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Aligning responsibility and relationships

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Contents

Abbreviations and acronyms

BNNI	Berkeley Nanoscience and Nanotechnology Initiatives
CCD	Criteria for Collectivization Duties
CCD-Nano	Criteria for Collectivization Duties adjusted to the context of nanotechnology research
EoC	Ethics of Care
NP	Nanoparticle
NNI	National Nanotechnology Initiative
OHS	Occupational Health and Safety
PP	Precautionary Principle
RRI	Responsible Research and Innovation
UC Berkeley	University of California, Berkeley

1 Introduction

1.1. Nanotechnology and nanoparticles

In recent years, we have seen the emergence of the field of nanoscience and nanotechnology (Roco 2011a). Nanotechnology has been defined as the "[u]nderstanding and control of matter and processes at the nanoscale, typically, but not exclusively, below 100 nanometers in one or more dimensions where the onset of size-dependent phenomena usually enables novel applications" (ISO et al. 2005). Scientists and engineers in a variety of disciplines, such as physics, chemistry, materials sciences and biology have found ways to understand, manipulate and/or create matter at the nanometer scale (Moor & Weckert 2004; Leydesdorff & Zhou 2007). This has led to applications of nanotechnologies in a variety of fields such as the semiconductor industry, ceramics and the chemical industry (Roco 2011). Moreover, technological innovation at the nanoscale has often been stimulated by national and international research programs (see for example National Science and Technology Council 2014; Cunningham & Werker 2012).

One of the main pillars of development in nanoscience and nanotechnology is the ability to create new and advanced materials. Nanoparticles have at least one dimension at the nanoscale. There are many different forms and types of nanomaterials. These include nanoparticles (such as nanosilver and titanium dioxide), nanotubes (such as carbon nanotubes), and more complex shapes such as spheres (nanocarriers). For the sake of clarity, I will use the term nanoparticles for all these varieties, but due to inconsistencies in word use in the published articles that are part of this thesis, some sections of the text (mainly Chapter 2) will use the term "nanomaterial."

Particles on this scale often acquire new properties and functionality. Specific size-dependent properties that nanoparticles may have concern changes in polarity, electrical charge or magnetic properties, as well as color (optical properties) (Schmid et al. 2003). Furthermore, some nanoparticles are reported to have high levels of reactivity relative to larger particles: due to an increase in the surface-area-to-volume ratio, nanoparticles react strongly in a much lower mass of the substance. In general, substances we have been using for years have been found to respond very differently once they are nanosized, which has opened up a whole new realm of opportunities. Another reason for using nanoparticles is that due to their small size they move through other materials and tissue more easily, which allows the miniaturization of products.

Nanoparticles are used in a variety of products and industries, such as in foodstuffs, for surface treatments and construction materials, as well as cosmetics (Grunwald 2012; Lee et al. 2010; Cushen et al. 2012). In most cases, they are used to improve the properties of already known products. Examples include nanoparticles such as nano titanium dioxide for producing transparent sunscreen, or nanosilver, which is applied in products for its antibacterial effects, (Chernousova & Epple 2013), or carbon nanotubes which have been used to reinforce materials in structural composites (Bonduel et al. 2016). In medicine, nanoparticles can cross the blood-brain barrier with relative ease, which creates an opportunity for the administration of many pharmaceuticals (Valavanidis & Vlachogianni 2016).

The exact number of products containing nanoparticles is unknown, as the nanocontent of products does not have to be indicated on the label (except for cosmetics). Furthermore, identifying all products containing nanoparticles is difficult because there are no generally accepted identification methods for nanoparticles (OECD 2016; Picó 2016) and because of the protection of confidential business information (Hildo Krop et al. 2015). Nevertheless, the contribution of nanoparticles to the market is expected to increase, given that the EU has identified nanotechnology as a key enabling technology (European Commission 2014; European Commission 2012).

1.2. Uncertain risks of nanoparticles

Despite all the promises made, novel nanoparticles are also associated with scientific uncertainty concerning potentially hazardous effects. The same new properties and functionalities that make nanoparticles interesting – for example, large surface-to-volume ratio, and mobility – are features that have sparked concerns about their toxicity (Myhr & Dalmo 2007). There are indications that the use of some nanoparticles may cause adverse health effects such as pulmonary disease (Song et al. 2009). It is also known that nanoparticles may be easily taken up in the body after inhalation and ingestion (Borm et al. 2006). For some particles, such as nanosilver (Gaillet & Rouanet 2015) and nanogold (Hadrup et al. 2015), more is known, but toxicological data are insufficient to determine exposure limits for most nanoparticles. With respect to ecotoxicity, the picture is similar. The accumulation of certain nanoparticles in surface water may be a threat to aquatic animals (Batley et al. 2013). This is a suspected effect of nanosilver (Blinova et al. 2013), while metal oxide nanomaterials are suspected of being toxic to bacteria and fungi (Djurišić et al. 2015). Unfortunately, current risk research is not conclusive to allow us to draw unambiguous conclusions about toxicity and ecotoxicity.

