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ORIGINAL PAPER

The Role of the Humanities and Social Sciences in Nanotechnology Research and Development

Mette Ebbesen

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Abstract The experience with genetically modified foods has been prominent in motivating science, industry and regulatory bodies to address the social and ethical dimensions of nanotechnology. The overall objective is to gain the general public's acceptance of nanotechnology in order not to provoke a consumer boycott as it happened with genetically modified foods. It is stated implicitly in reports on nanotechnology research and development that this acceptance depends on the public's confidence in the technology and that the confidence is created on the basis of information, education, openness and debate about scientific and technological developments. Hence, it is assumed that informing and educating the public will create trust, which will consequently lead to an acceptance of nanotechnology. Thus, the humanities and social sciences are seen as tools to achieve public acceptance.

In this paper, the author argues that this is a narrow apprehension of the role of the humanities and social sciences. The humanities and social sciences have a critical function asking fundamental questions and informing the public about these reflections. This may lead to scepticism, however, the motivation for addressing the social and ethical dimensions of nanotechnology should not be public acceptance but informed judgement. The author illustrates this critical function by discussing the role, motivation and contribution of ethics as an example. Lastly, the author shows that a possible strategy for incorporating the humanities and the social sciences into nanotechnology research and development is Real-Time Technology Assessment, where the purpose is to integrate natural science and engineering investigations with ethical, legal and social science from the outset.

Keywords Critical function · Ethics · Humanities · Nanotechnology research and development · Social sciences

M. Ebbesen
Interdisciplinary Nanoscience Center (iNANO),
University of Aarhus,
Ny Munkegade,
8000 Aarhus C, Denmark

M. Ebbesen (✉)
Centre for Bioethics and Nanoethics, University of Aarhus,
Taasingegade 3, Building 1443,
8000 Aarhus C, Denmark
e-mail: meb@teo.au.dk

The Humanities and Social Sciences as a Means of Gaining Public Acceptance

The hopes for nanotechnology are evident in the amount of public funding devoted to it over the past few years [1]. Nanotechnology, indeed, has been proclaimed the source for a revolution comparable to the emergence of the steam engine, electrification or computer technology [2, 3]. The visions for nanotechnology include advancing broad societal goals such as better health care, increased productivity, sustainable development and improved comprehension of nature [1]. However, nanotechnology may trigger an adverse public response along the lines of that experienced by genetically modified (GM) foods. European and American reports state that particular effort is devoted to integrating the humanities and social sciences into the interdisciplinary approach to nanotechnology. The overall objective is to gain the general public's acceptance of nanotechnology in order not to provoke a consumer boycott as it happened with GM foods. It is stated implicitly that this acceptance depends on the public's confidence in the technology and that the confidence is created on the basis of information, education, openness and debate. Thus, in a European report it says:

> Without a serious communication effort, nanotechnology innovations could face an unjust negative public reception. An effective two-way dialogue is indispensable, whereby the general public's views are taken into account and may be seen to influence decisions concerning R&D[1] policy. The public trust and acceptance of nanotechnology will be crucial for its long-term development and allow us to profit from its potential benefits. It is evident that the scientific community will have to improve its communication skills [4, p. 19].

A Dutch report states that the public must be informed about the scientific and technological developments within nanotechnology; and that the public moreover should participate in discussions of the pros and cons of nanotechnology. According to the report, this may prevent the introduction of nanotechnology from being boycotted by the general public the way GM foods have been:

> The confused ideas the public have regarding genetically modified organisms (GMOS) are a direct result of the inept way in which the public were informed about the introduction of this new technology … It may perhaps be possible to proceed more effectively as regards the introduction of nanotechnology. Doing so will require steps to be taken as soon as possible to keep the public informed about the scientific and technical developments. In addition, representatives of the public should be involved in substantive discussion of the pros and cons of nanoscience and nanotechnology [5, p. 27].

An American report states that the integration of researchers within the humanities and social sciences can establish a dialogue between nanotechnologists and the public. According to the report, this dialogue will assist in maximising the social benefits of the technology and in minimising the risk of debilitating public controversies:

> The inclusion of social scientists and humanistic scholars, such as philosophers of ethics, in the social process of setting visions for nanotechnology is an important step for the NNI.[2] As scientists or dedicated scholars in their own right, they can respect the professional integrity of nanoscientists and nanotechnologists, while contributing a fresh perspective. Given appropriate support, they could inform themselves deeply enough about a particular nanotechnology to have a well-grounded evaluation. At the same time, they are professionally trained representatives of the public interest and capable of functioning as communicators between nanotechnologists and the public or government officials. Their input may help maximize the societal benefits of the technology while reducing the possibility of debilitating public controversies [6, p. 15].

