Sci Eng Ethics (2013) 19:703–725
DOI 10.1007/s11948-012-9423-2

ORIGINAL PAPER

The Why and How of Enabling the Integration of Social and Ethical Aspects in Research and Development

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Received: 28 August 2012 / Accepted: 27 November 2012 / Published online: 6 December 2012

Abstract New and Emerging Science and Technology (NEST) based innovations, e.g. in the field of Life Sciences or Nanotechnology, frequently raise societal and political concerns. To address these concerns NEST researchers are expected to deploy socially responsible R&D practices. This requires researchers to integrate social and ethical aspects (SEAs) in their daily work. Many methods can facilitate such integration. Still, why and how researchers should and could use SEAs remains largely unclear. In this paper we aim to relate motivations for NEST researchers to include SEAs in their work, and the requirements to establish such integration from their perspectives, to existing approaches that can be used to establish integration of SEAs in the daily work of these NEST researchers. Based on our analyses, we argue that for the successful integration of SEAs in R&D practice, collaborative

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approaches between researchers and scholars from the social sciences and humanities seem the most successful. The only way to explore whether that is in fact the case, is by embarking on collaborative research endeavours.

Keywords Social and ethical aspects · Responsible innovation · Science and technology studies · Engineering ethics

Introduction

Research Context

Most New and Emerging Science & Technology (NEST), including life sciences, nanotechnology, nuclear energy and information technology, appear to raise political and societal concerns. Already in 1938, Robert Merton wrote that "[t]he goods of science are no longer considered an unqualified blessing" (Merton 1938:284). Precisely because innovations have a certain effect in society, responsible NEST based innovation requires that the benefits of science and technology are assessed in relation to the possible drawbacks in the full social context of the innovation. Policy makers devised regulations and guidelines encouraging NEST researchers to consider that context by taking into account relevant Social and Ethical Aspects (SEAs, European Group on Ethics 2007; European Commission 2011a; PBL 2012; 21st Century Nanotechnology Research and Development Act 2003). Science and technology actors, including NEST researchers, are encouraged "to develop science in society perspectives from the very beginning of the conception of their activities" (European Commission 2007:18). Nevertheless, researchers do not usually actively and consciously include SEAs in their daily work, neither in academia (Fisher and Miller 2009; Patra 2011), nor in industry (Burningham et al. 2007).

Incentivised by policy makers' calls for the integration of SEAs, scholars from the social sciences and humanities (social scientists[1]) have developed methods to facilitate NEST researchers to include such aspects in and during R&D[2] activities (see e.g. Fisher et al. 2006; Delgado et al. 2010), in the hope and expectation that his would help to create a "more accountable model of science and innovation" (Wilsdon 2005:29). Numerous approaches have been proposed and devised, including Constructive Technology Assessment (Schot and Rip 1997), Real-Time Technology Assessment (Guston and Sarewitz 2002), Ethical Parallel Research

[1] In the remainder of this article, we will refer to these scholars from the social sciences and humanities (sociologists, philosophers, ethnographers, humanists, science and technology studies practitioners, engineering ethicists, etc.) as 'social scientists.'

[2] In this article, we consider R&D practices to be phase the innovation processes where researchers work on the scientific and technological aspects of the innovations. In that sense, innovations are considered the outcome of R&D practices. We realise that innovation processes also contain other phases (e.g. authorisation, marketing, sales, maintenance), but to remain within the aim and scope of this article we focus on the integration of SEAs in R&D.

(Van der Burg 2009) and Midstream Modulation (Fisher 2006). Still, practical experience with such initiatives remains limited.

Paper Aim and Structure

The limited experience in SEA integration in R&D practice has shown that it may indeed be possible to establish such integration to some extent (see e.g. Lengwiler 2008; Delgado et al. 2010). Nevertheless, in existing approaches, the question what are the benefits for the participating researchers is mostly omitted *ex ante*. Societal and policy relevance of SEAs integration are stressed, and the relevance for researchers is largely omitted. Yet regardless of why policy makers and social scientists want researchers to include SEAs, we think there are good reasons for NEST researchers themselves to do so.

Existing literature on the integration of SEAs in R&D work provides various motivations. In this paper we aim to relate identified motivations for NEST researchers to include SEAs in their work, and the requirements to establish such integration from the perspective of NEST researchers, to existing approaches that can be used to establish integration of SEAs in the daily work of these NEST researchers. The possible perspectives of these NEST researchers on such motivations and requirements play a central role in our analysis. We first elaborate on the relevance of SEAs for R&D practice (Sect. 2). We then summarise various methods covered in literature which facilitate the integration of SEAs in R&D practice (Sect. 3). Next, we explore motives for researchers to integrate SEAs in their R&D practice and possible constraints for such integration (Sect. 4). Hereafter, we explore requirements for successful integration, seen from the perspective of researchers, based on existing literature on previous SEA integrative methods (Sect. 5). Subsequently we investigate to what extent these potential motives and conditions for successful integration are represented in existing approaches for SEA integration, by arguing on a scale of likeliness whether it is unlikely, possible, probably or very likely that the described methods align with the identified motivations and requirements (Sect. 6). We end with considerations and recommendations on how to successfully integrate SEAs in R&D practice (Sect. 7).

The Role of SEAs in R&D

Academic and industrial R&D environments are under transformation (Hessels et al. 2009). Academic R&D is increasingly conducted in partnerships with private investors. Simultaneously researchers are more pressed to account for the use of taxpayer's money (Fuller 2009), demonstrated e.g. in the explicit request to indicate societal use and relevance in R&D funding proposals. Concomitantly, industrial researchers are expected to develop state-of-the-art technical innovations, in a socially responsible way. The outcomes of their R&D work should positively influence corporate image and corporate social responsibility, by providing e.g. more sustainable and/or healthier products. Such contemporary R&D can be classified as ‘post normal’ (Funtowicz and Ravetz 1993), with ‘Mode 2’ characteristics (Nowotny et al. 2003).

Especially in specialised NEST fields (such as synthetic biology, where biological production systems are designed rather than discovered) the boundaries between ‘research’ and ‘development’, between ‘science’ and ‘technology’ have blurred. One cannot speak anymore of ‘scientist,’ ‘designer’ or ‘technologist,’ so we chose to use the term ‘researcher.’ NEST researchers are to take into account more considerations than purely scientific and technological ones, relating to e.g. intellectual property, environmental sustainability (corporate) social responsibility, communication, teamwork, collaborations and public opinion (Barling et al. 1999; Hessels et al. 2009). They are expected to adopt ‘responsible research and innovation’ (Von Schomberg 2011) practices, for which taking SEAs into account is a prerequisite.

Methods to Integrate SEAs in R&D Practice

Many activities designed for SEA consideration in R&D practice have focused on the role of citizens and other non-experts. Such public engagement and public communication activities have been reviewed earlier (Lengwiler 2008, Delgado et al. 2010). In contrast, we take NEST researchers and their practices as a starting point, rather than stakeholders external to R&D practice and review the role of researchers in literature on SEA integration.

Public Dialogue

The first category of methods we cover, we characterise as ‘Public Dialogue’ (PD). PD methods provide a way to take societal concerns, values, priorities and institutions into account in scientific and technological developments, in order to “find the common language and understanding, and to inform the ways in which all people, scientists and non-scientists alike, think about the priorities, directions, implications and consequences of science” (Jackson et al. 2005:353). The role of researchers, as scientific experts, is to connect the laboratory to the ‘world outside’ (Radstake et al. 2009). Practically, PD means for groups of people (researchers and other non-scientific experts) to come together and discuss NEST. This is claimed to enable the informing of interested publics early in NEST development, while also enabling researchers to sense and respond to public interests and concerns (Jackson et al. 2005). Involving non-specialists as partners in R&D provides a way for researchers to interact with society (Whitmer et al. 2010). Thereby researchers can learn about SEAs and anticipate and accordingly shape their R&D and possibly also market introduction strategies (Schot and Rip 1997). Activities used in PD approaches include e.g. consensus conferences, citizen juries, focus groups, public consultations and workshops.

