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PERSPECTIVES

What is the problem? A literature review on challenges facing the communication of nanotechnology to the public

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Abstract Ethical and societal issues concerning justice, safety, risks, and benefits are well-established topics in the discourses of nanotechnology innovation and development. That nanotechnology innovation should be socially and ethically responsible is generally accepted by scientists, policymakers, regulators, and industry, and the idea of public involvement and communication is part and parcel of the conceptualization of responsible technology development. This paper systematically reviews the social science research literature accumulated between 2002 and 2018 on the communication of nanotechnology. A critical and constructivist perspective on policy problems guides the analysis. Two questions are asked of this literature: what problems are identified regarding the communication of nanotechnology to the public? How can these problems be managed and/or resolved? Three different problem themes are identified: the public, societal institutions, and nanotechnology itself. While for some identified problems, there are corresponding solutions; in other instances, there is little alignment between problems and solutions. In conclusion, the paper recommends that in communicating nanotechnology to the public: (i) the objectives of communication should be defined; (ii) previous research should be used responsibly; (iii) communication strategies should be adapted to the context; and (iv) effort should not be spent trying to develop a generic framework for communication.

Keywords Responsible innovation · Nanotechnology · Science communication · Upstream engagement · Literature review

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Introduction

When nanotechnology hype began to mount almost two decades ago, it was readily recognized that to reach its full revolutionary potential, nanotechnology development had to be "responsible" (Macnaghten 2010; Pidgeon et al. 2011). The gigantic National Nanotechnology Initiative (NNI), established in the year 2000 in the United States (US), declared that "nanotechnology is helping to considerably improve, even revolutionize, many technology and industry sectors: information technology, energy, environmental science, medicine, homeland security, food safety, and transportation, among many others" (NNI 2018a). The responsible development of nanotechnology that addresses the ethical, legal, and societal issues (ELSI) of nanotechnology is one of the NNI's four objectives, understood to advance the other, i.e., research, commercialization, worker education, and public engagement. The way ELSI is addressed is assumed to determine public trust and the future of innovation driven by nanotechnology (NNI 2018b).

The NNI has served as a role model for other countries aspiring to compete in cutting-edge nanotechnology development. The responsible development of technology is currently a widely accepted ideal in European Union (EU) research and innovation policies (Coenen 2016). It is generally accepted by scientists, policymakers, regulators, and industry that issues concerning environmental impact, health, and safety should be addressed responsibly, ensuring that any new technology benefits society. ELSI has therefore become an important consideration in innovation (Coenen 2016). According to this ideal of technology innovation, the societal need for technology, technology regulation, and risk management and safety, as well as ethical implications must be thoroughly addressed (Pidgeon et al. 2011: 1696).

The ideal of the responsible development of nanotechnology implies sensitivity to public perceptions and public trust at an early stage of technology development (Breggin and Carothers 2006). Responsible technology development is further understood to have the capacity to counteract failure due to public lack of acceptance of, or opposition to, new technology. Already at an early stage of innovation, US scientists and policymakers worried that the public might turn against nanotechnology (Friedman and Egolf 2005). This is what happened in Europe with genetically modified organisms (GMOs): concern over risk and the lack of trust in science, experts, and regulators were factors that turned the public against the technology as such, the industry, and the products (Wynne 2001). For history not to repeat itself in the form of public distrust of regulatory agencies and scientific experts, consumer boycotts of products and companies, citizen pressure on policymakers and regulators, and amplification of risks in the media, foresight and sensitivity to public concern have been recurrent mantras regarding the development of nanotechnology (Sylvester et al. 2009). It has been argued that developers and industry, as well as policymakers and regulators, must be aware of possible public concerns and of the societal dynamics of media and interest groups before they manifest as protests and social movements (David and Thompson 2011).

Upstream engagement in nanotechnology, i.e., early public involvement in the processes of technology development and innovation, as well as the public provision of relevant and correct information regarding nanotechnology, has been envisaged as the road forward (Pidgeon et al. 2017; Rogers-Hayden et al. 2007). Social scientists have argued that technology should be democratically governed, which calls for "reflexive" learning processes to develop "scientific citizenship," reflexive governance, and citizen capacity in science (Miah 2017; Pidgeon and Rogers-Hayden 2007: 203). Communication with the public is generally agreed to be necessary for upstream engagement (Priest 2012), understood as part and parcel of the social regulation of nanotechnology (Pidgeon et al. 2017; Priest 2009: 761).

The responsible development of nanotechnology to safeguard the environment, human health, and safety, and to ensure that the new technology benefits society, is understood to require citizen involvement, dialog, and participation. If we look more closely into the literature on the "communication of nanotechnology to the public," several broad communicative goals can be identified (Delgado et al. 2011). Pidgeon and Rogers-Hayden (2007: 192) suggested three arguments for public engagement. The *normative* argument postulates that dialog is a good thing in itself: it is part of democracy and allows room for public values and attitudes in decision-making. The *instrumental* argument proposes that dialog with the public increases the legitimacy of decisions and enhances trust. The *substantive* argument claims that dialog creates better decisions and outcomes. The normative objectives of public inclusion and deliberation imply broad consultation with stakeholders and the public as well as foresight and reflexivity concerning ethical and legal issues. From this normative position, dialog and public participation are essential values related to innovation, and all these activities rely on information exchange and the understanding of messages.

Since the mid-1990s when the field emerged, considerable social science research into nanotechnology has been published. Policymakers have understood social science to be essential in grasping the dynamics of public attitudes and perceptions and in forming a basis for developing effective tools for gaining public acceptance of nanotechnology innovation (Ebbesen 2008). Social science research on nanotechnology is multidisciplinary, including sociology, psychology, political science, social anthropology, science and technology studies, and media and communication studies. The accumulated research has provided many insights into how nanotechnology is perceived by the public, how it is represented by the media, how media information affects public perceptions, and how policy is formed and developed. Many studies have been conducted in the US, the EU, and elsewhere (for overviews of the field, see Duncan 2011; Kahan 2009; Priest 2012; Ronteltap et al. 2011; Satterfield et al. 2009; Siegrist 2010).

This paper aims to present an overview of the research literature on the communication of nanotechnology to the public between 2002 and 2018. We will systematically identify the problems defined and solutions suggested in this research. We contribute by providing an extensive overview of the communication of nanotechnology to the public. By adopting a holistic critical and constructivist approach, this exercise provides a stepping stone to further research and policy work on what socially "responsible" nanotechnology innovation and development might mean and how it might be implemented. The study also contributes to the general discussion of science communication concerning new technology.

Method, research questions, and analytical framework

This paper presents a literature review of published peer-reviewed papers (listed in the references) that address the topic of the communication of nanotechnology to the public. The papers were identified through a search in the Scopus publication database conducted in February 2018 and through ongoing searches in Google Scholar. The search terms have been "nano" in conjunction with "communication," "public," "participation," "engagement," and "dialog" to appear in title, abstract, keywords, or main body of text. Altogether, 62 different published journal articles were identified. All 62 papers meeting the search criteria were included in the sample. The oldest study was published in 2002 and the latest in 2018. Some papers explicitly address nanotechnology communication and have "communication" among their keywords, whereas in others, the presence of the topic is less explicit. Many of the papers address communication issues in their discussion sections, where the implications of research findings for practice, regulation, or policy are considered. The papers were published in a broad range of multidisciplinary journals, though four dominate the sample (in order of frequency): *Journal of Nanoparticle Research*, *Risk Analysis: An International Journal*, *Public Understanding of Science*, and *Nanoethics*. The literature review is not claimed to be exhaustive, but the sample presents a broad range of published research papers giving ample insight into what scholars discuss when addressing the communication of nanotechnology to the public.