In the American report, it is stressed that informing the public is not enough; the public have to be educated to perceive the advantages of nanotechnology [6, pp. 100–101].

Thus, it is assumed that informing and educating the public will create trust and consequently an acceptance of nanotechnology. In that way, according to the American report, research into the societal implications of nanotechnology will boost the success of nanotechnology, and hence it will be possible to take advantage of the benefits of nanotechnology sooner, more effectively and with greater confidence [6, p. 2]. Hence, it is not assumed that information about nanotechnology may lead to scepticism. The

[1] Research and Development (R&D).

[2] National Nanotechnology Initiative (NNI)

public must perceive and be convinced of the benefits of the introduction of nanotechnology. No importance is attached to the public's informed judgment.

However, in contrast to the American reports, a few EU reports assume the citizen's right to informed judgement. But in these reports it is also stressed that educating people in science and technology must be prioritised in order to obtain this informed judgement:

> The Commission's strategy: Promote scientific and education culture in Europe. First of all, people must become more familiar with science and technology … The Commission is committed to improving transparency and consultation between administrations and civil society… If citizens and civil society are to become partners in the debate on science, technology and innovation in general… it is not enough simply to keep them informed. They must also be given the opportunity to express their views in the appropriate bodies … They aim to provide a space for scrutiny and informed debate on important issues of public concern, bringing together the public, interest groups and policy makers … The Commission will organise regular events enabling civil society to participate (in the form of public hearings, consensus conferences or interactive online forums) [7, pp. 7–18].

However, researchers point out that information and education are not the only factors influencing the public attitudes towards new technology. Returning to the Europeans' sceptical attitude towards GM foods, there is disagreement whether the scepticism is exclusively due to lack of information and education. If we first look at the results of the so-called Eurobarometer survey on the Europeans' attitudes towards GM crops and foods [8], it shows an increasing scepticism from 1996–1999 about GM crops (a rise from 20% to 32%) and about GM foods (a rise from 39% to 52%), respectively. In contrast, the figures were relatively stable from 1999 to 2002 (Table 1). However, regarding the application of biotechnology in medical science, the Europeans' attitudes were very positive in 2002: E.g. only 9% were opposed to genetic testing and 17% to cloning of human cells. Hence, the general public's attitude varied according to the specific biotechnological application. Applications within the plant and food area were assessed considerably more negatively than applications in the field of medicine. The ethicist Bryn Williams-Jones from the University of Cambridge writes:

Table 1 Europeans' attitudes towards GM crops and GM foods 1996–2002 (for a definition of the categories 'Supporters' etc., please see Appendix) [8]

		1996 (%)	1999 (%)	2002 (%)
GM crops	Supporters	45	36	36
	Risk-tolerant supporters	35	33	34
	Opponents	20	32	30
GM food	Supporters	30	23	22
	Risk-tolerant supporters	31	26	28
	Opponents	39	52	50

> Indeed, there tends to be widespread positive public regard for technologies that appear to have a clear benefit and minimal or at least well understood risks (e.g. biotechnologies that improve health care, such as genetic diagnostics or bio-pharmaceuticals). But when the benefits are dubious and the risks are potentially very serious and not well understood, as in the case of GM foods, then the public as consumer of new technologies may be very wary. The lesson for a nascent field such as nanotechnology—in which there are as yet few applications, but which is receiving billions of dollars of public monies—is that there must be broad and genuine public engagement in determining the scope and possible futures for this field [9].

