Collingridge's Dilemma and the Early Ethical Assessment of Emerging Technology: The Case of Nanotechnology Enabled Biosensors

Jenifer A. Buckley^a

^a Michigan State University

Department of Community Sustainability

480 Wilson Rd., #131

East Lansing, MI 48824

US

jenifer.a.buckley@gmail.com

Jenifer Buckley is an American Association for the Advancement of Science - Science & Technology Policy Fellow hosted by the U.S. Environmental Protection Agency. Her scholarly interests focus on how public agencies interact with the entities that they serve. She is particularly interested in how policy is “made” in enforcement actions just as it is made in more formal policy-making processes. She holds a PhD from Michigan State University, where she researched the food safety regulation of artisan food processors.

Paul B. Thompson^b

^b Michigan State University

W.K. Kellogg Chair in Agricultural, Food and Community Ethics

Department of Philosophy

368 Farm Lane, #526

East Lansing, MI 48824

US

thomp649@msu.edu

Professor Thompson is the author of 13 books and editions, such as *The Spirit of the Soil: Agriculture and Environmental Ethics*; *The Ethics of Aid and Trade*; *Food Biotechnology in Ethical Perspective*, and co-editor of *The Agrarian Roots of Pragmatism*. He has served on many national and international committees on agricultural biotechnology and contributed to the National Research Council report *The Environmental Effects of Transgenic Plants*. He is a Past President of the Agriculture, Food and Human Values Society and the Society for Philosophy and Technology, and is Secretary of the International Society for Environmental Ethics. He has continuing interests in environmental and agricultural ethics.

(Corresponding) Kyle Powys Whyte^c

^c Michigan State University

Department of Philosophy

368 Farm Lane, #503

East Lansing, MI 48824

US

517-432-1034

517-432-1320

kwhyte@msu.edu

Kyle Whyte holds the [Timnick Chair in the Humanities](#) in the Department of Philosophy at Michigan State University. He is a faculty member of the [Environmental Philosophy & Ethics](#) graduate concentration and serves as a faculty affiliate of the American Indian Studies and Environmental Science & Policy programs. His primary research addresses moral and political issues concerning climate policy and Indigenous peoples and the ethics of cooperative relationships between Indigenous peoples and climate science organizations. He is an enrolled member of the Citizen Potawatomi Nation.

Funding

This work was supported by the National Science Foundation under grant number SES-1055542.

Collingridge's Dilemma and the Early Ethical Assessment of Emerging Technology: The Case of Nanotechnology Enabled Biosensors

Abstract

Early ethics assessment of technological innovations promises to produce greater sensitivity to the potential for unfair impacts and problems of consent and distrust, yet faces a key challenge: ethical issues are hard to consider in advance. For technology, Collingridge (1980) describes a dilemma in which design inevitably comes before ethical assessment since the design influences heavily how the technology will interact with society. In this paper, we review an approach we undertook to early ethical assessment of nanobiosensors adapted for traceability systems to enhance food safety and animal and plant health monitoring. The approach is based on “expert committee” methods for integrating information from a range of disciplinary perspectives. It attempts to address the dilemma of early assessment through an integrative workshop discussion of how nanobiosensors *should be* represented during public engagement. Following the workshop, we conducted a metanalysis of the discussion transcript. The metanalysis shows that while the workshop approach responds to preliminary needs for the development of ethical assessment tools and processes, it also highlights inescapable challenges of ethical analysis. We identify key challenges and discuss their theoretical implications and implications for participatory assessment. We consider workshop discussion itself, and we consider the workshop as modeling one part of a cumulative process of assessment.

Key Words:

Ethics and Technology Assessment, ELSI, nanotechnology, biosensors, participatory assessment, innovation

1. Introduction

Researchers and policy-makers have long searched for better tools to anticipate the unwanted effects of technological innovations, and for at least four decades “unwanted effects” have included public protests against their implementation. Persistent resistance to the use of genetic engineering to improve agricultural crops and animals, continuing debates over advanced reproductive technologies like adult-cell mammalian cloning, and the uncertain future of nanotechnology and synthetic biology have increased awareness of the potential for public resistance among technical elites. While there continues to be inquiry and theory-building regarding the causes of protest and opposition to emerging technologies, other lines of scholarship attempt to address the phenomenon more proactively. Within this latter group,

research on technological ethics has been especially attentive to the tension between appropriate, beneficial innovations, on the one hand, and forms of technological change that warrant opposition in virtue of their unintended, unwanted and generally unacceptable consequences, on the other.

Beginning with Hans Jonas' *The Imperative of Responsibility* (Jonas 1984), work in technological ethics has laid equal emphasis on methods for anticipating the outcomes of innovation more effectively and on reflective and evaluative procedures. The anticipatory emphasis of technological ethics has analogs in risk assessment and scenario planning, while the procedural emphasis overlaps with research on participatory deliberation in the social and policy sciences. Indeed, the call for public involvement and consultation in the design of technological systems was sounded among management science and operations research professionals in the 1960s. Technological ethics can be distinguished from other related forms of anticipatory and procedural scholarship primarily in its goal of stating the normative commitments that are embedded in design assumptions, policy frameworks and in the mindsets of various stakeholders explicitly (Churchman 1968). Practitioners in technological ethics may or may not make recommendations or prescribe a given course of action, but they do emphasize clarity about when values are asserted as a rationale for choices in the design or implementation of technology. Understood as an analytic approach, ethics differs from some participatory methods for early assessment precisely in its assertion that explicit articulation of norms and value assumptions should be an important focus of the assessment process. Exploring how to assess ethical issues of emerging nanotechnologies remains an important area of inquiry, whether one believes that they will present risks of a sort that have been dealt with before or entirely new risks with which we have no experience (Rehmann-Sutter and Scully 2010).