The analysis was inspired by Carol Bacchi's (1999, 2012) approach to policy analysis. Her analytical and theoretical framework sees policy embedded in a discursive construct that, implicitly or explicitly, establishes problems in need of policy intervention via management and mitigation. From this perspective, problematizations that underlie policy are understood as often taken for granted: they are accepted as "truths" beyond questioning (Bacchi 2012). The "What is a problem?" approach allows for the systematic deconstruction and scrutiny of the underlying assumptions of policy problems. The analysis brings these assumptions into the open, enabling a critical approach to policy that can be applied both theoretically and in practical policy work.

According to Bacchi (1999), all problems with policy implications have a generic structure: something is identified as a problem for some reason, and then is isolated, defined, and characterized with regard to its causes and consequences. Defining the problem entails choosing certain elements, characteristics, and causal explanations while excluding others. Some elements are foregrounded while others are backgrounded. Since the problem definition and its characterization include causal assumptions about how the problem came into existence, the problem definition paves the way for solutions. Problem definitions and solutions are conceptually related since solutions are often logically and rationally contained in the problem framing (Lancaster and Ritter 2014). However, in policy work, this is not always the case: problems and solutions can be decoupled without any logical relationship between the two. The identification of a solution may also sometimes preclude the definition of a problem.

The research questions addressed to the literature were developed from the "What is a problem?" approach to policy analysis. The questions answer to the overall aim of providing a systematic and critical analysis of the social science research field of nanotechnology and public communication. Each article in the sample of 62 papers was read and analyzed with regard to the following questions:

1. How is the problem of the "communication of nanotechnology to the public" conceptualized, characterized, and explained?

2. What solutions are offered to the problem of the "communication of nanotechnology to the public"?
3. What is the relationship between the constructions of problems and of solutions concerning the "communication of nanotechnology to the public"?

The relationship between problem and solution was not analyzed at the level of the individual paper. Far from all papers did provide answers to all three questions. The analysis of the individual papers adds up to a meta-analysis of the material.

The remainder of the paper is organized into the following parts: (1) "Background: what do we know about public understanding of nanotechnology?" summarizes the main findings regarding public attitudes and perceptions necessary to understand how the problem of nanotechnology communication is discussed; (2) "The problem of communicating nanotechnology to the public" addresses problems and obstacles identified in the reviewed literature (this section explicitly addresses communication problems, categorizing them so that the problems can be juxtaposed to the proposed solutions in the next section); (3) "Solutions for the communication of nanotechnology to the public" offers solutions and recommendations identified in the reviewed literature for the successful communication of nanotechnology; (4) "Discussion" treats these findings in relation to the research field; and (5) "Conclusions" wraps up the review and suggests ways forward.

Background: what do we know about public understanding of nanotechnology?

This section summarizes social science findings essential to communicating nanotechnology to the public. In this section, the lessons from previous research are divided into the following themes: (i) public knowledge and attitudes and (ii) factors explaining public attitudes. The reviewed studies were carried out in different countries using different methodologies; while most used surveys and quantitative analysis, others relied on qualitative methods, such as interviews or focus groups. There are differences in theoretical and analytical framework for the studies, and their research designs differ, including case studies, experimental, cross-sectional, and even longitudinal research designs. The results are therefore not immediately comparable (Ronteltap et al. 2011). Our aim with the review was not to evaluate or discuss why there are differences between studies. Differences in findings can be explained by a number of factors: theoretical assumptions, hypothesis, and research design, of data collection and analysis, conceptual differences (Ronteltap et al. 2011), for example, in how trust is defined and operationalized. Sample characteristics also differ a lot. Studies are done on public understanding in different countries, with different regulatory frameworks, and with considerable institutional and cultural differences. These differences also explain diverging findings. Our objective was to identify common main findings regarding public understanding of nanotechnology, since such findings serve as a reference point for formulations of problems and solutions in the investigated sample of papers.

Public knowledge, attitude, interest, and engagement

Many studies have noted that the public lacks knowledge of nanotechnology and is unfamiliar with its basic concepts and principles (Castellini et al. 2007; Delgado et al. 2011; Larsson and Boholm 2018; Lin et al. 2013; Macoubrie 2006; Retzbach et al. 2011; Vandermoere et al. 2010). Although there are some national variations, studies in a number of countries confirm this result. One of the first studies of public attitudes toward nanotechnology (Bainbridge 2002) found that the public had a high level of enthusiasm for the benefits of nanotechnology and little concern over risks, and later studies have confirmed this result, demonstrating that nanotechnology is perceived by the public as beneficial and not associated with risk (Cobb and Macoubrie 2004; Duncan 2011). Other studies have found that a considerable portion of the public is indifferent toward nanotechnology (Vandermoere et al. 2010). Another often-noted finding is that the public is not homogeneous (Kim et al. 2014: 967), but consists of many groups and segments with different outlooks, values, and approaches to new technology (Cormick and Hunter 2014; Duncan 2011).

Nanotechnology is generally not an issue that spurs public engagement. Only a minority of citizens takes an active interest in nanotechnology and how it should be governed in society (Priest et al. 2011: 1731). When they are concerned, members of the public are worried about the societal implications of nanotechnology use, its environmental effects (Conti et al. 2011), and whether its benefits will be fairly distributed (McComas and Besley 2011). There are some concerns about how nanotechnology products might affect society in the future, as well as whether or not nanotechnology will contribute to social and environmental sustainability (Pidgeon and Rogers-Hayden 2007: 204–5). In general, the public does not have stable preformed attitudes on the subject of nanotechnology; rather, their attitudes are prone to fluctuate depending on how the media frames nanotechnology, current societal discussions of emerging applications, and their understanding of the benefits, risks, and possible ethical concerns (Satterfield et al. 2009, 2012).

A growing number of studies addresses public attitudes toward various applications of nanotechnology. Risks and benefits are assessed differently depending on the area of application (Pidgeon et al. 2009; Siegrist 2010). That attitudes differ a lot depending on the area of application is clear from many studies (Cacciatore et al. 2011; Cormick 2009; Gupta et al. 2012, 2015; Larsson and Boholm 2018; Pidgeon et al. 2009; Siegrist et al. 2007). For example, people are more favorable toward nanotechnology applications to remedy water quality, nanotechnology developments in medicine, and nanotechnology addressing problems in developing countries (Macoubrie 2006: 237). Applications such as cosmetics, on the other hand, are regarded as poorly justified and are generally not approved (Larsson and Boholm 2018; Macoubrie 2006: 236). The public has been found to be skeptical or doubtful toward nanotechnology in the food sector (Bostrom and Löfstedt 2010: 1658; Duncan 2011; Siegrist et al. 2007; Vandermoere et al. 2011).