The Eurobarometer surveys [8], which are based on responses from app. 1,000 individuals in each EU country, depict how different perceptions of biotechnology are distributed among the population on EU level and within the individual countries. However, these quantitative investigations are not sufficient to explain *why* the general public responds the way it does. As mentioned, the reports on research into nanotechnology blame the general public's lack of knowledge of new technology for the boycott of GM food products [5, p. 27]. Taking the studies on the Europeans' knowledge of GM crops and foods into consideration, it is fair to point out the lack of knowledge, for instance 64% of the European population believed that GM tomatoes contain genes as opposed to ordinary tomatoes (Table 2) [8]. However, science sociologist Claire Marris emphasises that studies show that a greater insight into GM organisms does not necessarily lead to a more positive attitude; on the contrary, it makes the public more sceptical and polarised [10, 11]. Marris [10] dismisses it as a myth that persons who are against GM foods are irrational, and that they would accept GM foods if they knew more about biotechnology. In the debate on GM crops there has been much focus on the public's confidence in the experts. The argument goes that without confidence in the experts the public will misunderstand risks and uncertainties. The public will then be persuaded by the opposing organisations using eye-catching headlines. Consequently, risk communications by trusted experts have long been offered as the solution to public scepticism [12]. A Swedish study [11] shows that confidence in experts only plays a minor role regarding the public perception of risk. Topics such as 'intervention in nature' and moral considerations generally mean a lot more. Researchers claim that the European population's perception of risk in connection with GM foods is much broader than the technical–scientific perception communicated by experts. In the public mind, risk also involves moral considerations (is it right doing this?), democratic considerations (who is funding and controlling biotechnology?) and uncertainties (will there be as yet unknown adverse consequences?) [12]. This is also the conclusion of a Danish qualitative investigation [13, 14, pp. 9–14] made in year 2000 based on focus group interviews. The overall picture shows that the arguments advanced in the discussion on biotechnology primarily relate to two types of utility: utility in terms of society and utility in terms of economy. Utility in terms of society concerns solving problems such as famine and environmental problems, curing diseases and relieving pain. The economic utility arguments concern business economic motives and biotechnology as a source of increased material wealth. Most often, the societal utility was considered a legitimate argument for the application of biotechnology, whereas business economic motives were used as arguments against the application of biotechnology. As mentioned, risk has often been limited to dealing with harmful effects on human health or the environment. The interviewees assessed the risk more broadly, including considerations on the possible violation of the order of nature, violation of the eigenvalue of nature and of God's creation. The respondents also mentioned power relations, democratic rights and the possible application of biotechnology to prevent poverty in developing countries. The referred studies indicate that viewed from a traditional (technical–scientific) risk assessment perspective, the use of new technology may be unproblematic. However, the application of new technology may yet still be rejected by the public due to social, economic, ethical and political aspects.

Table 2 Europeans' knowledge about GM crops and GM foods 1996–2002 [8]

	% Correct		
	1996	1999	2002
Ordinary tomatoes do not contain genes, while genetically modified tomatoes do	35	35	36
By eating a genetically modified fruit, a person's genes could also become modified	48	42	49
It is impossible to transfer animal genes into plants	27	26	26

European as well as American reports on research into nanotechnology focus on educating the public about the scientific and technical aspects of nanotechnology [7, pp. 7–18; 6, p. 142; 5, p. 27]. However, the studies referred to above on the public attitude in Europe towards GM foods and biotechnology in general indicate that social, economical, ethical and political dimensions of implementation of new technology are important to the public. A lesson to be learned from the introduction of GM foods in regard to the implementation of nanotechnology may hence be that information addressed to the public on nanotechnology should encompass more aspects than specific technical–scientific facts. It should deal with political, sociological and ethical aspects of nanotechnology.

The Critical Function of the Humanities and Social Sciences—The Contribution of Ethics

As described above, reports on nanotechnology state that the role of the humanities and social sciences is to maximise the societal advantages of nanotechnology, boost nanotechnology and reduce the possibility of debilitating public controversies. This entails for instance that ethics is reduced to a tool or a means to an instrumental end, which can be expressed as a reduction of ethics to a PR agent for the laboratory. I object that this is a narrow apprehension of the role of the humanities and social sciences to focus on creating trust in and acceptance of nanotechnology in the general public. The humanities and the social sciences have a critical function. For example the function of philosophy and ethics regarding implementation of any kind of new technology is to ask the fundamental questions such as: What impact will this new technology have on humanity? What is a good life? Will this new technology influence the realisation of a good life? What kind of society do we want? How does this new technology relate to that kind of society? The aim of posing these questions is not to build trust and acceptance in the public, but to make a critical assessment of new technology so that the public can make an informed judgement. This critical assessment does not have to be a negative one. Ethics is not only a demarcator saying thus far and no further. Instead, ethics may be viewed as a co-player firstly discussing the needs and goals of the public and society, and secondly serving as a framework to guide society towards these goals. As for nanotechnology, it should be contemplated which goals we wish to obtain by means of technology. Is it the goals stated in the reports on nanotechnology research strategies? Or is it totally different goals? To mention a specific example, some reports state that the aim of research into nanotechnology is to improve human quality of life [4, p. 1]. But what does improving human quality of life mean? An American report claims that part of the answer is improvement of human capabilities and performance while at the same time respecting fundamental values:

> At this moment in the evolution of technological achievement, improvement of human performance through integration of technologies becomes possible. Examples of payoffs may include improving work efficiency and learning, enhancing individual sensory and cognitive capabilities, revolutionary changes in health care, improving both individual and group creativity, highly effective communication techniques including brain-to-brain interaction, perfecting human–machine interfaces including neuromorphic engineering, sustainable and 'intelligent' environments including neuro-ergonomics, enhancing human capabilities for defence purposes, reaching sustainable development using NBIC[3] tools, and ameliorating the physical cognitive decline that is common to the aging mind … The aim is to offer individuals and groups an increased range of attractive choices while preserving such fundamental values as privacy, safety, and moral responsibility [15].