Indeed, the belief that there is a sharp line separating R&D and the eventual deployment of technology has come to be seen as one of the implicit value judgments that needs to be placed into question in a technology ethics assessment. Contrary to assumptions that may have been operative in Jonas's approach, there is no clear moment in the evolution of a technology when decision makers can pause and review its social and environmental significance reflectively. David Collingridge (1980) wrote that by the time one can truly anticipate outcomes, most of the important design and development decisions have already been made. Nonetheless, scholars and policy-makers continue to call for ethical assessment at the earliest design phases of nanotechnology (Brey 2012), in line with a tradition in the philosophy of technology that derives from the work of Jonas, while increasingly arguing that such assessments must engage members of the public (and especially stakeholder communities) (Feenberg 1991; Feng and Feenberg 2008).

Even if specific outcomes from a technology cannot be predicted with accuracy, early ethics assessment promises to create greater awareness of the potential for unfair impacts, especially among vulnerable populations. When technical elites become aware of this potential, they may become more sensitive to such impacts in their design activity. The hope is that even if an early ethics assessment is not definitive, awareness of ethical sensitivities associated with the expected trajectory of a technology could steer the design of nanotechnologies. At the same time, participatory assessment activities themselves have impacts, and the very process that is intended to improve the design and implementation of innovations can become a source of distrust. Approaches to early assessment that call for public participation are thus met with a challenge that can be understood as a specific form of Collingridge's dilemma. As will be discussed at greater length below, even an activity that is intended to fully engage and empower non-expert

stakeholders must be “designed”: It will not only deploy a theoretical model of an engagement process, it must of necessity provide non-expert participants with some representation or narrative of what the technology involves. Thus even “early” involvement of the public requires a *selection* of what story to tell, and as such involves value judgments that reflect assumptions about how the technology will be developed, and what might matter to stakeholders.

Ethics assessment promises to be particularly important for nanotechnologies that will be implemented within complex supply chains, such as agrifood in the United States, as there are numerous actors who may be impacted differently and whose situations designers are not aware of in advance. Advancements in food and agricultural technology have placed most food consumers in positions of both ignorance about the sources of their food and the methods of its manufacture and processing. This gap in consumer knowledge makes novel food technology vulnerable to stigmatization and social amplification of risk (Thompson 2015). In order to make a very early ethics assessment of nanobiosensors applied to management of livestock disease risks, we convened a workshop among a group with expertise reflecting different points of entry to the animal products supply chain. This paper analyzes transcripts from that workshop with an eye toward accomplishing the explicit articulation of ethical assumptions and normative value judgments that has always been the focus of technological ethics.

We begin in section 2 by discussing the opportunities and challenges of early ethics assessment. Section 3, then, provides the basic background for the emerging technology explored in the workshop. This is followed, in section 4, by a discussion of why the design and implementation of this technology may pose ethical concerns. Section 5 describes the workshop method that we employed as a way of initiating early ethics assessment, and section 6 covers the

results of having done the workshop. The discussion in section 7 explores dimensions that we found to complicate early ethical assessment and considers theoretical and practical implications.

2. Opportunities and Challenges of Early Ethics Assessment

As noted above, technological ethics emphasizes explicit articulation of assumptions about the putative risks, costs and benefits expected to flow from a technological innovation, as well as about patterns or methods of technology adoption or use that could have ethically significant dimensions. Much of the literature that has risen to the forefront in recent thinking on the assessment and governance of technical change has emphasized participation from members of the public and key stakeholder groups. There are at least three distinct reasons for regarding participation as important. First, developing an assessment or governance procedure that includes participation by a wide variety of stakeholders and potentially affected parties brings new *information* into the assessment process. No single body of expertise or experience can hope to capture the full range of ways in which a technology interacts with the environment and social institutions, so bringing people who are familiar with a broad range of human activities (as well as a broad knowledge of the environment) is an important way to reduce the probability of overlooking a potential outcome that would have been obvious to someone with a different body of disciplinary or experiential knowledge (Shrader-Frechette 1991; Jasanoff 2003; Morgall 2010).

Second, participants bring *values* to the assessment process that might not be reflected among a professionalized assessment elite. People from different racial, class, cultural and gender backgrounds will tend to regard potential outcomes differently, hence broadening the range of perspectives included in the assessment process reduces the likelihood that the ethically

most significant outcome for some important group will be neglected in the assessment process. Finally, to the extent that technologies constitute an important component of the infrastructure for modern society, decisions about technology become indistinguishable from more traditional legislative decision making with respect to their potential impact on people's lives. In this respect, participation in an assessment process becomes crucial to the *legitimation* of the ultimate decision to go forward with a given package of tools and techniques (Brey 2012).

On each count, participatory approaches to early assessment augment and strengthen an ethics based assessment. Greater information broadens the basis for anticipating patterns of use and potentially adverse outcomes, while no one is better placed to express key value judgments than the affected parties themselves. Legitimation simply *is* a key norm for technological ethics. However, participatory approaches suffer from two weaknesses. First, there is no reason to presume that a participatory approach will produce the explicit articulation of ethical dimensions that has always been the focus of technological ethics. Ethical norms and assumptions are often as implicit and taken for granted among stakeholder groups as they are among technical elites (Douglas 1975). There is thus a role for interpretive expertise in identifying and articulating the ethical significance and rationale behind the statements of technical experts and lay stakeholders, alike.

Second, Collingridge's concern poses a key challenge to technology assessment or anticipatory governance that involves significant participation on the part of non-experts. Specifically, if technical experts themselves are very limited in their ability to adequately anticipate the application and outcome of innovations in technical means, there is no reason to presume that participants will be able to envision outcomes with enough clarity to fulfill the three desiderata for participatory assessment. There is thus a need to conduct participatory

exercises through scenarios or descriptions to provoke the imagination of stakeholders so that new information and values can be elicited. Thus there is an important sense in which early assessment of ethical issues itself calls for an even earlier assessment that aims to provide enough background on the innovation and its likely areas of application so that stakeholders can actually participate in an evaluation process in a meaningful way.