Several studies focus on public views of the labeling of nanoproducts, which is understood to be an important regulatory tool to manage consumer products containing nanomaterials (Siegrist 2010). Labeling is therefore expected to have an important role in risk communication in the field of nanotechnology (Brown and Kuzma 2013). The public is favorable toward the labeling of nanotechnology used in food. They want labeling for all types of food and are also willing to pay for this, since they believe that labeling facilitates informed decisions related to risk management. Consumers also believe that they have a right to be informed (Brown and Kuzma 2013; Yue et al. 2015).

Factors explaining public attitudes toward and perception of nanotechnology

Many studies have explored the underlying causes of public attitudes toward and perceptions of nanotechnology, demonstrating that many interacting explanatory variables are involved (Pillai and Bezbaruah 2017). In a meta-analysis of the perceived risk of nanotechnologies, Satterfield et al. (2009) concluded that public perception is influenced by a considerable number of variables, such as framing effects, media exposure, trust in regulation, popular understanding of toxicity, attitudes toward environmental risks, the perceived naturalness of nanotechnology, psychometric variables, cultural bias, and religiosity, as well as income and education. In a review of public perception studies of nanotechnology, Siegrist (2010) identified values, trust, and worldview as key explanatory factors shaping views of nanotechnology.

Trust in and respect for science have been shown to be particularly important as an explanation for public attitudes toward nanotechnology (Ho et al. 2010). Many studies suggest that public opinion on nanotechnology is guided by general attitudes toward science and technology, and that broad ideas about the value and use of technology in society guide the formation of attitudes toward nanotechnology (Priest 2009; Priest et al. 2011: 1721). Very few people have personal experience of and familiarity with nanotechnology, an advanced broad transdisciplinary natural science field that is difficult for non-specialists to comprehend. Therefore, it makes sense that deference to scientific authority (Ho et al. 2010), interest and trust in science, and a general belief that scientific knowledge is beneficial all influence attitudes toward nanotechnology (Retzbach et al. 2011).

Another dimension attracting interest in several studies is the relationship between support of nanotechnology and knowledge of nanotechnology. Knowledge of nanotechnology generally increases acceptance, but only slightly (Priest 2009: 763; Siegrist 2010: 840). When people who state that they know little are exposed to information about nanotechnology, they do not automatically become more supportive (Anderson et al. 2014: 376). Why, then, is knowledge a weak predictor of attitudes toward risk when knowledge generally makes the public more confident in new technology? It has been argued that nanotechnology actualizes many ethical issues and dilemmas that do not go away or diminish with increasing knowledge of the technology (Pidgeon et al. 2011: 1697). Nanotechnology is also ambiguous due to its many areas of application, huge complexity, and broad scope of use (Renn and Roco 2006).

Values predict attitudes toward nanotechnology (Siegrist 2010). Religious belief has been shown to be negatively correlated with support for nanotechnology

(Ho et al. 2010). In another study, religiosity was found to be negatively related to the perceived benefits of nanotechnology (Cacciatore et al. 2011: 393). Other studies, however, do not find religiosity and ideology to be related to the perceived risk of nanotechnology (Anderson et al. 2014: 383). While risk perception has been shown to be gendered for other risk issues (Finucane et al. 2000), research on public attitudes toward nanotechnology has mixed findings. Some studies provide evidence that gender to some extent explains attitudes toward, or acceptance of, nanotechnology (Bainbridge 2002: 569; Satterfield et al. 2009: 756), while other studies find no gender effects (Macoubrie 2006: 236).

Studies have shown that public attitudes toward nanotechnology are affected more strongly by information on risks than on benefits (Satterfield et al. 2012: 257). In some studies, perceptions of the risks and benefits of nanotechnology seem to be related, with higher perceived risks reducing the perceived benefits (Cacciatore et al. 2011: 396). Attitudes toward nanotechnology are unstable and can change rapidly depending on new information and how it is presented (Satterfield et al. 2012). Due to the great uncertainty regarding nanotechnology and its potential implications, public attitudes and perceptions are more unstable than they are regarding other more traditional technological risk issues (e.g., chemical risks, radiation, nuclear power, and nuclear waste). One interesting finding is that women have less fixed and stable attitudes toward nanotechnology than do men, which might indicate that gender has higher explanatory power for new and less well-known technologies (Satterfield et al. 2012: 257).

Another factor influencing public opinion is media representations. It is generally agreed in the literature on public perceptions of nanotechnology that the mass media constitute a key factor influencing these attitudes (Scheufele and Lewenstein 2005). It was argued early on in the nanotechnology debate that the public often forms opinions on complex topics of which they have little knowledge and for which they lack relevant information based on the material provided by the mass media (Scheufele and Lewenstein 2005). How information is framed therefore influences risk perceptions of nanotechnology, so that risks are perceived differently depending on the social context of the information presented (Schütz and Wiedemann 2008: 377). Risk perception is influenced by what information is provided and opinions also change depending on information (Smith et al. 2008).

Studies have demonstrated that media use correlates positively with nanotechnology support (Ho et al. 2010) and that attention to science news correlates with support for nanotechnology (Cacciatore et al. 2011: 393). The media generally emphasize benefits over risks when reporting on nanotechnology (Anderson et al. 2009; Fitzgerald and Rubin 2010; Lewenstein et al. 2005; Kjølberg 2009; Metag and Marcinkowski 2014), although some studies note ambiguous representations and frequent associations with risk (Anderson et al. 2005, 2009; Boholm and Boholm 2012; Friedman and Egolf 2011; Laing 2005; Weaver et al. 2009). However, exposure to information does not have a uniformly positive effect on attitudes toward nanotechnology (Ho et al. 2010: 2711). The public perceives scientific uncertainty expressed in the media differently depending on their level of trust in and deference to science authority (Binder et al. 2016). Consequently, representations of science in the media are not necessarily directly linked to public risk perception of new technologies (Binder et al. 2016).

The problem of communicating nanotechnology to the public

That communication with the public on nanotechnology is a delicate matter has been an underlying assumption in the field since its inception. Several challenges for the public communication of nanotechnology have been identified, problems relating to some of the issues discussed above. In this section, we dissect identified problems explicitly noted as challenges in communicating nanotechnology to the public. These problems can be sorted according to basic problem definitions depending on how the sources of the problems are identified. Analytically, three main problem themes are distinguished: the public, societal organizations, and nanotechnology itself.

The public is a problem

The reviewed literature presents the public as a problem for the communication of nanotechnology in ways that can be categorized into three themes: (i) deficits (i.e., lack of knowledge, interest, and engagement), (ii) heterogeneity, and (iii) attitudes influenced by values and emotions.

(i) Deficits (lack of knowledge, interest, and engagement)

Lack of knowledge and engagement among the public is understood as a problem for nanotechnology communication because it might make information difficult for the public to comprehend, in turn making it difficult to interest the public in the information provided. As discussed in the section on background, regarding nanotechnology, the public arguably has poor knowledge, is unfamiliar with the technology, harbors misconceptions, and has difficulties understanding central concepts (Castellini et al. 2007: 187; Duncan 2011; Macnaghten 2010: 24; Pidgeon and Rogers-Hayden 2007; Schütz and Wiedemann 2008; Simons et al. 2009: 1596). They also lack engagement and interest (Petersen et al. 2007), making it difficult to reach out or involve the public in deliberative approaches.