Technology Assessment

Next we consider ‘Technology Assessment’ (TA) approaches. The overall aim of TA is to “reduce the human costs of trial and error learning in society’s handling of new technologies, and to do so by anticipating potential impacts and feeding these insights back into decision making, and into actors’ strategies” (Schot and Rip 1997). Various TA approaches include Constructive TA, Integrative TA, Participatory TA, TA in Social Context, Real-Time TA, and others. TA is mostly used as a philosophy, a rationale under which actual engagement activities with researchers and other (non-)scientific (non-)experts are carried out. Some of these approaches start from the perspective of allowing societal input in technological development. E.g. in Participatory TA (Durant 1999) the central question is how society can be represented in R&D, and initiatives have been analysed mainly with a focus on the exercise itself (Marris et al. 2008), without an explicit focus on researchers and their responsibilities.

In other approaches researchers do have a more explicit role. E.g. TA in Social Context (Russell et al. 2010:110) aims to “inform and engage stakeholders to improve understandings of technology in its social contexts and seeks to increase democratic input into decision making,” thereby seeking to “shape technology and social settings, not only via formal decision making avenues, but also by changing the way people think about technology and society.” Similarly, Constructive TA concentrates on dialogue among and early interaction with new actors in technology development to broaden the design of new technologies, by feeding TA activities’ outcomes back into this technology development. Van Merkerk and Smits (2008) have described and applied a 3-step CTA approach, where information is given to the participants first, followed by the development of future technological scenarios, which are subsequently discussed in dialogue workshops. The role of researchers is to provide information and discuss with others their viewpoints on the (desirability of the) developed scenarios. But, as Berloznik and Van Langenhove (1998) argued earlier, CTA remained a practice outside the laboratory: it does not necessarily involve researchers *during* R&D.

In contrast, Integrative TA has been defined as a research practice “in which during the actual performance of the R&D process, the researchers reflect on and if possible study the societal consequences of their research” (Berloznik and Van Langenhove 1998:30). This reflection should feed back into on-going R&D work, which is projected to avoid negative and unwanted consequences, and thereby perform more efficient and effective research. A similar TA approach that relates to researchers directly is Real-Time TA, which is embedded in R&D processes. Real-Time TA uses public opinion polling, focus groups, dialogue and scenarios, but also content analysis on (changes in) knowledge and perceptions. It aims to “elicit values and explore alternative potential outcomes,” to “enhance communication and identify emerging problems,” and to render innovation “more amenable to understanding and, if necessary, to modification” (Guston and Sarewitz 2002:98). In its proposed aims and methods it appears to be the most all-encompassing and most elaborately described in relation to daily research practice. It is explicitly designed for the 'mid-level,' the R&D environment.[3] In both the Integrative and Real-Time approach, the role of researchers is to reflect on SEAs, thereby influencing their own R&D, possibly helped by their managers or (professional) consultants, with certain procedures.

Collaborative Approaches

Public Dialogue (PD) and TA approaches rely on the contributions of researchers, but also require a mediating party (usually a social scientist) that organises the various interaction activities, such as focus groups and workshops. This mediator can potentially contribute to R&D work, but PD and TA literature does not explicitly reflect on the contributions of these mediators. In contrast, approaches exist in which social scientists are taking a more explicit role in the establishment of the outcome of R&D work, *collaborating* with researchers at their working floor, rather than only *contributing* (Calvert and Martin 2009). In contrast to PD and TA approaches, these 'collaborative' approaches rely explicitly on a reciprocal exchange of expertise: the role of the researcher is to consider SEAs in their work, while simultaneously the collaborating social scientist becomes more acquainted with R&D work. We describe three approaches that rely explicitly on close collaboration between NEST researchers and social scientists.

First, in Ethical Parallel Research, social scientists (e.g. ethicists) embedded in laboratories collaborate with the present researchers, in order to offer possibilities to take broader SEAs into account during R&D (Van der Burg 2009). The role of the researchers is to interact with a social scientist: through repeated interaction between the researcher and the social scientist, the social scientist can become a (trusted) insider, who can attune the 'soft impacts' to the specific context of R&D (Van der Burg 2010). Together they can find ways to use SEAs (highlighted by the social scientist) in a constructive way, relevant to R&D (as assessed by the researcher).

Second, 'sensitisation' is a similar strategy to invoke reflection on SEAs in researchers, through engagement to 'wider social imaginations' (Wilsdon et al. 2005), e.g. through 'repeated exposure' (Penders et al. 2009b:207–208) to a social scientist and the SEAs (s)he brings into the collaboration. Sensitisation has the potential to become contagious, in a sense that sensitised researchers may sensitise others. The power of the approach lies in its reciprocity: both the social scientist and the researcher learn about one another's worlds and viewpoints, and both have to cross the boundaries between science and society (Penders et al. 2009b).

Third, a more elaborately described method (both in methodological guidelines and in working principles) is Midstream Modulation (MM, Fisher et al. 2006). In MM, a social scientist ('embedded humanist') interacts regularly with researchers for a period of 3 months. The focus of MM is not necessarily on societal concerns, but rather on R&D decisions (Schuurbiers and Fisher 2009). The R&D decisions of

[3] The R&D process may contain three distinguishable phases, which have been illustrated by Schuurbiers and Fisher (2009). In the downstream phase of R&D, the central question is how to adopt and deploy R&D outcomes. In the upstream phase, it is asked what R&D to fund and carry out. In the midstream (mid-level), the main question is how to shape and implement R&D.

researchers are modulated into subsequent opportunities, considerations, alternatives and possible outcomes (Fisher 2007). Such opening up of researchers' decisions allows the social scientist to pinpoint specific possibilities to link these decision modulators to context relevant SEAs. Once researchers have become aware of the SEAs relevant to their R&D practice, they can start to actively integrate them by themselves (Fisher and Mahajan 2006; Schuurbiers 2011).

Motivations to Integrate SEAs

Next we explore why researchers may want to take SEAs into account during their R&D activities, and which challenges must be overcome to allow researchers to integrate SEAs relating to identified motivations.[4] We first describe normative, responsibility related motives. Second, we describe motivations related to society and the role of R&D in society. Third and last we describe reasons relating to R&D practice.[5]

Normative Perspective: Enhanced Reflexivity on SEAs for Researchers

It has been suggested that researchers should include SEAs in their R&D practices, as they carry a responsibility to society for doing so (see e.g. Berloznik and Van Langenhove 1998). Rip (1981) already noted that defining 'the' social responsibility of researchers is impossible, yet we can consider various responsibilities that may be ascribed to researchers. Verhoog (1981) argued that it is the permanent moral duty of all researchers to participate in discussions about the role of science in society, and the consequences of scientific discovery. Ziman (1998) argued that ethical reflection should become part of the 'ethos' of science. Bovens (1998) described the difference between active and passive responsibility. Passive responsibility is the accountability for researched or developed artefacts, whereas active responsibility relates to the deployment of responsible R&D practices. Doorn and Fahlquist (2010) have further elaborated on this, stating that it is more fruitful to stimulate researchers to adopt a more forward looking, active responsibility, focusing on the duties needed for responsible innovation (and responsible R&D herein) practices (Doorn 2012).

Yet the relevance of ethical aspects for responsible R&D can be made more explicit for researchers. Reflecting on ethics could improve researchers' ethical sensitivity, knowledge on relevant standards of (responsible R&D) conduct and improve ethical judgment and willpower (Davis 2006). Technological artefacts (as outcomes of technological development) co-shape our world, and as researchers develop such artefacts, they can (and arguably have the obligation to) consider connections between context of design and context of use (Mitcham 1994; Verbeek

[4] We review various motivations covered in literature. We cannot claim to be 100 % complete in our review, yet we can indicate most important trends and suggestions in literature.

[5] Our distinction of different motivations shows parallels to earlier analyses, distinguishing between substantive, normative and instrumental rationales for public engagement activities (see e.g. Stirling 2008). Yet, here we approach these motivations from the perspective of researchers.

2006; Swierstra and Jelsma 2006), e.g. pertaining to environmental impacts, economy and quality of life.

To consider SEAs in R&D practices, researchers need the ability to recognise and reflect on these aspects (Patra 2011). However, they are often unaware of the broader social and ethical contexts of their work (Fisher and Miller 2009) and as such, have difficulties identifying societal impacts (Owen and Goldberg 2010). Consequentially, usually researchers do not consider SEAs by themselves, possibly also because they are preoccupied with their own "specialized research problems and small circles of sponsors, colleagues, and rivals" (Brunner and Ascher 1992:296). The challenge therefore is to encourage researchers to start to identify and consider SEAs.