One approach to early assessment is called the ethical matrix (Mepham 2000; Croney and Anthony 2010; Brey 2012). It uses a two dimensional matrix as a heuristic device for the deliberative activities of a group involved in the assessment process. Usually (though not always), the horizontal axis of the ethical matrix has key ethical categories, such as (1) welfare, (2) autonomy and (3) justice (fairness); while the vertical axis lists domains in which the categories might be relevant. Some versions of the matrix utilize categories that list potential affected parties, such as “current generations,” “future generations”, “non-human animals” and “ecosystems” while others might break the list of affected parties into actors within the supply chain who will both be affected by the new technology and who may have responsibilities to other actors: primary producers, processors, retailers, consumers. During the assessment exercise, participants fill in the matrix by describing each ethical category as it affects each actor. The ethical matrix, then, helps to visualize a comprehensive set of moral concerns for each actor. Applied to technology design, the matrix can be re-drawn for each change made by the designers.

This approach helps those engaged in an assessment process to work through the potential implications of new technology by encouraging them to entertain ethical questions that might arise. It is thus primarily applicable to the second goal sought by an emphasis on participation, the attempt to provide a more comprehensive survey of the values that should be

reflected in decision making on technology. However, the ethical matrix, and any approach like it, requires two aspects to be known in advance before it can be applied early on for an emerging technology. First, the ethical categories must be relevant to the supply chain into which the emerging technology will be implemented. Second, there must be a reasonably accurate list of actors or affected parties. But this is precisely the sort of knowledge that remains speculative at the early design phases of emerging nanotechnologies. Gaining this knowledge requires that ethicists can find out what sorts of relationships among actors—who may range from designers to users—will crystallize after implementation of the technology. Particular ethical issues are likely to be best ascribable to the relationships, not to individual actors. There is thus a profound sense in which use of the ethical matrix only reinforces Collingridge’s dilemma.

With these challenges in mind, we convened a workshop as research activity that would occur before something like an ethical matrix type of early assessment would be possible. The activity was conceived as one component of a cumulative assessment process in which affected parties, relationships, and ethical categories are identified for further exploration in subsequent activities. The method is applied to the case of biosensors enabled by nanotechnology that have been proposed for use in U.S. agrifood traceability systems. The primary activity convened locally available individuals with expertise in nanobiosensor design, as well as various aspects of the supply chain for animal products (discussed below).

The goal was to integrate information that each of these individuals could supply on anticipatory governance and justice issues as they understood them. We requested each of our expert participants to discuss which actors should be engaged in a fully participatory type of anticipatory governance exercise, how they should be engaged, and how the integrated information elicited from a participatory workshop could be communicated back to the

designers. The co-authors of this paper then analyzed participant presentations and discussion after the workshop, focusing first on what ethical categories arose most frequently. We then analyzed various themes associated with these ethical categories and the morally salient relationships that presenters and participants associated with the themes. Morally salient relationships are those connections that will come about or be emphasized by the new technology and that have moral implications to them, such as trust, distrust, empowerment and exploitation.

The results discussed in this paper produce an initial landscape of morally salient relationships that are important to consider in relation to the development of biosensors enabled by nanotechnology. Yet we found through engaging with this method that there are various dimensions of how relationships among actors are envisioned by experts and entrepreneurs involved at the early stages of development which would complicate attempts to do further ethical assessment, like the ethical matrix and similar approaches. These dimensions include how democracy, efficiency and public goods are articulated, as well as potential problems that occur given that actors such as small producers are not in the position to speak on their own behalf.

3. Nanobiosensors and Agrifood Traceability

A biosensor is an analytical device composed of a biological sensing element (bioreceptor) in close proximity to a transducer; the interaction between the bioreceptor and the target analyte is converted into an electronic signal for direct reporting (Zhang et al. 2009). Biosensors are attachable to human skin as a way of monitoring metabolic properties. Applications include the reporting of health problems. They are also attachable to non-living objects for monitoring their physical and chemical properties while they transition through complex supply chains. Applications include reporting on food spoilage.

Nanotechnology can change active biosensors. Nanostructures, nanoparticles, nano-wires and nano-tubes can be incorporated into biosensors in ways that facilitate more rapid, sensitive and specific detection, while remaining portable, field-operable, and inexpensive (Pal and Alcocilja 2009). Such nano-enabled biosensors, or nanobiosensors, will be adapted for traceability systems in ways that seek to enhance food safety and animal and plant health monitoring. Traceability is the ability to follow or study in detail the history of a certain activity or process. In the U.S., the term has been applied to the monitoring of livestock health and transfer in food production processes, and can be implemented by governments and private industry. The ability to trace contaminated food and potentially diseased animals has been projected as a high priority (Holman 2006; Kuzma et al. 2006), especially given the animal and economic devastation brought about by bovine spongiform encephalopathy, foot and mouth disease and bovine tuberculosis outbreaks (Popper 2007; White 2007; Bickel 2010).

Zoonotic diseases like Bovine Spongiform Encephalopathy (BSE or mad cow disease) have led to substantial economic losses. In a case where it was reported in a dairy cow in the state of Washington in 2003, 53 countries, including major markets (Japan, Mexico, S. Korea & Canada) banned imports of U.S. cattle and beef. U.S. beef exports were valued at \$3.95 billion and accounted for 9.6% of U.S. commercial beef production in 2003. In 2004, even though Mexico and Canada partially reopened, exports declined by 82%. U.S. beef industry losses arising from the loss of beef and offal exports during 2004 were estimated at \$3.2 – \$4.7 billion (Coffey et al. 2005).

Non-zoonotic diseases, like Bovine Respiratory Disease (BRD), are also cause for concern in feedlot cattle in the U.S. In 1999, the National Animal Health Monitoring System (NAHMS) conducted a study of feedlots with a 1000- head or larger capacity, in the 12 top cattle

feeding states. In this sample, most feedlots (97.4%) reported an overall BRD incidence of 14.4%. While the disease generally presents a low mortality rate (1%), economic losses also include decreased weight gain and significant costs related to necessary treatment, such as antimicrobials, and non-steroidal anti-inflammatory drugs (Snowder et al 2006). The economic cost associated with BRD has been estimated to cost the U.S. beef industry \$750 million annually (Griffin 1997).

These examples clearly demonstrate the need for efficient and effective animal identification and traceability systems in the U.S. However, even where mandatory identification and tracking are implemented, economic losses may still be significant, as the spread of the disease may be faster than the capacity for detection and control allowed by the current tracking technology. For example, the foot and mouth disease outbreak in the United Kingdom in 2001 caused the slaughter (for disease control) of 594,000 cattle, 3,334,000 sheep, and 145,000 pigs. At the time of the outbreak, some productive animals in the UK were individually identified, however, in spite of this, losses added up to approximately \$10 billion (Thompson 2002).