(ii) The public is heterogeneous

A heterogeneous public constitutes a problem for nanotechnology communication because the level of knowledge and understanding will differ between subpopulations in society, making it difficult to develop communication strategies. As discussed in the above "Background: what do we know about public understanding of nanotechnology" section, the public is indeed heterogeneous and diverse (Duncan 2011: 685; Kim et al. 2014), and research has demonstrated that there are many different positions for or against nanotechnology for many different reasons (Priest 2006). The public is segmented into sets of beliefs and worldviews and has different attitudes accordingly (Cormick and Hunter 2014). As discussed in the "Background: what do we know about public understanding of nanotechnology" section, factors such as religiosity and gender affect perception and might have implications for how information is understood; moreover, cultural cognition and group values influence how people interpret nanotechnology-related information (Kahan 2010; Kahan et al. 2009).

(iii) The public relies on values and emotions

Values, beliefs, and emotions are understood to influence attitudes toward nanotechnology (Bostrom and Löfstedt 2010; Cormick and Hunter 2014). The role of values and emotions is identified as a problem theme, since it makes it difficult to foresee how information will be understood when attitudes are formed by values, feelings, hopes, and expectations rather than on factual knowledge (Simons et al. 2009: 1596). People may not believe in information and might reject information that is not consistent with their values and emotions (Simons et al. 2009: 1596).

Societal institutions are a problem

Another problem associated with communicating nanotechnology to the public is that societal institutions are understood as obstacles to successful communication. Societal institutions are seen as a problem for the following reasons: (i) mass media influence attitudes; (ii) mass media provide a fragmented picture of nanotechnology; (iii) nanotechnology regulation is fragmented; and (iv) there is lack of agreement on definitions and concepts.

(i) Mass media influence public attitudes

That mass media influence public attitudes is considered a problem for science communication because it skews public opinion and makes proper science communication difficult. Mass media are understood to influence public attitudes (Binder et al. 2016: 832); how media frame nanotechnology and the lack of reporting are understood to create a problem for science communication. There is a limited discussion of nanotechnology in the media and, when there is, risk is attenuated, which contributes to a lack of public interest and engagement (Pidgeon and Rogers-Hayden 2007: 195; Priest 2009: 759).

(ii) Mass media representations are fragmented and ambiguous

The media are understood to offer a fragmented and ambiguous picture of nanotechnology, not providing the public with adequate tools to make informed decisions. This scattered picture, ambiguity, and uncertainty in the news media arguably might pave the way for fear, contributing to public resistance to nanotechnology (Allan et al. 2010: 42).

(iii) Policy and regulation are fragmented

Regulatory uncertainty and fragmentation arguably make it difficult for the public to understand nanotechnology (Laux et al. 2018: 124), and consequently more difficult to communicate about nanotechnology to the public (Priest 2009: 764). This argument relates to the contemporary regulatory situation with its patchwork of nano-specific and non-nano-specific laws and regulations. Within the EU, there is the regulation Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), the EU Cosmetics Directive, and the European Food Safety Authority (EFSA), which requires food labeling for nanomaterials (EC 2013). There are regulatory inconsistencies regarding communication, since different legislations make different demands: sometimes warning labels, sometimes declarations of content, and sometimes public hearings are required in environmental impact assessment regulation (Priest 2009: 760).

(iv) Lack of consensus on definitions of concepts

A lack of standardized definitions and concepts among the involved actors is also understood as a problem when communicating nanotechnology to the public. It has been argued that no standardized framework is in place for categorizing nanotechnology and nanomaterials (Bostrom and Löfstedt 2010: 1652–3). Definitions of nanomaterials are based on different criteria depending on the purpose, varying among organizational, industry, regulatory, and research actors (Laux et al. 2018: 122–3). There is a broad range of definitions of nanomaterial and nanoparticle, and there are disagreements on what type of definition is the most suitable (Boholm 2016; Boholm and Arvidsson 2016). The "lack of a clear and shared understanding of key terms" is considered a problem for science and regulation, since it allows ambiguity and vagueness as well as conflicting messages (Boholm and Arvidsson 2016: 38).

Nanotechnology itself is a problem

It has been argued that the qualities (or lack thereof) associated with the physical and material properties of nanotechnology create challenges for communication for the following reasons: (i) these qualities give rise to low dread risk; (ii) they concern matter that is difficult to describe and visualize; (iii) there are many diverse applications and areas of use; and (iv) they are characterized by epistemic uncertainty.

(i) Absence of dread risk

Due to its material features, nanotechnology is not perceived as a high-consequence, low-probability risk, associated with involuntariness, dread, and lack of control (Renn and Benighaus 2013: 305–6), and it therefore fits poorly into traditional risk communication frameworks. Dread risk is a concept from psychometric studies of risk perception and pertains to risks perceived as uncontrollable, global, and catastrophic; having fatal consequences; inequitable; posing a high risk to future generations; not easily reduced; and increasing and involuntary (Slovic 1987: 282). Risk issues associated with the highest dread factor in early psychometric research were nuclear war, nuclear weapons, and nuclear reactor accidents (Slovic 1987). Nanotechnology scores low on the dread risk factor and is therefore considered a problem for risk communication due to an inability to attract necessary public attention and to communicate through recognizable risk scenarios (Renn and Benighaus 2013).

(ii) Beyond perception

Nanomaterials exist in a size range invisible to the naked eye and are not easily described to laypeople. It is therefore argued that, in the eyes of the public, nanotechnology is distant, unfamiliar, and intangible (Castellini et al. 2007: 187; Macnaghten 2010: 23; Pidgeon et al. 2011: 1695; Priest 2012: 22–3; Simons et al. 2009). Nanotechnology also arguably has uncanny associations, since it deals with matter that is "unbelievably small" and therefore "utterly beyond human action, perception and control" (Macnaghten 2010: 24–5). Communicating with the public about uncanny matter beyond perception is therefore understood to be challenging.

(iii) Applications are diverse

The diversity of nanotechnology applications is understood to create a problem for nanotechnology communication. Nanotechnology includes many diverse areas, heterogeneous substances, techniques, applications, industry branches, and risk issues. Public acceptance also differs between particular applications, qualities, and potential hazards (Duncan 2011; Macnaghten 2010: 24; Pidgeon and Rogers-Hayden 2007: 197; Pidgeon et al. 2011: 1695). As noted in the above "Background: what do we know about public understanding of nanotechnology" section, public acceptance of nanotechnology depends on its application (Berube et al. 2011; Simons et al. 2009), and the perceived risk and benefit profiles of different applications differ greatly.