The contribution of ethics may be a reflection whether it is possible to improve human subjects without compromising fundamental ethical values and fundamentally, whether improving human quality of life really equals improving its capabilities and performance.

However, ethics does not only ask fundamental questions, it also contributes with ethical assessment of specific nanotechnological developments. As I argue in Ebbesen et al. [16], predicted concrete ethical issues related to nanotechnology are rather similar to those related to biotechnology and biology that have been considered by ethicists since the 1970s. Hence, within nanotechnology much can be learnt from the ethical reflections on biotechnology and biology.

If we go into the literature on nanoethics, specific ethical issues of nanotechnology fall into three groups (Table 3): *risk problems* (a–d), *privacy problems* (e–f) and *problems of transhumanism* (g–h). None of these three groups of ethical issues of nanotechnology is unknown hitherto. In order to show that the potential ethical problems of nanotechnology are not new and unique, I point to parallels within the fields of biotechnology and biology that have been widely analysed (Table 3).

As to risk problems one can draw parallels between the fear of the uncontrolled spread of GM crops and the prospects of runaway proliferation of self-replicating nanosystems (a) and the uncontrolled function of nanorobots (b). The discussion of the possible toxic nature of nanoparticles (c) can be compared with the discussion of the toxicity of asbestos, which has run for years. The fear of biological warfare and terrorism caused by nanotechnology (d) is not only a future issue but of current

[3] Nanotechnology, Biotechnology, Information Technology and Cognitive Science (NBIC).

Table 3 Parallels drawn between currently analysed ethical issues and ethical issues of nanotechnology pointed out in the literature [6, 17–21]

Parallels drawn to currently considered ethical issues	The literature mainly focuses on the hypothesis that the introduction of nanotechnology could lead to:
Uncontrolled spread of GM crops and toxicity of asbestos	a. Prospects of runaway proliferation of self-replicating nanosystems Ethical issues: risk–benefit analysis, beneficence, nonmaleficence b. Uncontrolled function of nanorobots (nanobots) Ethical issues: risk–benefit analysis, beneficence, nonmaleficence c. Possible toxic nature of nanoparticles dispersed in the environment Ethical issues: risk–benefit analysis, beneficence, nonmaleficence
Terrorist attack September 11th (anthrax powders)	d. Biological warfare and terrorism Ethical issues: risk–benefit analysis, beneficence, nonmaleficence
Cell phones and internet 24 hours a day	e. Invasion of privacy as a result of improved communication capabilities Ethical issues: respect for autonomy and integrity f. Invasion of privacy as a result of dispersed nano-sensing structures (e.g. microphones) in the environment Ethical issues: respect for autonomy and integrity
Genetic enhancement (gene therapy)	g. Enhancement of human capabilities Ethical issues: what is a human being? h. Transhumans caused by the incorporation of nanostructures and nanomachines in the human body. How many nano-prosthesis will make you non-human? Ethical issues: what is a human being?

interest, especially since the terrorist attack on the US September 11th 2001 and the subsequent mail deliveries of anthrax powders.

On the matter of privacy problems, the fact that nanotechnology could lead to an invasion of privacy as a result of improved communication capabilities (e) is a currently discussed issue, as people can be reached by cell phones and internet connections 24 h a day. But, of course, the ethical problem of invasion of privacy could grow if nanotechnology leads to the spread of spying nanomicrophones in the environment (f).

As to problems of transhumanism, one can draw a parallel between the ethical issues of the enhancement of human capabilities and transhumans caused by nanotechnology (g, h) and the issue of genetic enhancement. Since the first experiments of gene therapy in cell cultures during the 1980s, ethicists have warned that gene therapy may lead to the enhancement of normal characteristics in contrast to treatment of disease [16].

I believe that a promising approach to the ethics of nanotechnology is so-called 'principlism', i.e. the claim that a limited number of basic ethical principles are generally accepted. Regarding the ethically relevant features of nanotechnology mentioned above (risk problems, privacy problems and problems of transhumanism) the general ethical principles about respect for autonomy and integrity and beneficence, nonmaleficence, and justice are at stake. Several examples illustrate this.

The first example is the fear that the dispersion of nano-sensing structures (e.g. microphones) in the environment may lead to an invasion of privacy (Table 3, f). Behind the ethical issue of respect for privacy lies a general ethical principle that the autonomy and integrity of humans ought to be respected. Autonomy means self-determination, and as an ethical principle, the respect for autonomy means that in questions concerning his/her own life each individual has the right to make his/her own decisions. The ethical principle of respect for integrity is closely related to respect for autonomy and means a person's sphere of experiences, of information and of self-disclosure, etc. should not be intruded upon under normal circumstances. It makes sense to speak of respect for this integrity especially in the case of human beings who are not able to exercise autonomy. This could be the case for toddlers, drug-dependent patients, persons who are senile or mentally troubled, etc. The principle of respect for integrity means, then, that prima facie no-one has the right to access information that is intimately linked to the life and identity of a human being [16].