Yet issues could be identified and considered, but quickly dismissed and discarded afterwards (Johnson 2007). The results of such reflection should have an effect on R&D practice, feeding back into on-going research practices (Doorn and Fahlquist 2010). Awareness on the SEAs of R&D is a logical precondition to doing things 'differently' (Fisher et al. 2006), more responsibly. In that sense, as Rip (2009) argues, being reflexive is better than not being reflexive. Enhanced reflexivity on SEAs is not about societal stakeholders standing over the shoulders of researchers, yet about "bringing about the public within" researchers by enabling them to reflect on the social and ethical dimensions of their work (Wilsdon 2005:25). The use of ethical aspects is to address possible issues during the development of technology. The understanding of the social and ethical context may not always lead to 'better' R&D decisions, but may help reveal the social and ethical bases of R&D decisions, leading to a more transparent and accountable decision making process (Wilsdon 2005). As such, the prospective for researchers to obtain skills to reflect on SEAs in a manner that is both useful and relevant for them (Flipse et al. 2012), placing themselves in a wider, societal frame (Rip 2009),[6] can be a motivation for researchers to consider SEAs.

Societal Perspective: Enabling Researchers to Communicate About Their R&D Work

As the public has concerns about technological developments (Collins and Evans 2002), and academic research is still to a large extent funded by public, taxpayer's money, it is argued that researchers carry responsibility to address the public's concerns (Editorial. 2004; Osseweijer 2006). In addition, since innovations affect society (Guston and Sarewitz 2002), societal actors should possibly have a say in which research activities researchers embark on. Beckwith and Huang (2005) argued that if society is to remain in step with technology, researchers should know

[6] These normative reasons may be of limited value to industrial R&D. Corporate R&D is not funded by public money. Still, there are reasons for industrial researchers to take into account SEAs. A broader set of SEAs in R&D could help increase corporate social responsibility (Wilsdon & Willis 2004). Notwithstanding, some may argue that companies only exert social responsibility for its (in)direct effect on turnover and profit (*cf.* Marshall and Toffel 2005), or as a form of risk management. Possibly, reasons for such integration are neither purely idealistic, nor purely economic, but a balance between the two (Penders et al. 2009a).

about the social and ethical implications of their research. Naturally, researchers can only take into account public input, if they have learned which considerations and concerns actually play a role. Reciprocally, the societal actors can only appraise technological developments if they know about them first (Stirling 2008). Therefore, researchers should communicate their activities and findings (SIRC 2001). But why would they want to communicate their results, and why would they allow society to have a say in what they do?

Researchers can possibly only build ‘public value’ if they take seriously the constraints and choices that they face (Wilsdon et al. 2005; Guston and Sarewitz 2002), pertaining to the social and ethical context of their work. Knowledge developed through ‘engaged’ research, taking into account multiple actors and viewpoints, is most likely to become socially accepted, relevant to policy and environmentally friendly (Overdevest et al. 2004). In addition, allowing societal input e.g. through the inclusion of outsider perspectives, is also a way to ‘democratise’ R&D (Van de Poel 2000; Nowotny 2003). Such democratisation may pertain to joint discussions on the future we want (enabled and facilitated by science and technology), where to put priorities and how applications and implications of science and technology should be governed and managed (Jackson et al. 2005), possibly meeting better societal design criteria (Van der Burg 2009). The consequences of letting the public help researchers on deciding how to spend government research funding should possibly be welcomed, not feared (Editorial 2004). E.g. societal assessments of new technology could ensure that newly developed innovations do not adversely affect health or the environment (Shatkin 2008).

Particularly in some NEST fields where public appreciation is relatively low, such as genetic engineering (Gaskell et al. 2011), researchers have may have something to gain from increased public appreciation of their technologies. Technologies can only be classified as desirable if they are assessed also in light of social implications. The goal of conveying information on R&D to societal actors is not necessarily to create consensus among stakeholders; it is even questionable whether such consensus is both reachable and desirable (Roelofsen et al. 2011). The point is to allow a serious deliberation on the pros and cons of new and emerging R&D, such as synthetic biology. This requires a role by researchers that includes active communication with other societal actors, including non-scientists.

Also, Wilsdon (2005) has suggested that engagement activities between science and society could help to challenge the stereotypes that researchers have of the public. There is still an assumption among many researchers that controversies over science occur because of public ignorance (Wynne 2006; Nisbet and Scheufele 2009; Groffman et al. 2010). The purpose of communication to the public is also still often seen as one-way, for the purpose of educating ignorant citizens (Davies 2008). Yet taking public ignorance as a starting point, has not been successful for science communication models (Groffman et al. 2010).

In “rearticulating their professional ethics,” taking SEAs into account, researchers could (re)build a bridge between science and society (Davies and Wolf-Phillips 2006:59). This requires researchers and societal actors, including public, policy makers, social scientists and humanities scholars, to interact, to learn about one another's considerations (Wolpert 2007). Communication is therefore an important skill for researchers to have (Nowotny 2003). However, researchers generally find communication outside their own community difficult or even dangerous (Davies 2008). Still, considerations of these "opinions, attitudes, fears, interests and hopes" could be as important as considering clear scientific and technological facts (Koivisto et al. 2009:1166). As such, obtaining communication skills in order to discuss and learn about SEAs, in a fruitful way with other societal actors, can be a motivation for researchers to consider SEAs.

R&D Perspective: Including Relevant SEAs that May Improve R&D Quality

There are also motivations for researchers to consider SEAs that pertain to the quality of R&D practices themselves. Integration of SEAs can help to shape R&D, before significant decisions have been made and become locked in (Rogers-Hayden and Pidgeon 2007) and it is too late to change the direction in which R&D trajectories are headed (Fisher et al. 2006). SEAs can positively enrich the process of scientific investigation (Funtowicz and Ravetz 1993; Van de Poel 2000, Ravetz 2004, Jackson et al. 2005; Doorn 2012). Experience integrating social and ethical considerations has shown that such integration may benefit research planning and stimulate researcher's creativity (Fisher and Mahajan 2006) and set better research goals and priorities (Van der Burg 2009).

As Hessels et al. (2009:390) argue, "[s]cientists are dependent on their societal environment for their survival, so they cannot easily break the contract with society." Scientific credibility is not only gained in a specialist community, but also in a societal context with financers, regulatory authorities and possibly customers and consumers (Penders et al. 2009a). Unintended societal impact or other consequences of technological development may be anticipated better through the inclusion of SEAs (Rogers-Hayden and Pidgeon 2007). Integrating SEAs in R&D trajectories could help to prevent controversy (Guston and Sarewitz 2002; Wilsdon 2005; Editorial. 2009) and yield more (socially) desirable outcomes (Van Merkerk and Smits 2008). In addition, considering SEAs could also impact the R&D-marketing interface, potentially aiding more successful innovation trajectories (Fortuin and Omta 2007).

Researchers frequently do not use the results of technology assessments or marketing studies; the social impacts are not integrated in their decision making processes (Schot and Rip 1997). It often remains unclear how broader considerations can be brought to the actual laboratory work in a constructive, positive way that adds to both science and society (Schuurbiers and Fisher 2009). Technological trajectories that assess future impacts and identify SEAs, need first evidence of being more successful than other trajectories, before such more accountable models of techno science can be deployed in everyday R&D practice (Guston and Sarewitz 2002; Whitmer et al. 2010). Also, which SEAs to include often remains unclear (Stegmaier 2009): these aspects are highly context dependent and apply only in specific situations under specific conditions (Vanclay 2002). As such, allowing researchers to include relevant SEAs in a constructive way, contributing to the quality of their R&D output, can be a motivation for researchers to include SEAs in their daily work.

Requirements for Successful Integration of SEAs in R&D Practice

After covering motives and challenges for SEA integration by researchers, we now move towards potential requirements for researchers for the successful integration in R&D practice. Considering that explicit integration of such aspects is still largely absent in R&D practice, the following questions rise which will be addressed subsequently. Where and when in R&D practice would SEAs integration be most useful? What to focus on in such integration? What could incentivise researchers to start to consider SEAs? And last, how can the relevance and use of doing so become perceived as credible by researchers?