Speed of response is important for maintaining and improving public health gains in food recall situations. A traceability system equipped with nanobiosensors in livestock could potentially monitor for important pathogens, detect metabolic disease, enhance reproductive efficiency, improve product quality, maintain animal welfare, screen inputs (feed, air, water), and be linked to animal identity and location. Examples are many. Biosensors could be placed in milk collection systems for detecting chemical residues or zoonotic pathogens. A biosensor could monitor in real time as milk is being collected, checking for chemical, biological, and pharmaceutical residues of interest that would then be gated into different collection vessels. One tank could contain the suspected residues, another would have safe products.

Nanobiosensors could measure nutrient output in feces or urine to monitor animal nutrient status. Biosensors could also be used to measure feed intake, water intake and core body temperature as an early indicator of adverse health events. Measurements of blood parameters would give early warning of impending metabolic diseases. Nanobiosensor signals could be filtered and translated by computer and summarized as management advice or warning messages. In terms of animal welfare, biosensors could be used to monitor for markers of “bad welfare” such as cortisol or other physiological markers.

4. Potential Ethical Issues

The introduction of nanobiosensors into agrifood supply chains certainly presents the possibilities of ethical issues that will affect various actors. That is, various morally salient relationships will emerge among actors around applications of nanobiosensors. Morally salient relationships are those connections that will come about or be emphasized by the new technology and that have moral implications to them, such as trust, distrust, empowerment and exploitation. For example, some producers may see their economic choices reduced in favor of more powerful corporate and governmental actors. Other actors may feel they were not consulted about how nanobiosensors would fit into their day-to-day business. The introduction of nanobiosensors will likely spur a constellation of these morally relevant relationships. Given the many unknowns regarding by whom nanobiosensors will be introduced and who will use and be affected by them, it is impossible to be fully confident about which morally salient relationships will emerge in complex supply chains and what ethical categories will be worth including in something like an ethical matrix or a stakeholder workshop. What can be known is that if there are any moral issues

at all, then they likely would fall under two broad areas, (1) anticipatory governance and (2) justice, which we will describe in what follows.

Governance concerns whether nanobiosensors will be introduced through democratic processes or authoritative compulsion. If nanobiosensors are *not* introduced through democratic processes, then it is reasonable to expect a host of issues such as the failure to achieve appropriately actors' consent, morally unjustified paternalism, government/corporate distrust and design flaws that pass greater costs and competitive disadvantages onto users and other actors. If they are introduced through democratic processes, then a range of moral issues still remain, even some of the ones listed, but more having to do with the nature of the processes, such as whether they provide meaningful opportunities for stakeholder and public participation or whether they serve to change power dynamics in the supply chain.

Justice compensates for the possibility that questions of governance may not be sensitive to important differences of actors in the supply chain, such as race, class, gender, and disability. Justice concerns whether nanobiosensors are introduced in ways that place further stress on disadvantaged populations, such as small producers. If nanobiosensors are *not* introduced *justly*, then perceptions of exploitation, social distrust, discrimination, procedural unfairness and disproportionate impacts (against already disadvantaged groups) are likely to arise. The potential for such perceptions should be understood in dual sense. First, the absence of just procedure is a factor that increases the probability of social resistance to emerging technology (though such resistance may or may not be realized in any particular case). In this respect, justice is consistent with the presumed economic interests of technology developers. But second, the potential for perceptions of exploitation and distrust is a substantive dimension of whether or not nanobiosensors are consistent with ethical norms for emerging technology. Ethical norms for

technology development require that steps are taken to ensure that the supply chain actors least able to exert influence on supply chain structure perceive nanobiosensors to be consistent with their interests. Justice also encompasses questions of how welfare is distributed based on the technology (distributive justice). The issue of autonomy also falls under procedural justice, insofar as autonomy concerns whether policy and implementation processes allow people the opportunity to determine their own destinies, as individuals and groups.

5. The Workshop

Our workshop, funded by a National Science Foundation (NSF) grant titled "Anticipatory Workshop on Agrifood Biosensors", was held at Michigan State University over two days in December 2010. Twenty participants represented academe, industry and the public sector, including eleven specialists in biosensor design and development, zoonosis in livestock, animal production, regulation, tracing and tracking technology, ethics of emerging technology, public engagement, social justice and both technical and social dimensions of standards development. The workshop consisted of 10 presentations that outlined the potential supply chain contexts in which nanobiosensors would be introduced, and attendant anticipatory governance and justice issues.

The workshop format was an expert forum modeled after scientific committee processes in which individuals with complementary domains of specialization convene to develop an integrated statement of what is known about a given problem, and to identify key areas for further research. The approach has been generalized as a method for sustainability science (Carpenter et al. 2009). Over the last thirty years, this method has been extended to an array of ethics and values problems in the medical arena by the Hastings Center of Garrison, NY

(Callahan 1999). In the case of this workshop, the goal was to produce integrated information, in the form of peer reviewed articles, on the potential social and ethical aspects of nanobiosensors.

The following three questions framed the workshop:

1. What are some of the potential anticipatory governance and justice issues that should be addressed early on?
2. How can semi-structured stakeholder workshops and other research activities be used to understand these issues?
3. How should information on the social and ethical dimensions be looped back to technology developers and policy-makers?

The questions were developed early on in the planning of the workshop with feedback from the potential participants and presenters. The participants were made aware that “anticipatory” referred to the idea of anticipatory governance and justice as defined in the previous section.

Questions 1 and 2 were intended to structure the workshop presentations and discussions around moral issues as well as foster discussion about the actors who would be significant in the supply chain. Question 3 aimed at structuring conversation around the topic of uptake, and what would be needed for technology developers to change their practices based on ethical analysis.