Another illustration is the prospect of runaway proliferation of self-replicating nanosystems (Table 3, a) and the spread of possible toxic nanoparticles in the environment (Table 3, c). In light of such a prospect one ought to perform a risk assessment. On this matter, the American bioethicists Tom L. Beauchamp and James F. Childress show that the moral evaluation of risk in relation to probable outcomes can have the character of risk–benefit analysis. They use the definition of 'risk' as possible future harm, where 'harm' is defined as a setback to interests, particularly in life, health and welfare [22, pp. 195, 199]. In the field of biomedicine, the term 'benefit' commonly refers to something of positive value, such as life or health. Risk–benefit relations may be conceived in terms of a ratio between the probability and magnitude of an anticipated benefit and the probability and magnitude of an anticipated harm [22, p. 195]. The terms 'harm' and 'benefit', as defined above, are ethically relevant to nanotechnology since ethical obligations or principles are generally accepted against inflicting harm (nonmaleficence) and promoting good (beneficence) [22, p. 4].

It should be evident, also, that there are societal implications at stake in relation to nanotechnology. These include issues such as the prioritising and commercialisation of science, the question of who should gain from nanotechnology etc. For instance, do we have a responsibility for sharing this technology with developing countries? Clearly, the ethical principle of justice is at stake [16].

As most ethicists will recognize, these general principles—respect for autonomy (and integrity), beneficence, nonmaleficence and justice—are part of the bioethical theory developed by Beauchamp and Childress. They published their theory for the first time in 1979 in the book *Principles of Biomedical Ethics*. The general ethical principles mentioned above have been used for years to analyse ethical issues in the field of biomedicine. The analysis above shows that nanotechnology does not demand a new kind of ethics, and we do not need new ethical principles such as 'nano-beneficence', old-fashioned beneficence should suffice as one general ethical principle among others. In short, the problems nanotechnology raises seem, so far, to be analogous to well-known problems raised by biotechnology and biomedicine, so that the problems of 'nanoethics' can be dealt with in the framework of bioethics [16]. However, to be meaningful this nanoethics research needs to be integrated into nanotechnology R&D.

Integrating Societal Concerns into Nanotechnology

As a case study of the integration of societal concerns into nanotechnology R&D, I will go into detail with the American 21st Century Nanotechnology Research and Development Act (2003) [23], which mandates the integration of the humanities and social sciences.

There is a tension in the US federal legislation on integrating societal concerns into nanotechnology R&D, namely the tension between the following two driving trends: (1) rapid development in the name of competitiveness and (2) a more considered approach in the name of social acceptability [24]. More specifically, the first driving trend of rapid development in the name of competitiveness is seen in Program Activity (5), which says that the Activities of the Program should ensure United States global leadership in the development and application of nanotechnology. Furthermore, it is seen in Program Activity (7), which stresses that the Activities of the Program should accelerate the deployment and application of nanotechnology research and development in the private sector, including startup companies. The second driving trend of the more considered approach in the name of social responsibility is seen in Program Activity (10), which begins as follows:

> … ensuring that ethical, legal, environmental, and other appropriate societal concerns, including the potential use of nanotechnology in enhancing human intelligence and in developing artificial intelligence which exceeds human capacity, are considered during the development of nanotechnology… [23].

According to Fisher and Mahajan [24] it is unclear whether Program Activity (10) is intended to be a means of achieving the objective of global leadership of the US or whether it actually represents an objective in and of itself. Fisher and Mahajan [24] write that either way a prima facie reading of the term 'consideration' would suggest careful reflection upon technological options in relation to societal concerns. However, such an approach would not be likely to be encouraged by the tendency to move hastily from the lab to the market place. Then again, it would be consistent with an interdisciplinary approach to integrate societal concerns that requires new perspectives and a highly coordinated administration. The legislation appears to prescribe both hastiness and reflection; if so, it contains an inherent contradiction. Fisher and Mahajan [24] state that a cynical reading could see most of what is outlined in Program (10) as a direct but empty concession to the power of popular but 'irrational' worries, designed to lull them into complacency.

