rather than exhaustive or definitive.

A third theme that emerged from discussion is that there is nearly universal dissatisfaction with existing mechanisms intended to ensure some level of responsibility. While IRBs came in for particular criticism, researchers were also pained by the limits of understanding in the legislative sphere, of oversimplified public dialog, and the ineffectiveness of whistle blowing.

Several researchers touched on the issue of incentive structures, particularly in academia, that rewarded specialization, and the power of incumbent political and economic forces to promote questionable research or retard good work (especially in politically contentious fields such as climate studies and biosciences).

QUESTIONS FOR FURTHER RESEARCH

Based on these conversations, a number of possible strategies for enhancing responsibility in innovation deserve further investigation. Many could be further developed at a relatively low cost.

Cases. The diversity of fields involved in innovation, and the rapidly changing theoretical landscape (especially with regard to sustainability), suggest that case-based approaches to expanding understanding of responsibility and irresponsibility are needed. Much of the Foundation's work in the U.S. so far has focused on innovators' perspectives, but a similar set of conversations with policy makers would be helpful.

Methods. The handful of cases described here point out techniques that might be applied more widely. Can new measurements of negative externalities help improve technology regulation? Can scenario planning be a useful approach for developing and communicating possible futures? Is the UN Declaration of Human Rights a useful reference document for innovators?

Boundaries, edge cases, and disruptive technologies. Are there technologies that should be relinquished, or conversely, technologies that should receive more funding and attention? How can they be identified? When and how will it be possible to get beyond the "utopia versus oblivion" mindset that seems to dominate many conversations about new technologies such as enhancement?

Additional fields. What do the greentech bubble and the current mania for "sustainability" imply about possibilities for responsibility in innovation? Is the green-tech industry powered by people with intrinsic motivations that should be factored in, or which might be looked at as responsibility?

Improving existing mechanisms. Institutional Review Boards, ethics committees, the precautionary principle, sustainability as a value, and other efforts that touch on responsibility might be tied together in new ways. IRBs in particular seem in need of repair.

Building communities of practice through engagement with policy makers, and with other innovators. "Community of practice" has often implied a narrow discipline, but encouraging responsibility means reaching beyond a particular specialty. Generalists may have credibility problems in particular scientific and academic environments, but specialists seem to be part of the problem. The fields of science and technology studies (STS), innovation studies (as done in business schools), and bioethics all seem particularly promising.

Language. Researchers in different fields often use different terms to describe similar concepts related to responsibility in innovation, while terms like "sustainability," "responsibility," and "innovation" take on different meanings in different fields. Some effort to unify the language around responsibility in innovation would clarify discussions and strengthen the most widely applicable ideas.

Media strategy. Debates over complex bioethical points conducted in 15-second soundbites on television are not capable of conveying the nuances involved in decisions facing policy makers. Finding ways to engage in public discussion without oversimplifying the issues is critical.

Cherry picking. Are there areas where it might be possible to bring more social responsibility into the innovation process (keeping in mind our broad definition of innovation)? Genetics, nanotechnology, robotics (GNR) and design, seem particularly promising areas to follow; it is less clear if there are policies that might be tracked in the same way.

Taking responsibility for the power of innovation by anticipating the future, and finding ways to improve the likely effects of innovation, is a desired goal for most innovators. Pursuing these and other questions may give them the means to do so.

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[1] A concept of the Bassetti Foundation: "L'innovazione è la capacità di realizzare l'improbabile."

[2] See the *Theory of Inventive Problem Solving (TRIZ)* and the work of The Altshuller Institute (http://www.aitriz.org/), and Genrich Altshuller (1996), *And Suddenly the Inventor Appeared: TRIZ, the Theory of Inventive Problem Solving* (paperback).

[3] The quote is from Peter Drucker's Innovation and Entrepreneurship (1985). Drucker also defined innovation as "Change that creates a new dimension of performance." The final two arose in various informal conversations at the Bassetti Foundation. The last two arose in various informal conversations at the Bassetti Foundation and elsewhere.