The content of the workshop included both the actual presentations and the discussions in between them, all of which were audio recorded. Qualitative analysis of workshop presentations and discussions was conducted using a hybrid model of open coding, which combines features of

formal coding and grounded theory (Rubin and Rubin 2005; Corbin and Strauss 2008). Concepts that are central to the study guide coding, and new concepts emerge within this analytic framework. This approach allowed us to analyze the data with a focus on known ethical issues and yet revise the framework to accommodate unexpected findings. Audio files of the workshop discussions were reviewed, and remarks concerning morally salient relationships were compiled in a spreadsheet.

All relationships were depicted in the format “A relates to B,” where A and B were both human actors. For example, discussion about the advantages of biosensors that provide livestock producers with early indication of an animal health problem was depicted as “Some innovators empower producers.” Two challenges arose in this approach. First, discussion included third-party statements about relationships between two parties. For example, livestock producers were not present at the workshop, but industry representatives and academics spoke of the ways in which biosensors might empower or constrain producers. For this reason, we expanded our analytic framework to identify the actors who made claims about relationships. This allowed another level of analysis that reveals what some parties believe about the moral situations of others. Second, participants spoke of non-humans such as *data* and *technology* as actors. For example, some participants stated that data might put the industry at risk. We treated these statements as synecdoche; that is, participants were using a part, e.g. data, to refer to a whole of humans and non-humans, e.g. those who control the connection of and access to data and hence put industry at risk.

Based on workshop notes, and a review of the workshop audio recording, the presenters and participants focused on four categories of morally salient relationships: autonomy, fairness, risk and trust. We define these categories as follows, based on how we interpreted the data.

Autonomy concerns whether the technology implementation will encourage or discourage the independence, control or knowledge of some set of actors. Fairness concerns whether benefits and burdens are distributed proportionately, in ways that do not force some actors into bad compromises, and such that actors have adequate access to the decision making mechanisms by which policy decisions are made. Risk concerns issues of who bears the potentiality of harms. Trust concerns whether actors in the supply chain relate to one another in ways where each believes that his or her interests affect those who can impact them.

This method was developed, in part, as an approach for analysis of workshops, focus groups, or other events at which ethically significant discussion occurs but for which few or insufficient plans have been made for analysis. In our case, the three questions that framed the workshop discussion proved to be too broad to guide the project assistants who took notes during discussion, and workshop notes provided an uneven source of data. The method aided in creating an analytically rich framework based on the audio recording of the discussion while obviating the need for transcription.

6. Results

Approximately 11 hours of workshop discussion were encoded for a total of 79 remarks related to autonomy, fairness, risk and trust. Within these categories, specific themes were identified.

Table 1 here.

Table 2 here.

Autonomy

Participants raised issues concerning the implications that biosensors have to the autonomy of individuals or groups. Discussion focused particularly on ways in which autonomy may increase or decrease, how an individual's or group's capacity for independence or control is affected, and the consequences of biosensors in terms of how potential users would have to be educated about how to use them.

Table 3 here.

A. Fairness

The allocation of the benefits and costs of biosensors depends on the stakeholders involved in decision making and standards setting. Workshop participants raised issues of democratic capitalism, participatory decision making, and procedural justice. The extent to which a group is able to exploit a technology—or to which a group is exploited by it—depends in part on the networks in which the group participates. The distribution of regulatory burdens was also a concern.

Table 4 here.

B. Risk

Biosensors may mitigate some risks and introduce new ones. They produce potential benefits for animal welfare, public safety, and the environment, while also introducing unknown toxicological risks and a need to address information security.

Table 5 here.

C. Trust

Questions of risk entail issues of trust, particularly related to information ethics, privacy and accountability.

Table 6 here.

The above tables are summarized in Figure 1, which presents actors and the morally salient relationships between them in a network graphic.

Figure 1: Graphical depiction of results, showing actors and the morally salient relationships between them

Figure 1 here

7. Discussion

The analysis of the workshop and discussion indicates a number of morally salient relationships involving the agents and patients and themes. But whether this information could be used in order to trace the potential supply chain, and ultimately do something like an ethical

matrix or similar approach, may depend on how participants and presenters discussed morality. In this section, we identify four key findings and elaborate the study's theoretical implications and implications for participatory assessment processes.

First, workshop participants used synecdoche like “the market,” “data” or “biosensors” to describe morally salient relationships. Although participants may not acknowledge or recognize it, these figurative devices implicitly stand for more complicated groups of actors. “Biosensors” likely stands for the array of designers and innovators who are currently working on developing nanobiosensors, who may or may not be aware of one another's activities and who may have different funding sources. So “biosensors” is being used as a term that refers to a more or less understood group of actors who are considered to be in some relation with a more specific or similarly amorphous group, such as small producers or consumers.

Second, “broad stakeholder input” may signify different things to different people. The participants in this workshop who emphasized the importance of broad stakeholder input in biosensor technology included an innovation scientist, a state veterinarian and an innovator. Stakeholders, for them, represented actors within existing supply chains, and broader stakeholder participation offered the necessary way of bringing together a network of actors who could be receptive to nano-enabled biosensors. Although our expert participants did not presume that a biosensor was inevitable or that some to-be-discovered design for a biosensor would resolve all (or indeed, any) of the challenges identified during the workshop, they did frame their understanding of “input” as a form of *response*. This is in contrast to alternative views of technological democracy that might envision stakeholders as initiators of R&D projects, or even as identifying the key problems to which technical expertise should be applied. This raises the issue of how democratization processes aimed at improving the voices of potentially

marginalized groups should be compared to democratization processes that are seen as instrumentally necessary for networking.

Third, we excerpted approximately 17 remarks in the spreadsheet in which participants raised questions of efficiency. While the concept of efficiency may not immediately suggest an ethical issue, it may signify objectives and priorities that are themselves based on unspoken values. For example, those designing biosensors have public concerns, such as human safety, at heart. They may see hurdles, such as those posed by the interdisciplinary collaboration expected by funders, as posing inefficiencies and discouraging the realization of truly beneficial innovation. This can be seen as an ethical issue in its own right insofar as the prevention of harms is an issue. But it differs from the ethical issues likely to be identified by other groups, such as small producers who are concerned about being exploited.