According to Fisher and Mahajan [24] it is unclear what is actually meant by 'societal concerns' in Program (10), and furthermore, it is unclear how these societal concerns are to be attended to. The phrase 'considered during' leaves the following open: Who does the considering, how, to what end and with what authority. On one reading scientists and engineers, humanists and social scientists, citizen groups and external regulators might consider the societal dimensions of technological decisions with an eye towards influencing nanotechnology development as seems appropriate to them. On another reading, societal concerns might be contemplated by one or more groups in relative isolation from nanotechnology R&D, which would occur independently of societal considerations and therefore be impervious to them. Without further clarification these questions might remain unresolved. The Act [23] however lists the following four strategies by which consideration is to occur; collectively these phrases can shed light on the above questions. As Program Activity (10) continues, it mandates that the consideration is to take place by means of:

> (A) establishing a research program to identify ethical, legal, environmental, and other appropriate societal concerns related to nanotechnology, and ensuring that the results of such research are widely disseminated;
>
> (B) requiring that interdisciplinary nanotechnology research centers … include activities that address societal, ethical, and environmental concerns;
>
> (C) insofar as possible, integrating research on societal, ethical, and environmental concerns with nanotechnology research and development, and ensuring that advances in nanotechnology bring about improvements in quality of life for all Americans; and
>
> (D) providing, through the National Nanotechnology Coordination Office … for public input and outreach to be integrated into the Program by the convening of regular and ongoing public discussions, through mechanisms such as citizens' panels, consensus conferences, and educational events, as appropriate [23].

Paragraph (10, A) promises little in the way of policy influence from what could be a mountain of research on societal concerns. However, in combination with the following paragraphs such research could have significant policy impacts. Paragraph (10, B) requires activities that address societal concerns to occur proximately to technological research and the use of the term interdisciplinary here suggests that there should be a relationship between the activities addressing societal concerns and the technological research, however, the paragraph does not specify of what kind this relationship should be. According to Fisher and Marajan [24] so far nothing in Program Activity (10) prevents research centers from carrying out discrete societal concerns activities that take place proximately to and simultaneously with technological R&D and yet are otherwise unrelated to it. There is no explicit linkage between the societal research of (10, A) and activities of (10, B) on the one hand and nanotechnology R&D on the other that would make certain that these are actually interdisciplinary as opposed to say fragmented or even mutually hostile. Paragraph (10, C) changes this pattern. It contains an explicit direction to integrate, hence to incorporate, assimilate and combine nanotechnological research and societal concerns research. This interdisciplinary integration prescribed in (10, C) potentially allows research on societal considerations to shape the course and hence the outcomes of nanotechnology R&D. Paragraph (10, D) supplements (10, C) by enhancing the expertise internal to technological disciplinary and interdisciplinary activities with external public input [24]. From the Act [23], however, it remains unclear how this interdisciplinarity should take form, hence how research into societal concerns should be integrated into the research process of nanotechnology. In the following I will go deeper into the developing literature on how the humanities and social sciences on the one hand and nanoscience on the other can get together.

Potential Strategy for Incorporating the Humanities and Social Sciences into the Research Process of Nanotechnology

As we have seen from empirical studies, it is important to integrate the humanities and social sciences into the interdisciplinary approach to nanotechnology to meet the public requirements. The analysis above shows that this is recognised by the 21st Century Nanotechnology Research and Development Act [23]. The literature gives several suggestions for potential strategies on how to integrate the humanities and social sciences into nanotechnology. In the following I will go into detail with the so-called Real-Time Technology Assessment (RTTA) developed by David H. Guston and Daniel Sarewitz [25]. According to Guston and Sarewitz [25] political economic studies of innovation pathways have already elucidated the roles of organisational structure, consumer feedback and various policy environments in this process, however, such scholarship has been less successful at actually enhancing linkages between innovation and societal action in ways that can add to the value and capability of each. Guston and Sarewitz [25] stress that an implicit societal demand for more sustained and pragmatic attention to strengthening such linkages can be seen in continuing public controversies over the societal implications of innovation, such as nuclear power, GM foods, cloned mammals and genetic screening. One limited way that federally funded R&D programs address this linkage is by supporting research into ethical, legal and social implications (ELSI) of initiatives such as the Human Genome Project, information technology and nanotechnology. However, Guston and Sarewitz [25] state that such work has not been well integrated into either the science policy process or the R&D process. They believe that the necessary and logical next step to ELSI is to integrate social science and policy research with natural science and engineering investigations from the outset—what they call Real-Time Technology Assessment (RTTA).

The model of RTTA comprises four components: (1) analogical case studies, (2) research program mapping, (3) communication and early warning and (4) technological assessment and choice. It is central to RTTA that these activities proceed simultaneously, are mutually supportive and are fully integrated into the innovation process [25].