(iv) Epistemic uncertainty

Nanotechnology is surrounded by considerable uncertainty regarding its nature, benefits, environmental risks, human health effects, and safety (Berube et al. 2011: 3097; Grieger et al. 2009). Uncertainty is arguably due to both the complexity of nanomaterials as such and to their future implications and consequences (Subramanian et al. 2014). Consequently, many uncertain parameters must be communicated in policy and regulatory work on nanotechnology (Williams et al. 2010). It is argued that communicating with the public about uncertain hopes and fears is much more difficult than is communicating established and known facts (Shatkin et al. 2010). For example, the public wants to know if there actually are nanoparticles in their food and, if so, whether or not this is a health risk; such questions pose a communication problem when science cannot provide clear-cut answers (Bostrom and Löfstedt 2010: 1658).

Solutions for the communication of nanotechnology to the public

In what follows, we will look more closely at specific problem solutions found in the reviewed literature and discuss to what extent they correspond to the problems identified and presented above.

Solutions if the public is seen as the problem.

As we have seen, the public is construed as a problem due to: (i) deficits (i.e., lack of knowledge, interest, trust, and engagement), (ii) heterogeneity, and (iii) attitudes influenced by values and emotions. Solutions involving the public are suggested in the following areas: (i) public education, (ii) academic research on public attitudes/understanding, (iii) targeted communication, (iv) dialog and participation, and (v) trust and transparency building. The first suggested solution (i) directly addresses the problem of the public knowledge deficit, while the next two (ii) and (iii) suggest that communication must develop from the current state of affairs and that it can be improved through better knowledge of the target audience; therefore, the first three solutions correspond to defined problems, although indirectly. The solution themes of dialog and participation (iv) and trust and transparency building (v), however, have no clear correspondence to any problem formulations. No problem constructions explicitly point to lack of dialog and participation or lack of trust and transparency as such. These solutions appear to be generally assumed to be good ways to move forward when it comes to communicating nanotechnology to the public. These solutions can be understood as legacies from the upstream engagement literature in the field of the public understanding of science and from parts of the risk communication literature that emphasize trust and transparency as key parameters of effective risk communication (Priest 2012: 81). This matter will be addressed more thoroughly in the "Discussion" section.

(i) Educate the public

From the conception that the public has a low level of knowledge, making communication problematic, it has been argued that education must be part of any successful communication strategy. People's knowledge and capacity for critical reasoning must be improved (Wiedemann et al. 2011: 1781). Gardner et al. (2010) suggested that educational programs to improve "risk literacy" in the public should be developed (p. 1965); they recommended that risk should be introduced as a topic in science education, so that students can learn to employ tools to "critically construct well-formed attitudes and perceptions regarding complex topics" (p. 1965). Risk literacy applied to nanotechnology, it is argued, should engender the understanding that nanotechnology is heterogeneous and includes many applications that can have specific controversial aspects.

It is suggested that education might be accomplished through the development and use of "evidence maps." Evidence maps consist of systematic characterizations and presentations of arguments in a risk debate, and when used to communicate risk assessments, they stimulate a scientific and logical way of reasoning about particular risk issues (Wiedemann et al. 2011). Evidence maps help present complex information in a coherent and pedagogical way. Their use arguably has the potential to resolve conflicts over risk issues, narratives, or arguments in a debate by characterizing and presenting arguments in a systematic way. This pedagogical and communicative tool is intended to help stakeholders and decision makers' structure information in ways that are more easily accessible to the public.

However, other voices warn of an overreliance on public education to overcome the difficulty of communicating nanotechnology to the public. According to Kim et al. (2014: 967), a communication strategy that has as its main goal educating the public by providing accurate information cannot be expected to create consensus on a risk issue or to lower risk perceptions. This is because attitudes toward nanotechnology depend on values, beliefs, and worldviews rather than on facts. Values are stable and resilient to new information or scientific facts, because factual information provided might not align with conceptual frames among members of the public.

One aspect of communicating nanotechnology to the public that has received a fair amount of attention in the literature is the labeling of nanotechnology products and nanomaterials. This growing body of literature is extensive and cannot be reviewed here due to the limited scope of this paper. However, we should note that labeling is understood as an important risk communication strategy for nanotechnology (Siegrist 2010: 843). It is also argued that more research is needed on how labeling and the information provided on labels influence the perception of nanotechnology products (Siegrist 2010). Brown and Kuzma (2013: 534) suggested that simply providing information on product labels alone will not be a sufficient public communication measure. They argue that education and information on nanotechnology in addition to labeling are also important. They furthermore recommend that government agencies actively engage in public outreach and education on nanotechnology and point out that consumers need education about how to use information on labels to make informed decisions (Brown and Kuzma 2013). There are also concerns that mandatory labeling could result in a lack of public support for nanotechnology, since this tool could be understood as signaling that significant risks are indeed involved (Siegrist et al. 2007: 463).

(ii) Academic research on public understanding

As a way of improving communication strategies, it has been argued that more research on public understanding is needed in order to learn what influences public opinions. The advocates have identified various knowledge gaps in the academic study of public attitudes toward nanotechnology that are relevant to communication. Macoubrie (2006: 222) argued that communication with the public on nanotechnology depends on in-depth knowledge not only of attitudes but also of their underlying drivers, i.e., laypeople's assumptions and premises. Priest (2009: 765) argued that more knowledge is needed of how different communication models work, and of what roles, goals, and objectives they entail. One area where more knowledge is needed that has been identified as particularly relevant to the communication of nanotechnology concerns how the public forms perceptions of benefits. Risk perception is a well-researched area, but the perception of benefits is less so (Satterfield et al. 2012: 257).

It has also been argued that it is important to understand under what circumstances perceptions might change (Satterfield et al. 2012: 257). It has been suggested that the mental models framework (Morgan et al. 2002) would be useful since it focuses on how members of the public cognitively construe risk from assumed causal mechanisms (Bostrom and Löfstedt 2010: 1657). However, others have questioned the relevance of the mental models approach, since nanotechnology has a somewhat different dynamic from those of several other risk issues for which traditional risk communication (and the mental models approach) was developed (Pidgeon and Rogers-Hayden 2007: 203).

Because the media are known to influence public opinion, it has been argued that we need a better understanding of how the media, including new media, work (Duncan 2011). Attention should be paid to new developments in the media coverage of nanotechnology to enable the "monitoring" of public opinion at different stages of the "issue–

attention cycle" (Ho et al. 2010: 2711). It has been argued that more knowledge is needed of how changes in media coverage (which might be sudden and drastic) affect public perception (Scheufele and Lewenstein 2005: 665).

(iii) Develop targeted audience-specific communication

When considering solutions, the focus is on targeted communication based on an understanding that the public is fragmented and that different audiences respond to information in different ways. Targeted nanotechnology communication is tailored to the understandings, values, needs, and knowledge of particular groups, with the aim of helping them understand nanotechnology and gain the tools needed to make well-balanced decisions for themselves (Duncan 2011; Ho et al. 2010: 2710–1; Pillai and Bezbaruah 2017: 41; Yue et al. 2015). Targeted communication is understood by its advocates as helping empower the public by providing information, so that members of the public might become informed despite their knowledge limitations (Simons et al. 2009: 1596). A key message in this line of thought is that the public cannot be treated as a single homogeneous mass expected to respond uniformly to science communication.