Where & When: Researcher's R&D Practice

Focusing primarily on the 'back-end' of R&D to integrate SEAs (i.e. once a technology is developed), possibly is too late to have significant influence on R&D itself (Rogers-Hayden and Pidgeon 2007), and as such may considered an incomplete, limited strategy (Berloznik and Van Langenhove 1998; Lengwiler 2008). In addition, judging R&D after it has finished, may be experienced as troublesome and irritating by researchers (Swierstra and Jelsma 2006). Focus has therefore shifted more 'upstream' (Wilsdon 2005; Burningham et al. 2007), enabling a role for SEAs in actual R&D processes. It is argued that relevant SEAs should be identified as early as possible in R&D (Doorn 2012). Some have therefore proposed that integration should start from the outset of R&D (Guston and Sarewitz 2002; European Commission 2007), or at least while a technology is still emerging (Lucivero et al. 2011).[7] The earlier the stage of development, the more 'degrees of freedom' available to change the direction of a new development (Gorman et al. 2009), and hence the more opportunities for SEAs to influence on-going R&D.

Yet, when SEAs are included in upstream funding and authorisation decisions, there is no guarantee that SEAs are actually going to be used in R&D itself (Shove and Rip 2000): those who apply for funding or are in charge of regulation, are not necessarily the same as those who carry out the research. Also, when too early, the possible impacts of technology may be difficult or even impossible to predict (Collingridge 1980), rendering consideration of SEAs without use and relevance for R&D practice. Even realistic future scenarios may 'cast a shadow' on current scientific and technological work, and current aspects are then possibly overlooked (Nordman 2007; Nordman and Rip 2009). In addition, regulating and restricting R&D too soon might 'choke off' the potentially beneficial technologies being developed (Randles 2008).

[7] This may be considered especially important in socially and politically problematic R&D areas, such as the life sciences, with concerns of e.g. genetically modified organisms, synthetic biology and stem cell technology. Failure to attend to these concerns early may turn out to be costly (Rogers-Hayden and Pidgeon 2007), both in monetary and public appreciation related terms.

Approaches focusing on the front- and back-ends of R&D may be very relevant for research authorisation and implementation. Yet, from the perspective of NEST researchers, the R&D phase probably provides the best opportunities to integrate SEAs (Doorn and Fahlquist 2010). This is where innovations get their first and final shape and where researchers' influence is probably largest (Fisher et al. 2006). As such, one possible requirement for the successful integration of SEAs in NEST is that such integration occurs during the R&D practice of researchers, at their laboratories.[8]

What to Focus on in Integrating Ethical and Social Aspects: R&D Decisions

Relevance to R&D practice can only be elucidated in a local R&D context (Russell et al. 2010). Ultimately, from the perspective of researchers, R&D is about making choices in order to reach specific goals. In integrating SEAs, R&D decisions[9] may provide a good starting point: as Fisher and Mahajan (2006:5) state, "due to the experimental and trial and error nature of research […] decisions are in a continuous state of revision and transition." The point of including SEAs in decision making is not to overanalyse and possibly paralyse technological development, but rather to inform and enrich such decision making (Shatkin 2008). Inclusion of SEAs may do so by enabling the inclusion of a broader and more diverse community of decision makers (Sarewitz 2005), helping to shape the trajectory of technological development (Wilsdon et al. 2005), broading the kinds of SEAs that shape science and technology, and enabling a richer discussion about the "visions, ends and purposes of science," (Wilsdon 2005:25). So, for researchers to integrate considerations of SEAs in their daily work, it seems required that these SEAs relate to the local and context specific R&D *decisions* that researchers make.

Incentives and Initiatives: Organisational Support

If researchers start taking SEAs into account, their practices should first open up to such aspects. Yet access to R&D institutes can be difficult or even impossible to acquire (Doubleday 2004; Patra 2011; Penders et al. 2009a), and engaging researchers requires at least as much attention as engaging citizens (Radstake et al. 2009). Sometimes institutions discourage or even restrict researchers to collaborate with outsiders (Whitmer et al. 2010), particularly in industry due to intellectual property and secrecy concerns (Wilsdon and Willis 2004). For companies, their competitive advantage may be at stake (Bercovitz and Feldman 2007), and social

[8] Still, the laboratories where R&D work is largely carried out, are un(der)examined as places for increased reflexivity on SEAs (Conley 2011), both in universities (Patra 2011) and industry (Davies and Wolf-Phillips 2006; Van Merkerk and Smits 2008; Stegmaier 2009).

[9] These can range from micro-level decisions on e.g. technical, social and economic aspects (e.g., which temperature to set for optimal research outcomes, which technician to ask to perform experiments, and choosing between a more and less expensive analysis kit) to macro-level decisions (e.g., which type of production plant to build to make the most sustainable product, which organisations to cooperate with to reach the most favourable outcomes, and which machinery and raw materials to buy from which supplier). In all such decisions, researchers are likely to be involved to a certain extent.

scientists may not be used to environments where the stakes are that high (Penders et al. 2009a). Nevertheless, the lion's share of R&D is carried out in commercial research institutes, both in terms of budget and in terms of labour intensity (European Commission 2011b). Yet here the opening up of the scientific process and inclusion of SEAs appear to be lacking (Wilsdon and Willis 2004), and the necessary access to and interaction with researchers has to be negotiated (Penders 2008).

The effectiveness of approaches to include SEAs in R&D requires and depends on the willingness of individual researchers, and the support of their institutions (Groffman et al. 2010). Yet, there may be lack of both incentives for researchers—and their managers (Doorn and Fahlquist 2010)—to deploy socially responsible R&D practices. Swierstra and Jelsma (2006) have argued that engineers focus on the technical side of their research projects because of the lack of incentives and resources. Wilsdon et al. (2005) argued that researchers need more opportunities to talk about their R&D decisions, considerations and purposes, while at the same time institutions need to provide opportunities for social and ethical considerations to influence decision making. Organisations in which researchers work are in the position to recognise and reward such activities. For the successful integration of SEAs in researchers' daily practice, it seems required that reflection on SEAs must be acknowledged and rewarded by the institutions in which these researchers work.

Credible Engagement: Confidence in SEAs Gradual Introduction

Considering that SEAs are not regularly integrated in R&D practice, researchers need time to learn to use these aspects (Grin and Van der Graaf 1996). Researchers will not start to consider SEAs overnight. Fisher and Mahajan (2006) posited that integration of SEAs occurs in 3 'modulation' steps. First, researchers must become aware of the *de facto* modulators (SEAs) that influence their R&D practice and decisions. Second, they grow more and more aware of these aspects and can reflect on them by themselves in *reflexive* modulation. Third, this reflexivity can evolve into realisations of where to actively use SEAs in their decision making, in *deliberate* modulation. Such *deliberate* modulation will only happen after time, when researchers are confronted with SEAs on a regular basis (Flipse et al. 2012). It seems required that sustained and regular contact with SEAs allows researchers to gradually learn about those SEAs relevant to their practice (Schuurbiers 2011).

Aligning Existing Methods with Requirements for Successful SEAs Integration

In the sections above we described three approaches that may allow researchers to take SEAs into account (Sect. 3). We continued with a display of motivations for researchers to use SEAs in their daily R&D practice (Sect. 4) and the possible requirements for integration of SEAs in that practice (Sect. 5). In this section we compare these motivations and requirements to the described approaches (Table 1). Below we argue, on a scale of likeliness, why it is unlikely, possible, probable or

Table 1 Motivations for researchers to participate in approaches that may introduce Social and Ethical Aspects in their daily Research and Development Practice (Unlikely–Possibly–Probably–Very Likely)

	Public dialogue approaches	Technology assessment approaches (3rd generation)	Collaborative approaches
Enhanced reflexivity on SEAs for researchers	Possibly	Probably	Very Likely
Enhanced communication skills for researchers	Probably	Probably	Probably
Focus on relevant SEAs that may increase R&D quality	Unlikely	Possibly	Possibly
Focus on actual R&D practice	Unlikely	Possibly	Very Likely
Focus on local and contextual R&D decisions	Unlikely	Unlikely	Very Likely
Organisational incentives and initiatives present	Unlikely	Unlikely	Very Likely
Researchers can gradually become acquainted with SEAs	Unlikely	Unlikely	Very Likely

very likely that the motivations and requirements align with the three approaches, i.e. Public Dialogue, Technology Assessment and Collaborative approaches.