Analogical Case Studies

The first component is the development of analogical case studies. Studying past examples of transformational innovations can help to develop analogies and frameworks for understanding and anticipating societal response to new innovations. Since patterns of societal responses can strongly influence the outcomes of research it is important to have knowledge about past examples about who has responded to transforming innovation in the past and the types of responses. For instance, the recent example of GM foods can help anticipate public concerns and responses to new technology such as nanotechnology [25]. As pointed out earlier, the predicted concrete ethical issues related to nanotechnology are rather similar to those related to biotechnology and biology that have been considered by ethicists since the 1970s. This means a knowledge base has already been acquired from ethical reflections on biotechnology and biology which is a good starting point and foundation for a discussion of ethical reflections on nanotechnology [16]. Bioethics discussions have so far often been focused on ready-made science. However, ELSA studies of nanotechnology can by use of RTTA enter at an early stage of development and extrapolate possible future scenarios based on knowledge from the biotechnological development for example.

Research Program Mapping

The second component of RTTA is mapping the resources and capabilities of the relevant innovation enterprise to identify key R&D trends, major participants and their roles and organisational structures and relations. While case studies help to situate evolving technologies in their historical context, research program mapping monitors and assesses current R&D activities at regional, national and international levels [25].

Communication and Early Warning

The third component is eliciting and monitoring changing knowledge, perceptions and attitudes among stakeholders. Communication among researchers, decision makers, the media and the public significantly determines the complex societal relation to innovation. Communication and early warning aspects of RTTA provide empirically grounded research-based strategies for enhancing the quality of the communication of not only scientific technical development but also social development including political, sociological and ethical aspects [25]. More specifically, communication among researchers from the different disciplines related to nanotechnology could consist in presenting research at conferences and publishing research in journals not related the researcher's own core discipline but to the other disciplines related to nanotechnology. Also, to make interdisciplinary research cooperation possible there is a need for establishing interdisciplinary nanotechnological research cultures in which the humanities and the social sciences are integrated. Some nanoscience centres already include sociologists and ethicists.[4] Communication among researchers, decision makers, the media and the public could consist in public hearings and consensus conferences, where it is important that researchers representing different schools and thoughts on science, technology, the humanities and social sciences are present.[5]

Guston and Sarewitz [25] state that the recent controversy over GM foods offers a cautionary tale about the need for communication and early warning, since few would disagree that stakeholders lacked a satisfactory process to address the issue in a productive manner until it was too late. To illustrate how the process of communication and early warning might unfold, Guston and Sarewitz [25] offer an example on research in artificial zeolites (aluminosilicate crystals whose nanoscale pores is designed to particular size, which means that they can capture specific pollutants). These crystals could be disseminated in contaminated air and function like free-floating nano-scrubbers to clean up the pollution. This approach may respond to public concerns about air pollution but also to concerns or fears about the consequences of respiration of the crystals. Communication and early warning activities would elucidate public attitudes about such consequences at an early stage. Such insights could influence the design of activities described in the next section on technological development and choice [25].

Technological Assessment and Choice

The fourth component of RTTA is engaging in analytical and participatory assessments of potential societal impacts. According to Guston and Sarewitz [25] informed societal response to innovation depends

[4] An example of an interdisciplinary nanotechnological research network is the *Frontiers Network of Excellence* funded by EU's Sixth Framework Programme. The network consists of 12 partners from all over Europe researching into physics, chemistry, materials science, electronics, molecular biology, and health sciences. To integrate the social sciences and the humanities in the interdisciplinary network, it is stressed that a sociologist and an ethicist are part of the network. At Cambridge University, which is one of the partners, the sociologist Robert Doubleday had a post doctoral position until year 2006. He has a background in chemistry and sociology. The University of Aarhus, which is also a member of the network, has employed an ethicist, Mette Ebbesen, who has degrees in molecular biology, philosophy, and ethics.

[5] Over past decades, participatory consensus conferences have spread internationally in an attempt to prevent societal conflicts over controversial technologies. The model of participatory consensus conferences—widely referred to as "the Danish Model" was originally developed by The Danish Board of Technology in the mid-1980s. Researchers point out that evaluations of such conferences seem to rest on the assumption that this type of procedure has universally agreed goals and meanings and that therefore consensus conferences can readily be interpreted and applied across national boundaries [26]. However, Nielsen et al. [26] investigated three consensus conferences on GMOs which took place in France, Norway and Denmark and concluded that interpretations of the concept of participation, the value attributed to lay knowledge versus technical expertise, ideas about the role of laypersons as well as what role public participation would be allowed to play in a democratic society vary considerable from country to country. Hence, the model of consensus conferences needs to be interpreted in the context where it is to be implemented.

on how well various societal actors (from scientists to the general public) are prepared for the evolving impacts of the innovation. Science and technology policy research needs to establish processes that can help society prepare for making *actual choices* about the progress direction and application of as well as responses to potentially transforming innovation. For instance, the release of autonomous artificial cells into the environment and the health implications of respirable artificial zeolites could well create public concerns. Early articulation of such concerns (which can be scientific, ethical, sociological or political concerns), before innovation trajectories are strung out into the market place, could help form research strategies and goals, and thus lead to greater concordance between public aspirations and nanotechnology innovation activities [25]. In this way importance is attached to the public's informed choice at an early stage of development.