The core message from this perspective is that the public consists of various audiences differing in ethnicity, race, language, religion, and so on. Specific audiences should therefore be identified and addressed separately as distinct "interpretative communities," as there is no such thing as "one size fits all" in communication (Priest 2009: 764). In the same vein, Kahan (2010: 297) argued that information about nanotechnology should be presented so that it is "agreeable to culturally diverse groups." Kim et al. (2014: 978) recommended that risks and benefits be addressed in special communication campaigns tailored to the audiences' particular cognitive styles. For people who process information systematically, more information should be provided, and for those who rely on heuristics, communication should take account of values (Kim et al. 2014: 978). Following this line of reasoning, Ho et al. (2010: 2710–1) suggested forming partnerships with religious institutions to reach religious segments of the public.

(iv) Develop dialog and participation

Another solution is to develop initiatives and strategies for involving the public in dialog and policy processes (Sodano et al. 2016: 725; Vandermoere et al. 2011: 204). Priest (2009) argued that opportunities should be made for public discussion and education and for the public to give opinion feedback to policymakers. A need has been identified for "outreach efforts on meaningful public engagement and dialogue that builds relationships among risk managers and the public, rather than one-sided efforts designed to educate and inform the public" (McComas and Besley 2011: 1758–9).

These deliberative approaches, it is argued, should involve scientists, engineers, and laypeople (López-Vázquez et al. 2012: 203) as well as the policy sector (Sodano et al. 2016: 725). Others have argued that the industry must take more responsibility for communication (especially in the case of nanofood). In the nanofood sector, it is recommended that the industry should use trade associations as partners, collaborate with social scientists, and promote public engagement (Duncan 2011). A concrete suggestion is to facilitate "group talk" to critically engage with future-oriented techno-scientific politics in which policy-oriented critical social scientists have a distinct role in developing dialog between the public, science, and policy concerning new technology (Macnaghten 2010: 32). However, it is also argued that public participation must be structured so that "cultural polarization" is avoided between different groups (Kahan 2010: 297).

(v) Build transparency and trust

To engage the public, it has been argued that trust must be established, and that transparency is a good way of doing so. It is assumed that greater trust and transparency will almost automatically increase public acceptance of nanotechnology (Vandermoere et al. 2011: 204). Siegrist (2010: 842) emphasized the need to induce high public trust in government and regulation. It has also been argued that new thinking about how to be proactive and transparent in communication and that establishing new relationships with the public are ways forward toward integrating and communicating research and risk assessment (Shatkin et al. 2010: 1685).

To build trust, it has been argued that it is important to consider who should communicate nanotechnology information to the public and that already trusted institutions should be involved (Simons et al. 2009: 1596–7). Capon et al. (2015: 11) argued that risk communication is best undertaken by trusted scientists. Ho et al. (2010: 2710) suggested that policymakers should promote and instill trust in scientists and deference to scientific authority among the public, for example, by arranging for "eminent scientists" to hold seminars. Similarly, Shatkin et al. (2010: 1685) recommended that an independent and trusted "entity" should be established for the purpose of managing and improving science communication.

Solutions if societal organizations are seen as the problem

We have seen that societal organizations are construed as a problem for the communication of nanotechnology for the following reasons: (i) the mass media influence attitudes; (ii) the mass media provide a fragmented picture of nanotechnology; (iii) policy and regulation are fragmented; and (iv) there is a lack of consensus on definitions and concepts. The proposed solutions to these problems are the following: (i) media management, (ii) strengthening policy and regulation, and (iii) increasing clarity and consistency in communication. These solutions correspond to the problem constructions, by trying to eliminate what are considered obstacles in society to the successful communication of nanotechnology.

(i) Media management

Managing the media in various ways is a common suggestion for improving nanotechnology communication from the perspective of the scientific community. A practical suggestion for connecting the media more closely to science is that a science media center could be set up to serve as an "independent agenda-free organization for evidence-based science" (Duncan 2011: 688). It has also been argued that risk communication should preferably be in place before any negative events are reported in the news media (Simons et al. 2009: 1596), so those concerned can be prepared to address any event or public scandal. To achieve stronger public engagement, it has been recommended that new media and peer-to-peer communication be utilized (Bostrom and Löfstedt 2010: 1657). Ho et al. (2010: 2711) recommended that public officials should use the mass media to run campaigns, and should sponsor science programs on public broadcasting channels to offer accurate and up-to-date nanotechnology information to the public.

(ii) Strengthening policy and regulation

As communication is understood to be hindered or made more difficult by policy and regulation fragmentation, one solution is regulatory change. Government regulatory bodies, it is argued, must ensure compliance with guidelines in order to effectively manage toxicity and safety, in order to maintain public trust (Ho et al. 2010: 2710). Major public investment in risk research, early warning systems and monitoring, stringent pre-market authorization, mandatory labeling, and establishment of a public register of products and producers have also been recommended (Sodano et al. 2016: 725).

(iii) Increase clarity and consistency in communication

To improve communication regarding nanotechnology, it has been argued that communication must be clear and consistent (Shatkin et al. 2010: 1685). Communication should address terminology issues as well as ensure clarity, consistency, and parsimony in communication (Shatkin et al. 2010: 1686). Boholm and Arvidsson (2016) suggested that the terms nanoparticle and nanomaterials should be defined and used consistently, given a particular purpose, to serve as the basis for a shared understanding among relevant regulators and parties. Another recommendation is that the "exact method and phrasing" of messages must be carefully considered (Smith et al. 2008: 471–2). Reisch et al. (2011: 650) recommended that the "latest research on the potentials and risks of nanoproducts and nanomaterials should be translated into an easily understandable format" to be disseminated to consumers.

Although there are calls for more clarity in the messages communicated to the public, there is a striking disagreement on how messages should be formulated and what should be emphasized. Some believe that the benefits of nanotechnology should be highlighted in a balanced way to promote public acceptance of nanotechnology (Kim et al. 2014:

977). Steenis and Fischer (2016: 1262) suggested that communicating the personal benefits of nanotechnology in food will be a key element in building acceptance. They also suggested that more attention should be paid to identifying and communicating the concrete benefits of nanotechnology to actual consumers (Steenis and Fischer 2016: 1264). Sodano et al. (2016: 7249) have generally recommended that policymakers should engage in communication aimed at increasing public acceptance by conveying information about benefits and "urging greater trust in industry and science."

However, it is also argued that if nanotechnology benefits are overemphasized, the public might have problems accepting nanotechnology if disturbing news about hazards emerges in the future. Risk must therefore be addressed in order to keep the public prepared for negative information (Satterfield et al. 2012: 258). Experts have an important role as communicators and should "demonstrate their willingness to speak candidly about potential risks" (McComas and Besley 2011: 1759). Sodano et al. (2016: 725) recommended against policymakers communicating policies with the sole aim of attempting to increase public acceptance; they should instead address risks associated with nanotechnology. Science-based information that is open and balanced is understood to be an important tool helping the public form well-grounded opinions (Cobb and Macoubrie 2004: 404).