Fourth, there are certain tradeoffs, such as transparency versus security, that are issues in complex supply chains like agrifood where large scale economic and health issues are at stake. These tradeoffs though are rather complicated. Both designers and, say, processors, are interested in security broadly speaking, and in ways that perhaps blur the ethical categories. Security can be understood in terms of risk to the supply chain and consumer health, or in terms of the loss of autonomy of smaller actors. Transparency can be understood as that which designers and innovators desire in order to achieve the democratization needed to crystallize a network capable of adopting the technology, or it can be understood as that which is desired by less powerful actors in order to feel that due process is being served.

7.1 Theoretical implications

Ethical norms are involved in processes of technological innovation that are developed in technological ethics. Understood as a theoretical discipline, the conceptual models of *how* ethical norms are involved are intended to serve the primary goal of explicitness discussed above. On the one hand, these models are intended to advance our understanding of ethical conduct. As Jonas noted long ago, technological innovation is embedded in complex social causalities that challenge the traditional assumptions about ethical responsibility: no longer can we presume that ethical responsibility is a relationship existing among individuals who are known to one another in virtue of their spatial and temporal contiguity. Thus one goal of technological ethics is simply to help scholars of ethics articulate and examine the way that developing or utilizing modern technologies implicates people in ethically significant relationships with one another. On the other hand, an ethics model can have practical application when it helps the people implicated in ethically significant relationships understand and appreciate both the impact of their action on others and the responsibility they may have to affected parties. This means that the language in which norms are made explicit must be meaningful and “speak to” the concerns of actors who might themselves be slow to articulate their concerns in an explicit fashion. We discuss the significance of our findings for scholarship in technological ethics in this section, and note some practical implications below.

The relationships summarized in Figure 1 (and articulated in substantially greater detail in Tables 3 through 6) provide just such a conceptual model for the technological ethics of nanobiosensors. The tables identify the actors or agents who bear responsibility and identify the affected parties to which responsibilities are owed. The arrows represent morally significant forms of action. One key finding from the workshop is that these forms of action have both beneficial and harmful valences. This finding reinforces a point that is often overlooked: it is *not*

the case that technological ethics is necessarily antagonistic to the development of technology. A conceptual model of ethical relationships can provide reasons for going forward with technology as readily as it can provide reasons to constrain or modify it. One fault of pro-technology rhetoric has been its reliance on over-generalized notions of progress and hype (Berubi 2006; Thompson 2008). In contrast, relationships such as those identified in Tables 3 through 6 provide more persuasive and powerful arguments for moving forward with technology development.

At the same time that more specific and detailed conceptual models provide a basis for more persuasive arguments in favor of technology, they also provide much more relevant information about where the key areas of sensitivity are likely to be. Of course, as Collingridge's dilemma states, it is virtually impossible to anticipate the full implications of a technology, but the results of our workshop suggest that it is still possible to piece together a picture of where sensitivities are likely to emerge. In this respect it is important to notice that the significantly detailed model of ethical relationships emerged from an expert conversation, but the experts involved represented a broader array of subject matter expertise than may have been supposed by those who have criticized reliance on expertise. It is particularly significant that although experts in the design and development of nanobiosensors contributed important observations, many of the key ethical relationships were identified by experts in animal disease control, in the management of commercial livestock production and in information technologies that are central to the organization of the food industry supply chain. This is not to suggest that reliance on such expertise could substitute entirely for the perspective and participation of actual supply chain actors. However, it does suggest that some of the limitations associated with the *idea* of expertise may instead be the result of reliance on experts representing a fairly narrow subset of subject matter areas. This theoretical finding anticipates some key practical implications discussed next.

7.2 Implications for participatory assessment processes

We have suggested that early ethical assessment is an emergent, cumulative process in which each activity refines concepts and identifies gaps to be further addressed in subsequent activities. The workshop modeled an early component of such an approach. In itself, the workshop was not expected to generate actionable outcomes. Instead, it laid necessary groundwork for more comprehensive participatory exercises such as those in which ethical matrices or scenarios are developed. In this section, we consider our results in light of criteria for participatory assessment discussed above—1) eliciting information, 2) articulating values, and 3) legitimating the decision making process—and we offer suggestions on facilitating similar assessment activities.

First, the workshop generated critical information, improving our understanding of how nanotechnology interacts with the environment and social institutions. The findings from Tables 3 through 6 can be interpreted as a practical decision aid for developers of nanobiosensors, at least within the range of their application to animal disease management. Much of what we have found might be generalized to other applications of biosensors, or to nanotechnologies more broadly, though it is important to recognize both the limitations of this study and the fact that other nanotechnologies will have impacts that have lack any useful analogy to the case of animal disease control. However, the study shows that developers and regulators of biosensors might do things that reduce the autonomy (e.g. freedom of choice and range of potential response) for livestock producers. They might adopt procedures for moving biosensors forward that are unfair to a number of stakeholder communities. They might configure biosensors (and associated policies for their implementation) in ways that impose risk on a variety of affected parties, and the way in which nanobiosensors are integrated into the technological infrastructure of food

industry supply chains can increase or initiate lack of trust. Furthermore, all these negative ethical impacts can occur without anyone intending or being aware of them. Nevertheless, technology developers who ignore those relationships in autonomy, fairness, risk and trust that indicate negative ethical valence may not only be legitimate targets of ethical critique, but can also expect affected parties to initiate resistance activities. Although the model developed in this paper should be tested and further developed through participation with a broader range of stakeholders, it nonetheless provides a provisional map that parties can follow in taking steps to avoid ethical miscues and irresponsible actions.

Participants discussed specific stakeholder groups that were not represented, such as livestock producers, retailers, and government agencies. As public policy-makers continue to explore means of engaging stakeholders on issues of technological innovation, their experience and input would be particularly relevant in future research.

Although assessment processes may aim for “broad stakeholder participation”, an unexamined use of the term may mask conflicting values and priorities among participants. Facilitators should encourage discussion of the objectives that participation achieves and elicit definitions of “broad.” Whose participation is important; what does this participation achieve; and what are the consequences (and to whom) if this participation is not obtained? The question of whether “breadth” implies opening the participatory exercise to priorities or concerns that may have little immediate relevance to the technical potential of the innovations under review is also relevant.