One described motivation for researchers to include SEAs is to expand the considerations they use, which can be beneficial for the quality of their work. To do so, researchers have to be enabled and encouraged to reflect on these SEAs. Technology Assessment and Collaborative approaches presented in literature explicitly focus on such enhanced reflexivity, as was indicated in Sect. 3. For Collaborative approaches, there is even empirical evidence that reflexivity is indeed increased (Fisher and Mahajan 2006; Van der Burg 2009; Schuurbiers 2011). Public Dialogue approaches could also help to increase researchers' reflexivity on SEAs. Nevertheless, this was not explicitly the focus of these PD activities and not investigated as such in PD literature. Therefore, we argue that it could be possible for PD approaches to enhance researchers' reflexivity on SEAs, that it is probably so that TA approaches do so, and very likely that Collaborative approaches do so.

To further allow researchers to include SEAs, we argued that they may want the skills to communicate about such aspects, rather than only the skill to communicate about the technological aspects of their R&D work. Because of the nature of PD and TA approaches, in which researchers interact and hence communicate with other, non-scientific people, it is probably so that their communication skills can increase through that interaction. Still, this was not investigated explicitly in literature on all three approaches. We therefore argue that it is probably the case that PD, TA and Collaborative approaches enhance researchers' communication skills.

We argued that researchers may be motivated to let SEAs play a role in R&D practice, provided that doing so increases the quality of R&D work and its outcomes. In that sense, PD approaches may be of limited value for the quality of R&D, for these activities focus mainly on the desirability of and societal role for NEST. PD activities seem to be too much detached from R&D practice. For TA approaches, the idea is that experiences gained through activities such as scenario workshops, feed back into R&D decisions, thereby increasing both the quality and outcome of R&D. Nevertheless, we have not found conclusive evidence in TA literature that this occurs, and TA methods do not elaborately describe opportunities to identify or measure changes in R&D practice. In contrast, Collaborative approaches focus explicitly on R&D practice, rather than the outcomes of that practice. Also, methods to identify and assess changes in R&D practice are described in literature on Collaborative approaches. Yet, to what extent this actually leads to an increased R&D quality, remains to be assessed. We therefore argue that it is unlikely that PD approaches can enable researchers to identify relevant SEAs that may increase R&D quality, but that this may be possible in TA and Collaborative approaches.

For researchers to take SEAs into account seriously, we illustrated in Sect. 5 that it is important that these aspects are relevant for R&D practice. As stated above, PD activities do not focus on R&D practice, but rather on its outcomes. Also, it is questionable whether there is an actual public desire for engagement on broader social and ethical issues in science and technology (Burningham et al. 2007; Delgado et al. 2010). TA approaches may have good motives, yet there are many barriers and drawbacks (Sarewitz 2005; Genus and Coles 2005). Wilsdon (2005) has described that while these approaches provide a glimpse of more accountable science and innovation practices, these activities are still ‘embryonic’, and their outcomes and effect difficult or even impossible to predict. Also, concerns appear to emerge that such “exercises are not serving the theoretical ideal of guiding the direction of techno-scientific development,” but rather focus “on preventing controversies by familiarizing the public with technologies before they become commercialized” (Rogers-Hayden and Pidgeon 2007, in Delgado et al. 2010:853). In contrast, Collaborative approaches focus explicitly on R&D practice, and are shown to be of relevance there (Van der Burg 2009, Schuurbiers 2011). As such, we argue that it is unlikely that the requirement that activities focus on actual R&D practice, for successful SEA inclusion in R&D practice, is met in PD approaches. Still, for TA approaches it is possible that this requirement is met, and for Collaborative approaches it is very likely that these activities focus on actual R&D practice.

We also discussed that in order for researchers to see the relevance of SEAs, it is required that these relate to the choices that researchers make. As PD approaches do also not focus explicitly on R&D practice, it is unlikely that there is a direct influence on R&D decisions. By contrast, the idea of TA is that the results of the activities feed back into R&D decisions, but there appears to be no evidence that this is actually occurring. The link to “choices, priorities and everyday practices” of R&D remains “fuzzy and unclear” (Wilsdon and Willis 2004:18). Written accounts of Collaborative approaches that show an effect on R&D decisions pertaining to SEAs do exist (Fisher 2007; Schuurbiers 2011). We therefore argue that it is unlikely that PD and TA approaches focus explicitly on local and contextual R&D decisions, whereas for Collaborative approaches this seems very likely.

We argued that organisational support for the integration of SEAs is required for the successful integration of such aspects in R&D practice. While researchers in both academic and industrial institutions are probably allowed to participate in all three approaches, there is a difference between PD/TA approaches and Collaborative approaches. The former usually involve activities that occur once or twice, and last usually one or a few hours. The latter, collaborative approaches, take much longer, e.g. 3 months in the case of Midstream Modulation. Researchers need management support to participate in such longer activities (Gorman et al. 2009; Van Merkerk and Smits 2008), while they are probably more 'free' in deciding to participate in a one-time activity in PD/TA. As such, researchers are unlikely to be incentivised by their organisation to participate in PD and TA approaches (since they may decide on that by themselves). Also, usually PD and TA approaches are not initiated by the organisation in which researchers work, but by interested social scientists. But, participation in longer-term collaborative approaches probably needs to be authorised by a researcher's organisation. As such, when such approaches are carried out, it is very likely that organisational support must be present when researchers participate.

We also argued that it takes time for researchers to see the relevance of SEAs and start to use them in their decisions, and as such it is required that they gradually become acquainted with SEAs. This involves sustained interaction between researchers and other (non-)scientific experts (Sect. 5). As PD and TA approaches usually take place on a limited number of occasions, it is unlikely that researchers *gradually* become acquainted with SEAs. In Collaborative approaches, evidence (Fisher 2007, Schuurbiers 2011) suggests that researchers indeed start to consider SEAs when considerations on such SEAs are gradually introduced in their R&D practice. As such, it is very likely that researchers become gradually acquainted with SEAs in collaborative approaches.

Discussion

The outcome of our analysis, depicted in Table 1, suggests that seen from the perspective of NEST researchers, collaborative approaches would be the most successful in allowing them to include SEAs in their daily R&D practice. There is an explicit focus on reflexivity and communication, and an immediate relevance to R&D and R&D decisions. Researchers are allowed to gradually learn about SEAs and incorporate them by themselves in their work. Only a direct link to improved R&D practice seems to be lacking.

This analysis does not render PD and TA approaches useless to researchers. These activities can be useful for e.g. descriptive analyses on interactions between researchers and societal actors, and for identifying public and scientific concerns over technological development. And possibly also for social scientists aspiring to participate in collaborative research with NEST researchers, to learn about relevant SEAs from multiple perspectives. But, considering the relevance of these approaches for researchers: since these approaches were not explicitly designed to influence relevant R&D decisions by researchers directly, they seem less appropriate for the explicit goal of SEAs integration after our analysis. Still, while collaborative approaches seem most appropriate to invoke SEAs sensitivity in researchers, it may work best in "tandem with [other, SF] sources of intervention, feedback, and collaboration, such as ELSI research, upstream engagement, CTA, RTTA, and others" (Fisher et al. 2006:494). Additionally, there are also constraints and limitations to collaborative approaches, pertaining to the role of the engaging social scientist and to the relationship between the researcher and the social scientist. Below we elaborate on these limitations, followed by an outline with various recommendations for successful SEA integration in R&D practice.

Collaborative Research: The Role of the Social Scientist

Ultimately communication processes occur between individuals, not institutions: individuals frame and shape communication processes (Davies 2008). In collaborations, this entails interaction between a researcher and a social scientist. Such collaborations can only work when the social scientist works in close proximity to the R&D (laboratory) floor, where (s)he can explore context relevant SEAs, helping in "pointing out uncertainties, scientific controversies and additional challenges that might constrain or redirect the development of the technology" (Lucivero et al. 2011:6). As Conley (2011:715) argues, there is a growing need for people with specific competences, including the ability to interact with researchers while also being able to "navigate political, governmental and industrial terrains." Such expertise "need not lie in the hands of formally trained scientists alone" (Carolan 2007:12). Social scientists can be mediators within techno-scientific culture (Kaiser 2012), facilitating the integration SEAs in R&D practice. This asks a hybrid form of interactional and contributory expertise (Collins and Evans 2002) of the social scientist, who should have a basic understanding of the R&D that is going on (Webster 2007), complemented with knowledge on SEAs, ensuring that public viewpoints are not dismissed (Davies 2008; Doorn and Fahlquist 2010).