Guston and Sarewitz [25] stress that RTTA promises for encouraging contextually sensitive innovation. Its research program mapping improves opportunities for strategically oriented innovation. Its communication and early warning components help assure awareness about innovation among researchers and the public, and its technology assessment and choice component provides a mechanism for such awareness to be reflexively incorporated into innovation. They believe that nanotechnology is an obvious example where RTTA can be helpful. On one hand the funding of nanotechnology is enormous by reference to inevitable societal benefits and on the other hand, fears of nanotechnology gained credibility by Eric Drexler with the description of potentially disastrous consequences of autonomous self-replicating nano-devises. According to Guston and Sarewitz [25], this tension between promised societal benefits and fears of nanotechnology creates a promising opportunity to develop and apply RTTA at the early stages of nanotechnology development. They state that RTTA can inform and support natural science and engineering research and that it can provide an explicit mechanism for observing, critiquing and influencing social values as they become embedded in nanotechnological innovations, which will maximise the benefits of the innovation, minimise its risks and ensure responsiveness to public interests and concerns.

Despite the fact that the reports on nanotechnology R&D focus on the integration of the humanities and the social sciences to gain public acceptance, the developing ELSA projects that have received significant support from their national funding bodies actually have more sophisticated visions of their role than public acceptance. These visions are manifested in the newly funded Center for Nanotechnology in Society at Arizona State University, where the group draws on RTTA and David Guston is a key figure. The visions are also manifested in the large Dutch nanotechnology assessment activity in NanoNed where Arie Rip is a key figure. This group draws on the so-called Constructive Technology Assessment (CTA), where the attempt is to broaden the design of new technologies through the feedback of technology assessment activities into the actual construction of technology. CTA has three particular analytical achievements: (1) Socio-technical mapping, which combines the stakeholder analysis of traditional technology assessment with the systematic plotting of recent technical dynamics, (2) early and controlled experimentation through which unanticipated impacts can be identified and if needed ameliorated and (3) dialogue between innovators and the public to articulate the demand side of technology development. These elements should let societal aspects become additional design criteria of new innovations. RTTA differs from CTA in at least two ways: First RTTA does not engage in experimentation with new technologies because RTTA is embedded in the knowledge creation process itself. Second, RTTA uses more reflexive measures such as public opinion polling and focus groups to elicit values and to explore alternative potential outcomes [25]. Since the American group in Arizona draws on RTTA and the Dutch group draws on CTA, these groups have a more sophisticated role than public acceptance. This fact means a brighter future for the critical function of the humanities and the social sciences than the one indicated in the reports on strategies for nanotechnology R&D.

Conclusion

By considering American and European reports on nanotechnology R&D I have pointed out that the overall objective to integrate the humanities and social sciences into the interdisciplinary approach to nanotechnology is to gain the general public's acceptance of nanotechnology in order not to provoke a consumer boycott as it happened with GM foods. In the reports, it is assumed that informing and educating the public about scientific and technological developments will create trust and consequently an acceptance of nanotechnology. However, researchers and empirical studies indicate that public attitude towards biotechnology is shaped not only by information, education, openness and debate about science, but also by risk perception and by moral and democratic considerations. This paper has shown that from these empirical studies we can learn that public information on nanotechnology should address political, sociological and ethical aspects to meet public requirements. The humanities and social sciences do research into several of these aspects, for instance, they reflect on the objectives we wish to realise by introducing new technology and the values at stake. These reflections aim not to build trust and acceptance in the public, but to critically assess new technology so that the public can make informed judgement. Hence, it is a misconception of the motivation and role of humanities and social sciences to focus exclusively on trust and acceptance. I have illustrated this critical function by discussing the role, motivation and contribution of ethics as an example, and I have considered RTTA as a possible strategy for incorporating the humanities and the social sciences into nanotechnology R&D.

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Appendix: Supplement to Table 1

Table 4 Definition of the categories

Category	Useful	Risky	Morally acceptable	Encouraged
1. Supporters	Yes	No	Yes	Yes
2. Risk-tolerant supporters	Yes	Yes	Yes	Yes
3. Opponents	No	Yes	No	No

Categories 1 and 2 are similar in being supportive, but they display different perceptions of risk. For the 'supporter', risk is not an issue. The 'risk-tolerant supporter' perceives risk but then discounts it. Opponents take a position exactly opposite to that of supporters [19]

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