Second, participants revealed implicitly normative value judgments. The synecdoche that participants used reflected the ambivalence that is often characteristic of normative commitments as they are expressed in real life beyond the research context. In our workshop, the referents

behind terms such as “data” and “technology” remained unexamined. Yet such terms signify different actors and values depending on the speaker and context. Facilitators of workshops, focus groups, or other discussions of emergent technologies should seek to minimize this ambivalence by encouraging participants to expand upon such terms. For example, discussion that shifts the focus from “the data” to the actors who control data, and to the specific purposes that data serve, may illuminate participants’ views of the ethical implications of this term. A more fully explicit statement of the ethical assumptions or values relevant to an emerging technology will almost certainly involve further interpretive activity that exposits the multiple ambiguities of normative expressions.

Similarly, the ethical implications of concepts such as “efficiency” and “security” may not readily be apparent to participants. Participants may assume that “efficiency” conveys the same meaning and has the same significance to other stakeholders. Facilitators should be alert to the axiological implications of participant remarks and elicit further discussion. For example, the meaning of “efficiency” depends upon the objectives of a process as well as assumptions about the relevant inputs and outputs of that process. Efficiency in achieving a safe food supply is evaluated differently than is efficiency in improving producers’ livelihoods. Efficiency in achieving food safety is evaluated differently depending on how participants define “safe.” Participants may also take for granted the ethical importance of achieving security. Discussion that probes into questions of who gains and loses, and what is gained and lost, by specific security measures may unveil the ethical implications of assumptions about security.

Third, the model contributes to legitimacy of decision making processes in nanobiosensor development and identifies ways in which biosensors might be indicated for ethically important reasons. In this, the model provides both an initial mapping of things to avoid or limit through

both appropriate design and responsible implementation of biosensors, and ways to enhance their benefits and potential for success. As noted elsewhere (Busch and Lloyd 2008; Thompson 2011), efforts once underway take on momentum that is difficult to reverse. It is thus important for actors (e.g. technology developers) crucial to the early stages of design and implementation to be proactive. Further testing of the model sketched here would be one of things required by responsible nanotechnology. The indications available suggest reasons for thinking that Collingridge's dilemma is too pessimistic. There are things that developers of nanobiosensors could and should be doing to better steer the design and implementation of this important nanotechnology.

References

- Berubi, D. (2006). Nano-hype: The truth behind the nanotechnology buzz, Prometheus Books, Amherst, NY.
- Bickel, A. (2010). Ag department drops livestock tracing program. *McClatchy - Tribune Business News*.
- Brey, P. (2012). Anticipatory Ethics for Emerging Technologies, *NanoEthics*, pp. 1-13.
- Busch, L., J.R. Lloyd (2008). What Can Nanotechnology Learn from Biotechnology? in: K. David, P.B. Thompson (Eds.) *What Can Nanotechnology Learn from Biotechnology? Social and Ethical Lessons for Nanoscience from the Debate over Agrifood Biotechnology and GMOs*, Academic Press, Amsterdam, pp. 261-275.
- Callahan, D. (1999). The Hastings Center and the Early Years of Bioethics. *Kennedy Institute of Ethics Journal*, 9(1), pp. 53-71.
- Carpenter, S. R., Mooney, H. A., Agard, J., Capistrano, D., DeFries, R. S., Díaz, S., et al. (2009). Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proceedings of the National Academy of Sciences*, 106(5), pp. 1305-1312.
- Churchman, C.W. (1968). *Challenge to Reason*. New York: McGraw Hill.
- Coffey B., Mintert J., Fox S., Schroeder T., & Valentin L. (2005). The Economic Impact of BSE: A Research Summary (Kansas State University Agricultural Experiment Station and Cooperative Extension Service). *Livestock Economics*, MF-2679.
- Collingridge, D. (1980). *The social control of technology*, St. Martin's Press, New York.
- Corbin, J. and A.L. Strauss. (2008). *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*. Los Angeles: Sage Publications, Inc.
- Croney, C.C., R. Anthony. (2010). Engaging science in a climate of values: Tools for animal scientists tasked with addressing ethical problems¹, *Journal of Animal Science*, 88, E75-E81.
- Douglas, M. (1975). *Implicit Meanings: Essays in Anthropology*, London: Routledge and Kegan Paul
- Ebbesen, M., S. Andersen, F. Besenbacher. (2006) Ethics in Nanotechnology: Starting From Scratch?, *Bulletin of Science, Technology & Society*, 26, pp. 451-462.
- Feenberg, A. (1991) *Critical theory of technology*, Oxford University Press, New York.
- Feng, P., A. Feenberg. (2008). Critical Theory of Technology and the Design Process, in: P.E. Vermaas,

Kroess, P.A., Light, Andrew, and Moore, Steven (Ed.) *Philosophy and Design*, Springer, New York, NY.

Griffin, D. (1997). Economic impact associated with respiratory disease in beef cattle. *Veterinary Clinics of North America Food and Animal Practice*, 13, pp. 367-377.

Holman, M. (2006). *The Nanotech Report*, 4th Edition. Lux Research, Inc.

Jasanoff, S. (2003). "Technologies of Humility: Citizen Participation in Governing Science." *Minerva* 41 (3):223-244. doi: 10.1023/a:1025557512320.

Jonas, H. (1984). *The imperative of responsibility: in search of an ethics for the technological age*, University of Chicago Press, Chicago.

Kaufmann, A., J. Claude, C. El-Bez, M. Audetat. (2010). Why Enroll Citizens in the Governance of Nanotechnology?, in: M. Kaiser (Ed.) *Governing Future Technologies*, Springer, Dordrecht, pp. 201-215.

Kuzma, J., VerHage, P., Woodrow Wilson International Center for, S., & The Pew Charitable, T. (2006). *Nanotechnology in agriculture and food production : anticipated applications*. Washington, DC: Project on Emerging Nanotechnologies.

Mepham, B. (2000). A framework for the ethical analysis of novel foods: The ethical matrix, *Journal of Agricultural and Environmental Ethics*, 12, pp. 165-176.