[4] See "What Have You Changed Your Mind About?" (http://www.edge.org/q2008/q08_2.html) "…did the nuclear bombings of Hiroshima and Nagasaki bring World War Two to an end? Until this year I used to say, perhaps. Now, because of new facts, I say no."

[5] See Gerhart, Peter (2008) "Responsibility and Proximate Cause" (http://works.bepress.com/peter_gerhart/4), accessed November 26, 2008.

[6] See Whittingham, R.B. (2008). *Preventing Corporate Accidents: An Ethical Approach*, p 24 discusses externalities as "... the innate propensity of the corporate body, as far as possible, to 'externalize the costs' of doing business in order to maximize profitability. Historically, this process of externality has taken place at the expense of the vulnerable and less powerful sections of society, such as the workforce and the public as well as the environment. It operates on the principle that every cost that can be externalized is a cost that the company does not have to pay, thus increasing the amount of profit that can be generated..."

[7] Wikipedia has a surprisingly good discussion of this issue; see http://en.wikipedia.org/wiki/Moral_hazard, accessed November 26, 2008. For purists who discount Wikipedia as a source, this article contains a good set of other references.

[8] See the Usability Professionals' Association's discussion of user-centered design at http://www.upassoc.org/usability_resources/about_usability/what_is_ucd.html, accessed November 27, 2008.

[9] See, for example, the IRB Forum, http://www.irbforum.org/, accessed November 27, 2008.

[10] See the STS Wiki at http://en.stswiki.org/index.php/Main_Page, and the web site for the European Association for the Study of Science and Technology at http://www.easst.net/, both accessed November 26, 2008.

[11] See Report of the World Commission on Environment and Development, http://www.un.org/documents/ga/res/42/ares42-187.htm, accessed August 5, 2008.

[12] See, for example, Sustainable Innovation 08 (http://www.cfsd.org.uk/events/tspd13/tspd13_programme.htm); Real Innovation, (http://www.realinnovation.com/theories_strategies/sustainable_innovation.html); and *Sustainable Innovation: The Organisational, Human and Knowledge Dimension* (Contributing Editor: René Jorna)(http://www.greenleaf-publishing.com/productdetail.kmod?productid=682), all accessed November 17, 2008.

[13] The Wikipedia discussion on accountability is surprisingly good. See http://en.wikipedia.org/wiki/Accountability.

[14] *The Self-Restraining State: Power and Accountability in New Democracies*, eds. Andreas Schedler, Larry Diamond, and Marc F. Plattner (Boulder and London: Lynne Rienner Publishers, 1999), p. 13.

[15] See *Communication from the Commission on the Precautionary Principle* (http://ec.europa.eu/dgs/health_consumer/library/pub/pub07_en.pdf).

[16] A summary of articles published about Chapela's experience is at http://www.historycommons.org/entity.jsp?entity=ignacio_chapela; there has also been extensive coverage in the *San Francisco Chronicle*, "Embattled UC teacher is granted tenure," May 21, 2005 (http://www.sfgate.com/cgi-bin/article.cgi?f=/c/a/2005/05/21/BAG8VCSGL41.DTL). The announcement of the research and the controversy around it was covered by the BBC. See "Maize GM threat," BBC, Wednesday, March 13, 2002, http://news.bbc.co.uk/2/hi/programmes/crossing_continents/1871216.stm, and "Doubts over Mexican GM maize report," BBC, Sunday, April 14, 2002, http://news.bbc.co.uk/2/hi/science/nature/1911535.stm.

[17] See the Bassetti Foundation "Interview with Dr. Ignacio Chapela," http://www.fondazionebassetti.org/en/ubois/2006/11/an_interview_with_dr_ignacio_c.html.

[18] See http://www.cc.gatech.edu/ai/robot-lab/, accessed March 22, 2009

[19] Video is at http://ftp.delta-v.org/aircraft/vid/224Helicopter_Kills.mpeg; discussion is at http://www.boards.ie/vbulletin/showthread.php?t=152665.

[20] See http://www.un.org/Overview/rights.html, accessed July 12, 2008.

[21] See, for example, Models for Innovation Diffusion (Quantitative Applications in the Social Sciences) by Vijay Mahajan, Robert A. Peterson.

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