Solution if nanotechnology itself is seen as the problem

As seen above, the physical properties of nanotechnology (and the associations evoked) have been identified as a problem for communication for several reasons: (i) they give rise to low dread risk; (ii) they concern small and difficult to perceive properties of matter; (iii) they relate to many different applications and areas of use; and (iv) they are associated with epistemic uncertainty. The suggested solution addressing nanotechnology itself as a problem is to improve our knowledge of nanotechnology, a solution intended to reduce the epistemic uncertainty associated with nanotechnology. Problems (i)–(iii), however, although understood as problems for the communication of nanotechnology to the public, lack any suggested solutions.

(i) Improve knowledge of nanotechnology

It has been suggested that nanotechnology risk assessment and lifecycle assessment should be advanced in order to improve the quality and accuracy of risk communication. Laux et al. (2018) proposed that nanomaterials must be characterized and understood during different lifecycle stages; they also argued that the risk assessment of nanomaterials must be developed, since knowledge derived from risk assessment is the fundamental content to communicate to the public. Similarly, Pidgeon et al. (2011: 1696) noted a need for more "sophisticated quantitative studies" of the risk of nanomaterials in order to improve communication with the general public.

Discussion

This review of the scholarly debate on nanotechnology communication and the public has identified problem definitions as well as solutions for communicating with, and involving, the public. An overview of the field reveals that there is congruence between problem constructions and solutions for some topics, but not others. There are systematic overlaps, but also some striking decoupling between problem definitions and recommended solutions for policy and practice. An overview of problem formulations and solutions is provided in Table 1.

In this section, we will discuss problem definitions and solutions in relation to the research field producing these problem definitions and suggested solutions.

One important reason for the lack of congruence regarding problem formulations and suggested solutions is that there is no consensus as to the goals of communicating nanotechnology to the public. The rationale for such communication stems from underlying normative ideals rather than from a need to address certain identified problems. There is an underlying, deeper identification and conceptualization of a problem about the role of citizens in society in relation to new technology. This underlying problem formulation addresses the need for communication with citizens about emerging technology and is part and parcel of the ideals of responsible innovation intimately linked to the development of nanotechnology in the US and the EU.

Table 1 Overview of problems and solutions to communicating nanotechnology to the public

Problem	Solution
The public	
Deficits of knowledge, interest, and engagement	Education
	Dialog and participation
Heterogeneous	Targeted audience-specific communication
Values and emotions	Dialog and participation
	Academic research
	Transparency and trust
Societal institutions	
Mass media influence public attitudes	Media management
Fragmented and ambiguous mass media representations	Media management
Fragmented policy and regulation	Strengthen policy and regulation
Lack of consensus on concepts	Clarity and consistency in communication
Nanotechnology itself	
No dread risk	
Beyond perception	
Diverse applications	
Epistemic uncertainty	
	Improve knowledge of nanotechnology particularly risk assessment an life cycle analysis

A normative position often assumed in the literature is that communication on nanotechnology should promote empowerment and reflexivity among the public to "encourage deeper thought about issues that might otherwise be ignored" (Priest 2009: 762), and that communication should "empower people to participate in making decisions that reflect their own values rather than (necessarily) the values of the technology promoters or detractors." What is called "upstream engagement" in the literature on the public understanding of science strives to promote civil society–science policy dialog in which the public is included in decision-making on technology (Pidgeon and Rogers-Hayden 2007: 192; Pidgeon et al. 2017). Upstream engagement to involve the public is understood to enhance the legitimacy of new technology (Priest 2009: 760).

The normative stance implies that policymakers must try to "integrate the public's views into risk decision making" (McComas and Besley 2011: 1750). It is recommended that a collaborative problem-solving approach should be used in nanotechnology policy to identify issues of concern among the public (Macoubrie 2006: 222). This perspective on the communication of nanotechnology is understood to be essential to empower people in decision-making concerning nanotechnology (Simons et al. 2009). It is advocated that this communication with the public should be two-way communication or dialog (Pidgeon and Rogers-Hayden 2007: 193; Priest 2009; Toumey 2013: 226); that openness and transparency about uncertainties should guide the regulation and management of risks (Priest 2009); and that transparency should be seen as crucial to creating public trust (Priest 2009: 760). According to the norms of upstream engagement, solutions emphasize participation, dialog, transparency, and other modes of motivating the public to engage in discussions and decision-making regarding nanotechnology.

Another stance is the "deficit model" of the public understanding of nanotechnology (Rogers-Hayden and Pidgeon 2007; Priest 2012: 26). This model identifies elements lacking among the public, elements understood to be crucial to communication, such as knowledge (the public has poor knowledge), trust (the public mistrusts regulators, policymakers, scientists, and/or the technology), and engagement (the public is not interested and does not care) (Rogers-Hayden and Pidgeon 2007). If the public is understood to lack proper knowledge of nanotechnology, a main communication goal will be to educate and inform the public. From this perspective, communication should provide information to educate the public about nanotechnology, the underlying science, and the actual associated risks and benefits (Delgado et al. 2011). If communicative actions to address deficits in knowledge (more education) or deficits in trust (more transparency) are successful, it is assumed that public acceptance of nanotechnology will increase (Ebbesen 2008). There is a certain overlap in the two positions when it comes to building public trust. If the public is understood to lack trust and engagement, a main communicative goal will be to engage through participation and various efforts to create dialog (Rowe and Frewer 2000).

The different problems and solutions identified in the reviewed literature should be understood in relation to different overarching ideas about public upstream engagement, and about knowledge and/or trust deficits. These ideas are related to two partly overlapping interdisciplinary social science research fields: risk communication, which is part of risk research, and science communication, which is part of science and technology studies (Pidgeon and Rogers-Hayden 2007; Priest 2009; Renn and Benighaus 2013). Scholars from the risk communication field tend to focus on providing correct, factual information on risk issues, correcting misunderstandings and false beliefs, influencing and correcting lay mental models of the causes and effects of a risk issue, and raising awareness of scientific knowledge (Shatkin et al. 2010). Scholars from science and technology studies, on the other hand, emphasize more broadly the role of technology in society: how technology is organized and institutionalized and how actors engage in technology, as well as what power relations, meaning systems, ideological frames, and norms surround technology as a social phenomenon (Pidgeon and Rogers-Hayden 2007).

The fundamental challenges acknowledged in both fields are basically the same: how to stimulate debate when the topic is not prominent in society? How to create engagement when the public is not interested? How to disseminate knowledge of an issue that does not engage people? How to create engaged citizens with an interest in science and innovation? How to disseminate knowledge when there is a lack of engagement and interest? (Petersen et al. 2007). The communication of nanotechnology can be understood as a paradox: there are norms of science participation and the scientification of public knowledge, on one hand, and a lack of public interest and capacity to participate, on the other (Binder et al. 2016: p. 831). The paradox in play is that upstream engagement initiatives even might create an awareness of risk, socially amplifying the perceived risks of nanotechnology among the public (Pidgeon et al. 2011: 1696).