Social scientists cannot permit themselves to become too much detached from technology and researchers (Penders et al. 2009b), and should avoid taking the role of an outside critic (Johnson 2007). However, getting too close, thereby becoming too much embedded in the scientific establishment that critical views become more or less impossible, poses a danger for social scientists (Penders 2008; Gorman et al. 2009). They should remain objective and critical (Webster 2007; Schuurbiers 2011).

From Coexistence to Collaboration

Placing a researcher in a room together with a social scientist is no guarantee for collaboration. It often remains unclear what entitles social scientists to intervene in R&D (Stegmaier 2009), also for researchers who are expected to participate in collaborative approaches. Activities bringing together researchers and social and ethical viewpoints are often uninvited (or considered uninvited) from the side of the researcher (Delgado et al. 2010). Researchers frequently argue (and are sometimes even trained to think) that it is their responsibility to just to their science, and they are not responsible for the implementation of their findings (*cf.* Beckwith and Huang 2005; Fisher and Miller 2009). Engagement activities to include SEAs appear to be absent or are not regarded necessary or desirable by researchers (Burningham et al.

2007). Especially young researchers seem to be less engaged in dialogue, and as such seem reluctant to engage in activities to include SEAs (Chilvers 2006).

Researchers in some NEST fields reluctantly admit that collaboration comes naturally to them, but that it's "a necessary condition for forging ahead in a culture where the walls of science have become partly transparent" (Shapin 2008:3). Burningham et al. (2007) also demonstrated that the public is not necessarily seen as a group that has knowledge that merits engagement. Patra (2011) described that even though she found researchers to be aware of several SEAs, most of them fail to think about the repercussions of these on their own research. Researchers may frown upon allowing critical views in their own environment. Social scientists might even be seen as antagonists of science and technology, or considered a break on progress (*cf.* Shelley Egan 2010; Patra 2011). This may to some extent be understandable in light of past engagement activities in which social scientists were telling researchers what *not* to do in their R&D (Van der Burg 2009). Currently, collaborative approaches are more constructive in nature, enabling and encouraging researchers to adopt a forward looking responsibility (*cf.* Doorn and Fahlquist 2010). Possibly, social scientists need to clarify this to researchers, should they want researchers to participate in collaborative approaches. Still, researchers will only participate in collaborations with social scientists if the benefits of doing so are clear to them, and they probably want to be presented with credible evidence that those benefits exist. Success stories may help to present such evidence.

Still, collaborative approaches cannot guarantee that public controversies of technology can be avoided (Russell et al. 2010). These approaches will probably not solve issues of trust in and appreciation of science on their own (Editorial. 2004; Rogers-Hayden and Pidgeon 2007). This indicates that expectations of social scientists and researchers need to be aligned. As far as researchers are concerned, they probably find it tolerable to be studied (Penders et al. 2009a), but some may also fear to be scrutinised (Macilwain 2009). Yet researchers may expect from collaborations that social scientists act as a means, a medium through which science may become more effectively accepted and acceptable, thereby acting as the 'midwife' through which science can be made more socially responsive and responsible (Webster 2007). But social scientists do not wish to function only as 'lubricants' or mediators between science and society (Rip 2009), indicating when science may acquire a socially warranted status, as 'handmaidens' of new technology (Macilwain 2009). Also, they do not see it as their task to pre-empt and deflect societal responses, to become 'token ethicists' (Schuurbiers and Fisher 2009), or to solely help scientists communicate (Editorial. 2009). SEAs are not to be used as 'window dressing', aiming to make technologies (seem) more desirable *ex post* (Johnson 2007) or as 'checkbox ethics' (Doorn 2009). Similar to technologies not necessarily always being benign, ethics is also not always benign or virtuous (Randles 2008), and cannot make (immoral) developments more ethically sound.

On the other side, social scientists cannot expect researchers to take SEAs into account just because social scientists tell them to. Social scientists must be equipped with the right tools to facilitate SEAs integration, and even then a chance remains that SEAs are not incorporated into practice, that researchers are not 'sensitised' to such aspects (Penders 2008). Researchers are most likely to accept and adopt suggestions by social scientists if these are translated into the technical language used by the researchers themselves (Carolan 2007). Yet, if researchers were to be continually pushed, or 'indoctrinated' to take SEAs into account, that could lead to irritation and even termination of the interaction between social scientists and researchers (Penders 2008). Instead, a more Socratic approach is advisable (Calleja-Lopez and Fisher 2009).

Development of a good relationship between the social scientist and the researcher takes time (Schuurbiers 2011). Through repeated interaction over the course of the NEST development, they can both "become acquainted with each other's way of thinking and evaluating" (Van der Burg 2010:311). Only then can coexistence of the two within an R&D environment evolve into a collaboration in which they both contribute to an improved, more responsible R&D practice.

Outlook

In this paper we set out to elucidate the why and how of integration of SEAs in R&D practice, seen from the perspective of NEST researchers. Researchers can only take SEAs into account if they are able to reflect on them by themselves. To enhance that reflection, they must be able to communicate about them. Yet, researchers will want to include only SEAs that are relevant to their own R&D, when it enhances their own work. This means that activities aiming to include SEAs, must be relevant for R&D practice, and more specifically to the decisions that researchers make. Also, their organisations must be willing to provide initiatives to integrate SEAs. In addition, researchers need time to become acquainted with SEAs to gradually start to understand and use them in daily practice. In our comparative analysis, we compared Public Dialogue, Technology Assessment and Collaborative approaches with these requirements for integration (Table 1). Only Collaborative approaches such as Midstream Modulation appear to provide researchers with the necessary conditions to integrate SEAs in their daily practice.

Still, there are many hurdles on the collaborative road towards a more responsible R&D. The first results of Collaborative approaches have only recently started to appear. Through further research the possibilities of collaborations can be more thoroughly explored, and more success stories could be formulated that are needed to convince researchers to participate in collaborative approaches. Also, social scientists need to be equipped with the right tools to help to facilitate SEAs integration. In addition, both need to attune expectations in order to come to fruitful collaboration. Next, it must be assessed whether collaborations lead to sustained SEAs integration, also when collaborations have come to an end. Possibly then SEAs integration can become an institutionalised, standard part of R&D practice. Still, the only way in which the above can be elucidated is by engaging in collaborative research. We hope that our analysis will further help and incentivise social scientists to undertake collaborative endeavours with their counterparts from the natural sciences.

Acknowledgments This article is the result of a research project of the CSG Centre for Society and Life Sciences carried out within the research programme of the Kluyver Centre for Genomics of Industrial

Fermentation in The Netherlands at the Delft University of Technology, Department of Biotechnology, Section Biotechnology & Society (BTS), funded by the Netherlands Genomics Initiative (NGI)/ Netherlands Organisation for Scientific Research (NWO). We thank Dr. Ibo van de Poel for his critical review of an earlier version of this manuscript.

References

21st Century Nanotechnology Research & Development Act. (2003). Public Law 108–153.

Barling, A., De Vriend, H., Cornelese, J. A., Ekstrand, B., Hecker, E. F. F., Howlett, J., et al. (1999). The social aspects of food biotechnology: A European view. *Environmental Toxicology and Pharmacology, 7*, 85–93.

Beckwith, J., & Huang, F. (2005). Should we make a fuss? A case for social responsibility in science. *Nature Biotechnology, 23*(12), 1479–1480.

Bercovitz, J. E. L., & Feldman, M. P. (2007). Fishing upstream: Firm innovation strategy and university research alliances. *Research Policy, 36*, 930–948.

Berloznik, R., & Van Langenhove, L. (1998). Integration of technology assessment in R&D management practices. *Technological Forecasting and Social Change, 58*(1–2), 23–33.

Bovens, M. (1998). *The quest for responsibility. Accountability & citizenship in complex organisations*. Cambridge: Cambridge University Press.

Brunner, R. D., & Ascher, W. (1992). Science and social responsibility. *Policy Sciences, 25*(3), 295–331.

Burningham, K., Barnett, J., Carr, A., Clift, R., & Wehrmeyer, W. (2007). Industrial constructions of publics and public knowledge: A qualitative investigation of practice in the UK chemicals industry. *Public Understanding of Science, 16*, 23–43.