Morgall, J. (2010). *Technology assessment: A feminist perspective*: Philadelphia, PA: Temple University Press.

Pal, S., & E. C. Alocilja. (2009). Electrically active polyaniline coated magnetic (EAPM) nanoparticle as novel transducer in biosensor for detection of *Bacillus Anthracis* spores in food samples. *Biosensors and Bioelectronics*, 24(5), pp. 1437-1444.

Popper, D. E. (2007). Traceability: Tracking and Privacy in the Food System. *Geographical Review*, 97(3), 365-388.

Rehmann-Sutter, C., J.L. Scully. (2010). Which Ethics for (of) the Nanotechnologies, in: M. Kaiser (Ed.) *Governing Future Technologies*, Springer, Dordrecht, pp. 233-252.

Rubin, H.J., and Rubin, I.S. (2005). *Qualitative Interviewing: The Art of Hearing Data*. Thousand Oaks, Calif.: Sage.

Schummer, J. (2009). Cultural Diversity in Nanotechnology Ethics, *Nanotechnology & Society*, in: F. Allhoff, P. Lin (Eds.), Springer Netherlands, pp. 265-280.

Shrader-Frechette, K. S. (1991). *Risk and rationality: philosophical foundations for populist reforms*. Berkeley: University of California Press.

Snowder, G. D., et al. (2006) "Bovine respiratory disease in feedlot cattle: environmental, genetic, and economic factors." *Journal of Animal Science* 84.8: pp. 1999-2008.

Thompson, P.B. (2002). Why Food Biotechnology Needs an Opt Out. In *Engineering the Farm: Ethical and Social Aspects of Agricultural Biotechnology*, edited by B. Bailey and M. Lappé. Washington, D.C.: Island Press.

Thompson, P.B. (2008). The Presumptive Case for Nanotechnology, in: F. Allhoff, P. Lin (Eds.) *Nanotechnology & Society: Current and Emerging Ethical Issues*, Springer, Dordrecht, NL, pp. 39-54.

Thompson, P.B. (2010). Agrifood Nanotechnology: Is This Anything? , in: U. Fiedeler, C. Coenen, S.R. Davies (Eds.) *Understanding Nanotechnology: Philosophy, Policy and Publics*, IOS Press, Amsterdam, Netherlands.

Thompson, P.B. (2011). Understanding and Coping with Social Risk in Emerging Technology Risk Assessment, in: S. Ripp, T.B. Henry (Eds.) *Biotechnology and Nanotechnology Risk Assessment: Minding and Managing the Potential Threats Around Us*, Oxford University Press, New York, NY, pp. 1-16.

Thompson, P.B. (2015). *From Field to Fork: Food Ethics for Everyone* New York: Oxford University Press

White, L. (2007). The Chase to Trace. *National Provisioner*, 1/2001.

Zhang, D., Carr, D. J., & Alocilja, E. C. (2009). Fluorescent bio-barcode DNA assay for the detection of *Salmonella Enterica* Serovar Enteritidis. *Biosensors and Bioelectronics*, 24(5), 1377-1381.

Table 1: Summary of morally salient categories and themes identified in workshop discussion

Category	Theme
Autonomy	increase or decrease in actionability independence/control education
Fairness	democratic capitalism discourse and power disproportionality exploitation network effects participatory decision making/procedural justice regulatory burdens
Risk	animal welfare environment food safety public safety security
Trust	accountability privacy information ethics

Table 2: Actor groups commonly mentioned in workshop discussion

Agrifood Industry
Innovators
Manufacturers
Government
Livestock Producers
Researchers
Meat Processors/Packaging
Retailers
Public
Animals

Table 3: Implications of biosensors for autonomy

agent ↓ developers of biosensors	may increase autonomy of	patient ↓ livestock producers
<p>Biosensors may allow instantaneous tracking of disease. —beef cattle specialist [91]</p> <p>Biosensors could be used at any step in production process. They could also be used to monitor the outputs, like manure or phosphorus output, for environmental quality. —veterinarian [83]</p> <p>Biosensors empower farmers so that they can control situations. —agricultural engineer</p>		
developers of biosensors	may decrease autonomy of	livestock producers
<p>Mandatory animal identification may burden cattle producers. —veterinarian [1]</p> <p>There is no standard output for readers, so that producers who want to use them are inconvenienced. —packaging scientist [68]</p>		
government agencies	may increase autonomy of	livestock producers
<p>ID requirements increase marketability of livestock, confidence in animal movement, and disease eradication efforts. —veterinarian [57]</p>		
government agencies	may decrease autonomy of	livestock producers
<p>The information requirements burden producers. Moreover, producers need to change practices in order to comply with ID tag requirements. Strings must be cut off of IDs immediately; otherwise they get lost when cattle burrowing their heads into a bail. —veterinarian [41]</p>		

Table 4: Implications of biosensors for fairness

Table 5: Implications of biosensors for risk

agent		patient	
developers of biosensors	may reduce risk to	producers using biosensors	
producers using biosensors	may reduce risk to	animals, consumers, society	
Benefits of biosensors are food safety and security, marketability, confidence in animal movement, disease eradication efforts. They can reduce antibiotic usage. —veterinarian, 57 —beef cattle specialist 99			
Biosensors	may reduce risk to	the public	
Biosensors are about defense. They're about plugging porous borders. The objective is to protect the public. —agricultural engineer [2, 13]			
Is society willing to accept the technology to make animals healthier or food safer? —veterinarian 80			
Biosensor	may create risk for	society	
Many of the materials haven't been tested from a toxicological point of view. An issue is how to screen for nanoparticles. "The sizes vary, the modifications vary, and then they're different materials." — agricultural engineer 5			
developers of biosensors	may create risk for	producers using biosensors	
producers using biosensors	may create risk for	animals, consumers, society	
There is a cost of failures, e.g., what happens if internet goes down. —packaging scientist, 71			
Information security creates a need for dialogue. The need for information creates conflicts; information needs to be secure. There is a need to exclude some users from the information. —veterinarian 36 —packaging scientist, 75			
It is the failure to address a social issue that produces a risk issue. —ethicist (PT), 103			

Table 6: Remarks on the implications of biosensors for trust