The findings of this review of the literature on communicating nanotechnology to the public support the findings of another literature review on research into “societal responses” to nanotechnology. Ronteltap et al. (2011) reviewed 107 papers published between 2002 and 2010 with the aim of identifying overarching frameworks and common problem formulations. They found that the field is heterogeneous and fragmented, lacks uniform research problems and problem definitions, and lacks a generally agreed-upon theoretical framework as well as consistent concepts and terminology. There was a lack of collaboration between natural and social sciences and it was difficult to compare research and research findings. Ronteltap et al. (2011) also noted a plethora of divergent problem formulations, solutions, and recommendations for practice and policy reflecting the orientations of diverse academic fields, research paradigms, and ways of conducting policy-relevant research. They concluded that the fragmented problem definitions and suggested solutions reflected a lack of cross-fertilization between subfields and disciplines. There is a lack of agreement on the research problems, theoretical framework, or even common goals and objectives. Hence, it is difficult to extract viable lessons and policy implications for reflexive innovation in the field.

We have reached similar conclusions regarding the construction of the field of research on nanotechnology and communication with the public. However, we found a broad consensus in the cited literature about a need for communication with and/or involving the public as part of the responsible innovation of nanotechnology. However, there is little agreement on how exactly to achieve this, or even why it is desirable. The reviewed literature presents different problem formulations as well as different solutions to achieve successful communication strategies. The solutions are sometimes decoupled from the problem definitions, and the problem definitions and solutions are sometimes also decoupled from research. One important reason for this is the normative stance of public deliberation in relation to the responsible innovation of nanotechnology. A lack of agreement on theories and perspectives creates contradictions in the debate on nanotechnology communication, and different recommendations are based on divergent views of the public, of the effects of interventions, and of the goals of communication.

Conclusions

What lessons can be learned from the almost two-decade-long debate on the communication of nanotechnology to the public? Although the debate is fragmented and is based on conflicting ideals that are difficult to balance, the communication of nanotechnology is nevertheless seen as an important issue in society. Successful science communication is important for establishing trust in science and the scientific community, as well as in other societal organizations, and controversies surrounding nanotechnology might seriously affect trust in society more generally. Communication strategies and goals are important, as communication done the wrong way very well might lead to a backlash, and information intended to soothe the public might instead stir up concern. As Pidgeon et al. (2011) argued, it is paradoxical that upstream engagement initiatives might activate risk perceptions and contribute to the social amplification of nanotechnology as associated with risk (Pidgeon et al. 2011: 1696). From insights gained from the reviewed literature, we wish to conclude by making some constructive suggestions for nanotechnology communication. A summary of recommendations is presented in Table 2.

Table 2 Communication of nanotechnology to the public: recommendations

1	Define objectives of communication: decide why to communicate and what is to be communicated
2	Utilize previous research in a responsible way: research should be systematically assessed, focus on metadata rather than individual studies
3	Develop communication to match the context: be consistent and focus on the message
4	Do not aspire for a generic framework for communication: take into account application area, industry sector, regulation, consumer interest, public perception, and acceptability

Define objectives of communication We suggest that the reasons why nanotechnology should be communicated to the public be identified and defined. Why is communication about nanomaterials important, and what do we want to achieve through this communication? It is important to be specific and transparent about the general objectives of communication and public involvement, and to define the objectives of specific communication initiatives and of initiatives intended to involve the public in any deliberative approach. By addressing this issue upfront, it is easier to avoid conflicting goals in any communication strategy. Recognizing objectives is an important step in designing and implementing communication regimes for nanotechnology, with consequences for who should communicate and whom should be targeted.

Utilize previous research in a responsible way When the rationale for communication is defined, it is possible to systematically utilize previous research findings. Although certain fundamental challenges with communicating nanotechnology are not easily resolved, public attitudes and opinions and what might influence them are relatively well researched. Taken together, we actually know quite a lot about public knowledge, public attitudes, what influences public attitudes, and how these attitudes can be expected to change due to different circumstances. Relevant studies have treated different groups in society, different countries, and consequently different regulatory and societal contexts. Considerable research has also examined media representations and how media information influences public attitudes and perceptions, research that can be utilized in designing communication strategies.

While recognizing the importance of utilizing previous research on the public understanding of nanotechnology when designing successful communication strategies, we also call for caution in how research is utilized in formulating communication strategies. Individual studies can be used, but analyses of metadata should be employed to draw more general conclusions. General problem formulations and underlying assumptions need to be considered. There is an immanent risk of making recommendations for communication based on individual studies, when the body of literature in fact presents contradictory results. The methodological, theoretical, and normative points of departure of the studies, as well as their empirical scope, need to be recognized and critically assessed by asking questions such as: what conclusions can be drawn from the studies? Are the results of a study in one country translatable to another? Can we assume that the identified differences will remain stable over time?

Recommendations for targeted communication are often stressed in survey studies identifying differences between groups in society, implying that information should be tailored to differences in knowledge and cognitive style between audiences. Recommendations for targeted communication are often a conclusion drawn from the results of individual studies identifying statistically significant differences between two groups (e.g., religious–non-religious, men–women, and well educated–poorly educated). This might seem a reasonable implication of such studies; however, differences between groups are often small even though statistically significant, and similarities might still be important. Furthermore, different studies report different results, for example, with gender differences seeming to matter in some studies, while others find no such differences. Targeted communication might even polarize and compromise the perceived integrity of societal organizations and the scientific community. Tailored messages can be interpreted as conflicting information or as attempts to manipulate, and as a communication strategy might even cause a backlash. Therefore, targeted information should be carefully tested and evaluated before being put into practice.

Develop communication to match the context This study has identified several not easily changed problems relating to the communication of nanotechnology: the qualities of nanoparticles, the fragmentation of current regulation, media reporting, a lack of interest and engagement among the public, and the fact that public attitudes are influenced by beliefs, values, and emotions rather than by factual knowledge. From a communication perspective, these things are not easily changed, and communication strategies should instead be developed in relation to context. The communication of nanotechnology to the public cannot rely on changes in regulation, changes in public interest or engagement, or changes in the physical properties of nanomaterials or nanoparticles. The public cannot be expected to become involved in dialog and communication processes that do not interest them. Some suggested solutions involve changing the media representations. While it might be a good idea for scientists to provide good didactic information for the media, it might not be a good idea to try altering how the media evaluate what news is deemed relevant to communicate or to intervene in the workings of the media and the principles of news evaluation. Criticizing or trying to manipulate the free press might cause serious backlashes in public trust.

Do not waste effort developing any generic framework for communication While the fragmentation of the field is recognized in the reviewed literature, many of the recommendations assume that the communication of nanotechnology is a uniform, generic problem. There are, however, large differences between nanotechnology applications and areas of use: there are different technologies used for manufacturing, different bulk materials, different industrial sectors, and consequently different responsible regulatory bodies. Nanomaterials involve a wide range of techniques and materials with very little in common in terms of potential risks and benefits, and there is large variation in public perception depending on the specific uses. The communication of nanotechnology cannot be addressed as a generic problem, as it is context dependent. For this reason, diverse communication strategies might have to be developed for different application areas. Besides being inefficient and difficult to implement, a unified framework for the communication of nanotechnology might very well prompt serious backlashes. For example, by applying mandatory labeling across diverse areas of nanotechnology application, hazards identified in one application area might have seriously negative effects on public perceptions of other completely unrelated products as regards toxicity or potential risk scenarios.

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