Calleja-Lopez, A. & Fisher, E. (2009). Dialogues from the lab: Contemporary maieutics for socio-technical inquiry. Proceedings of society for philosophy & technology, University of Twente, The Netherlands.

Calvert, J., & Martin, P. (2009). The role of social scientists in synthetic biology. *EMBO Reports, 10*, 201–204.

Carolan, M. S. (2007). The precautionary principle and traditional risk assessment. Rethinking how we assess and mitigate environmental threats. *Organization Environment, 20*(1), 5–24.

Chilvers, J. (2006). Engaging research councils? An evaluation of a Nanodialogues experiment in upstream public engagement. University of Birmingham. Available at http://www.bbsrc.com/web/FILES/Workshops/nanodialogues_evaluation.pdf. Accessed 24 Aug 2012.

Collingridge, D. (1980). *The social control of technology*. New York: St. Martin's Press.

Collins, H. M., & Evans, R. (2002). The third wave of science studies—studies of expertise and experience. *Social Studies of Science, 32*(2), 235–296.

Conley, S. N. (2011). Engagement agents in the making: On the front lines of socio-technical integration. *Science and Engineering Ethics, 17*(4), 715–721.

Davies, S. R. (2008). Constructing communication: Talking to scientists about talking to the public. *Science Communication, 29*, 413–434.

Davies, K. G., & Wolf-Phillips, J. (2006). Scientific citizenship and good governance: Implications for biotechnology. *Trends in Biotechnology, 24*(2), 57–61.

Davis, M. (2006). Integrating ethics into technical courses: Micro-insertion. *Science and Engineering Ethics, 12*(4), 717–730.

Delgado, A., Kjølberg, K. L., & Wickson, F. (2010). Public engagement coming of age: From theory to practice in STS encounters with nanotechnology. *Public Understanding of Science, 20*(6), 826–845.

Doorn, N. (2009). Responsibility ascriptions in technology development and engineering: Three perspectives. *Science and Engineering Ethics, 18*(1), 69–90.

Doorn, N. (2012). Exploring responsibility rationales in research and development (R&D). *Science, Technology and Human Values, 37*(3), 180–209.

Doorn, N., & Fahlquist, J. N. (2010). Responsibility in engineering: Toward a new role for engineering ethicists. *Bulletin of Science Technology Society, 30*(3), 222–230.

Doubleday, R. (2004). Political innovation. Corporate engagements in controversy over genetically modified foods (thesis). London: University College London.

Durant, J. (1999). Participatory technology assessment and the democratic model of the public understanding of science. *Science & Public Policy, 26*(5), 313–319.

Editorial. (2004). Going public. *Nature, 431*, 883.
Editorial. (2009). Mind the gap. *Nature, 462*, 825–826.
European Commission. (2007). Energy research in the 7th framework programme. pp. 1–30. Available at ftp://ftp.cordis.europa.eu/pub/fp7/energy/docs/energy_research_fp7_en.pdf. Accessed 24 Aug 2012.
European Commission. (2011a). Horizon 2020— The framework programme for research and innovation. communication from the commission to the European parliament, the council, the european economic and social committee and the committee of the regions. pp. 1–14.
European Commission. (2011b). Analysis Part I: investment and performance in R&D—Investing in the future. Innovation union competitiveness report 2011, pp. 41–154. Available at http://ec.europa.eu/research/innovation-union/pdf/competitiveness-report/2011/part_1.pdf. Accessed 24 Aug 2012.
European Group on Ethics in Science and New Technologies to the European Commission. (2007). Opinion on the ethical aspects of nano medicine—Opinion No. 21. Available at http://ec.europa.eu/bepa/european-group-ethics/docs/publications/opinion_21_nano_en.pdf. Accessed 24 Aug 2012.
Fisher, E. (2006). Embedded Nanotechnology Policy Research. *Ogmius, 14*, 3–4.
Fisher, E. (2007). Ethnographic invention: Probing the capacity of laboratory decisions. *Nanoethics, 1*, 155–165.
Fisher, E., & Mahajan, R. L. (2006). Midstream modulation of nanotechnology research in an academic laboratory. Proceedings of ASME International Mechanical Engineering Congress & Exposition (IMECE), Chicago, Illinois, pp. 1–7.
Fisher, E., Mahajan, R. L., & Mitcham, C. (2006). Midstream modulation of technology: Governance from within. *Bulletin of Science, Technology & Society, 26*(6), 485–496.
Fisher, E., & Miller, C. (2009). Contextualizing the engineering laboratory. In S. H. Christensen, M. Meganck, & B. Delahousse (Eds.), *Engineering in context* (pp. 369–381). Palo Alto: Academica Press.
Flipse, S.M., Van der Sanden, M.C.A. & Osseweijer, P. (2012). Midstream modulation in biotechnology industry: Redefining what is 'Part of the Job' of researchers in industry. Science & Engineering Ethics. Online 25 Oct 2012, pp. 1–24.
Fortuin, F. T. J. M., & Omta, S. W. F. (2007). The dynamics of the strategic network relations between corporate R&D and business: A longitudinal analysis in a large, technology-based multinational company. *Journal on Chain & Network Science, 7*(2), 95–108.
Fuller, S. (2009). *The sociology of intellectual life. The career of the mind in and around academy*. Coventry: University of Warwick.
Funtowicz, S. O., & Ravetz, J. R. (1993). Science for the post-normal age. *Futures, 25*(7), 739–755.
Gaskell, G., Allansdottir, A., Allum, N., Castro, P., Esmer, Y., Fischler, C., et al. (2011). The 2010 Eurobaro meter on the life sciences. *Nature Biotechnology, 29*(2), 113–114.
Genus, A., & Coles, A. M. (2005). On constructive technology assessment and limitations on public participation in technology assessment. *Technology Analysis & Strategic Management, 17*(4), 433–443.
Gorman, M. E., Werhane, P. H., & Swami, N. (2009). Moral imagination, trading zones and the role of the ethicist in nanotechnology. *Nanoethics, 3*(3), 185–195.
Grin, J., & Van der Graaf, H. (1996). Technology assessment as learning. *Science, Technology and Human Values, 21*, 72–99.
Groffman, P. M., Stylinski, C., Nisbet, M. C., Duarte, C. M., Jordan, R., Burgin, A., et al. (2010). Restarting the conversation: Challenges at the interface between ecology and society. *Frontiers in Ecology and the Environment, 8*, 284–291.
Guston, D. H., & Sarewitz, D. (2002). Real-time technology assessment. *Technology in Society, 24*(1–2), 93–109.
Hessels, L. K., Van Lente, H., & Smits, R. (2009). In search of relevance: The changing contract between science and society. *Science & Public Policy, 36*(5), 387–401.
Jackson, R., Barbagallo, F., & Haste, H. (2005). Strengths of public dialogue on science-related issues. *Critical Review of International Social & Political Philosophy, 8*(3), 349–358.
Johnson, D. G. (2007). Ethics and technology 'in the Making': An essay on the challenge of nano ethics. *Nanoethics, 1*(1), 21–30.
Kaiser, M. (2012). Commentary: Looking for conflict and finding none? *Public Understanding of Science, 21*, 188–194.

Koivisto, R., Wessberg, N., Eerola, A., Ahlqvist, T., & Sirkku, K. (2009). Integrating future-oriented technology analysis and risk assessment methodologies. *Technological Forecasting and Social Change, 76*(9), 1163–1176.

Lengwiler, M. (2008). Participatory approaches in science and technology: Historical origins and current practices in critical perspective. *Science, Technology and Human Values, 33*(2), 186–200.

Lucivero, F., Swierstra, T., & Boenink, M. (2011). Assessing expectations: Towards a toolbox for an ethics of emerging technologies. *Nanoethics, 5*(2), 129–141.

Macilwain, C. (2009). Genetics: Watching science at work. *Nature, 462*, 840–842.

Marris, C., Joly, P. B., & Rip, A. (2008). Interactive technology assessment in the real world. Dual dynamics in an iTA exercise on genetically modified vines. *Science, Technology and Human Values, 33*(1), 77–100.

Marshall, J. D., & Toffel, M. W. (2005). Framing the elusive concept of sustainability: A sustainability hierarchy. *Policy Analysis, 39*(3), 673–682.

Merton, R. K. (1938/1973). Science and the social order. In Storer, N.W. (Ed.) The sociology of science—Theoretical and empirical investigations. Chicago: University of Chicago Press. pp. 267–278.

Mitcham, C. (1994). Engineering design research and social responsibility. In K. C. Shrader-Frechette (Ed.), *Research ethics* (pp. 153–168). Totowa: Rowman & Littlefield.

Nisbet, M. C., & Scheufele, D. A. (2009). What's next for science communication? Promising directions and lingering distractions. *American Journal of Botany, 96*(10), 1767–1778.

Nordman, A. (2007). If and Then: A critique of speculative nano ethics. *Nanoethics, 1*, 31–46.

Nordman, A., & Rip, A. (2009). Mind the gap revisited. *Nature Nanotechnology, 4*, 273–274.

Nowotny, H. (2003). Democratising expertise and socially robust knowledge. *Science & Public Policy, 30*(3), 151–156.

Nowotny, H., Schott, P., & Gibbons, M. (2003). Introduction: 'Mode 2′ revisited: The new production of knowledge. *Minerva, 41*, 179–194.

Osseweijer, P. (2006). A short history of talking biotech: Fifteen years of iterative action research in institutionalising scientists' engagement in public communication (thesis). Amsterdam: Vrije Universiteit.

Overdevest, C., Huyck Orr, C., & Stepenuck, K. (2004). Volunteer stream monitoring and local participation in natural resource issues. *Human Ecology Review, 11*, 177–185.

Owen, R., & Goldberg, N. (2010). Responsible innovation: A pilot study with the UK engineering and physical sciences research council. *Risk Analysis, 30*(11), 1699–1707.

Patra, D. (2011). Responsible development of nanoscience and nanotechnology: Contextualizing socio-technical integration into the nanofabrication laboratories in the USA. *Nanoethics, 5*(2), 143–157.

PBL Netherlands Environmental Assessment Agency. (2012). Sustainability of biomass in a bio-based economy. pp. 1–22.

Penders, B. (2008). From seeking healths to finding healths (thesis). Maastricht: Universitaire Pers Maastricht.

Penders, B., Verbakel, J. M. A., & Nelis, A. (2009a). The social study of corporate science: A research manifesto. *Bulletin of Science Technology Society, 29*(6), 439–446.

Penders, B., Vos, R., & Horstman, K. (2009b). Sensitization: Reciprocity and reflection in scientific practice. *EMBO Reports, 10*, 205–208.

Radstake, M., Van den Heuvel-Vromans, E., Jeucken, N., Dortmans, K., & Nelis, A. (2009). Societal dialogue needs more than public engagement. *EMBO Reports, 10*, 313–317.

Randles, S. (2008). From nano-ethicswash to real-time regulation. *Journal of Industrial Ecology, 12*, 270–274.

Ravetz, J. (2004). The post-normal science of precaution. *Futures, 36*(3), 347–357.

Rip, A. (1981). Maatschappelijke verantwoordelijkeheid van chemici (thesis). Nootdorp: Drukkerij P.Th. v.d. Sande.

Rip, A. (2009). Futures of ELSA. *EMBO Reports, 10*, 666–670.

Roelofsen, A., Boon, W. P. C., Kloet, R. R., & Broerse, J. E. W. (2011). Stakeholder interaction within research consortia on emerging technologies: Learning how and what? *Research Policy, 40*(3), 341–354.

Rogers-Hayden, T., & Pidgeon, N. (2007). Moving engagement upstream? Nanotechnologies and the royal society and royal academy of engineering's inquiry. *Public Understanding of Science, 16*(3), 345–364.

Russell, A. W., Vanclay, F. M., & Aslin, H. J. (2010). Technology assessment in social context: The case for a new framework for assessing and shaping technological developments. *Impact Assessment & Project Appraisal, 28*(2), 109–116.

Sarewitz, D. (2005). This won't hurt a bit: Assessing and governing rapidly advancing technologies in a democracy. In M. Rodemeyer, D. Sarewitz, & J. Wilsdon (Eds.), *The future of technology assessment* (pp. 14–21). Washington, DC: Woodrow Wilson International Center for Scholars.
Schot, J., & Rip, A. (1997). The past and future of constructive technology assessment. *Technological Forecasting and Social Change, 54*(2/3), 251–268.
Schuurbiers, D. (2011). What happens in the lab does not stay in the lab: Applying midstream modulation to enhance critical reflection in the laboratory. *Science and Engineering Ethics, 17*(4), 769–788.
Schuurbiers, D., & Fisher, E. (2009). Lab-scale intervention. *EMBO Reports, 10*(5), 424–427.
Shapin, S. (2008). Who are the scientists of today? Seed magazine 19. Available at http://seedmagazine.com/stateofscience/sos_feature_shapin_p1.html. Accessed 24 Aug 2012.
Shatkin, J. A. (2008). Informing environmental decision making by combining life cycle assessment and risk analysis. *Journal of Industrial Ecology, 12*(3), 278–281.
Shelley Egan, C. (2010). The ambivalence of promising technology. *Humanities, Social Sciences & Law, 4*(2), 183–189.
Shove, E., & Rip, A. (2000). Users and unicorns: A discussion of mythical beasts in interactive science. *Science & Public Policy, 27*(3), 175–182.
SIRC (Social Issues Research Council) in partnership with the royal society and the royal institution of Great Britain. (2001). Guidelines on science and health communication. Available at http://www.sirc.org/publik/revised_guidelines.pdf. Accessed 24 Aug 2012.
Stegmaier, P. (2009). The rock 'n' roll of knowledge co-production. *EMBO Reports, 10*, 114–119.
Stirling, A. (2008). Opening up and closing down. Power, participation, and pluralism in the social appraisal of technology. *Science, Technology and Human Values, 33*(2), 262–294.
Swierstra, T., & Jelsma, J. (2006). Responsibility without moralism in techno scientific design practice. *Science, Technology and Human Values, 31*(3), 309–332.
Van de Poel, I. (2000). On the role of outsiders in technical development. *Technology Analysis & Strategic Management, 12*(3), 383–397.
Van der Burg, S. (2009). Imagining the future of photo acoustic mammography. *Science and Engineering Ethics, 15*(1), 97–110.
Van der Burg, S. (2010). Taking the soft impacts of technology into account: Broadening the discourse in research practice. *Social Epistemology, 23*(3–4), 301–316.
Van Merkerk, R. O., & Smits, R. E. H. M. (2008). Tailoring CTA for emerging technologies. *Technological Forecasting and Social Change, 75*(3), 312–333.
Vanclay, F. (2002). Conceptualising social impacts. *Environmental Impact Assessment Review, 22*, 183–211.
Verbeek, P. P. (2006). Materializing Morality—Design ethics and technological mediation. *Science, Technology & Human Values, 31*(3), 361–380.
Verhoog, H. (1981). The responsibilities of scientists. *Minerva, 19*(4), 582–604.
Von Schomberg, R. (2011). Prospects for technology assessment in a framework of responsible research and innovation. In M. Dusseldorp & Beecroft R. (Eds.) Technickfolgen abschätzen lehren. Bildungspotenziale transdisziplinärer Methoden. pp. 39–62.
Webster, A. (2007). Crossing boundaries: Social science in the policy room. *Science, Technology and Human Values, 32*, 458–478.
Whitmer, A., Ogden, L., Lawton, J., Sturner, P., Groffman, P. M., Schneider, L., et al. (2010). The engaged university: Providing a platform for research that transforms society. *Frontiers in Ecology and the Environment, 8*, 314–321.
Wilsdon, J. (2005). Paddling upstream: New currents in European technology assessment. In M. Rodemeyer, D. Sarewitz, & J. Wilsdon (Eds.), *The future of technology assessment* (pp. 22–29). Washington, DC: Woodrow Wilson International Center for Scholars.
Wilsdon, J., & Willis, R. (2004). *See-through science. Why public engagement needs to move upstream.* London: Demos.
Wilsdon, J., Wynne, B., & Stilgoe, J. (2005). *The public value of science. Or how to ensure that science really matters*. London: Demos.
Wolpert, L. (2007). Is cell science dangerous? *Journal on Medical Ethics, 33*(6), 345–348.
Wynne, B. (2006). Public engagement as a means of restoring public trust in science—Hitting the notes, but missing the music? *Community Genetics, 9*(3), 211–220.
Ziman, J. M. (1998). Why must scientists become more ethically sensitive than they used to be? *Science, 282*(5395), 1813–1814.