The limitations of measurement techniques and exposure scenarios, or other unforeseen interaction effects, make it difficult to measure and predict the potential toxic effects of nanoparticles in humans and the environment (Katherine Clark et al. 2012; Levard et al. 2012). Issues that need to be resolved include the incomplete characterization of some nanomaterials (Djurišić et al. 2015). A recent report of an OECD meeting was at least moderately positive in its review of the methods available to map the physical-chemical properties of nanoparticles, but the standardization of methods stands in the way of their application in risk assessment (OECD 2016). Furthermore, it is difficult to predict the fate and behavior of nanoparticles in natural environments (Bour et al. 2015), and it has also been argued that the release of nanoparticles from consumer products and solid composites is often difficult to model (Mackevica & Hansen 2016).

This uncertainty cannot simply be ignored. We know from experience with other materials and compounds that hazardous effects may only become known after a significant amount of time. The European Environmental Agency report *Late Lessons from Early Warnings* from 2002, and its successor in 2013, teach us that there are ample cases of products that are only shown to be toxic or have other harmful effects over a longer timeframe (Harremoës et al. 2002; European Environmental Agency 2013). For example, dichlorodiphenyltrichlorethane (DDT) was widely used in the 1950s and 1960s as an insecticide to fight malaria, but is now banned because of its adverse environmental impact. Perchlorethylene (PCE) was used in the 1960s and 1970s in drinking water distribution pipes until it was shown that these pipes polluted water supplies with this human carcinogen. More recently, the use of Bisphenol A (BPA) in consumer products (in particular for babies) has become the subject of discussions concerning its suspected disruptive effect on the endocrine system. Another recent example is estrogens from birth control pills, which are still widely used even though data shows an impact of these hormones on aqueous wildlife.

With nanoparticles increasingly being used, people and the environment could potentially be put at risk. However, both the risks and benefits of nanoparticles will only become fully clear through their use and application. It should be emphasized that the concerns about the toxic effects of nanoparticles extend to the category of newly engineered nanoparticles. Increasingly, process-generated nanoparticles, such as particulate matter from combustion processes, as well as ultrafine dust particles, are being identified as potential environmental and health risks. In this thesis, however, I will focus on risks associated with intentionally engineered nanoparticles.

1.3. Managing the uncertain risks of nanoparticles

Being able to identify and, to a certain extent, estimate risks is an important step in preventing future harm. In this regard, it is first necessary to clarify exactly what is meant by risk. There are several ways in which the term is used, for example, to denote an actual hazard, or to denote a cause or probability of a hazard occurring (see for an overview Van de Poel & Nihlén Fahlquist 2012). In engineering contexts, risk usually refers to the likelihood of an unwanted effect occurring, multiplied by the seriousness of the consequences of that effect. However, the topic of this thesis is the “uncertain risks” of nanoparticles. In relation to such risks, following the distinctions drawn in the framework depicted by Felt and colleagues, “we know the types and scales of possible harms, but not their probabilities” (Felt et al. 2007, p. 36). In the case of nanoparticles, the potential negative outcomes are largely known (e.g., harm to the physical wellbeing of people), but this cannot be captured in terms of statistical probability. This uncertainty causes problems for the management of risk, as we will see in this section (and will expand on in Chapter 3).

Traditional methods for weighing risks against benefits – for example, using cost-benefit analysis – all rely to a great extent on probabilistic information about risks and are therefore inadequate to deal with uncertain risks. They do not offer much guidance when there is less certainty about the size and likelihood of hazards. In such cases, risk assessment is often based on the qualitative assessment of experts (Renn & Roco 2006), although we will see in Chapter 3 that this is not easily done. Even for the “relatively” simple risks associated with nanoparticles, compared to more active nanostructures, consensus has not been reached. The recent OECD report on the physical-chemical characterization of nanoparticles repeatedly emphasized the limitations of the study, as it only relied on one expert’s assessment, which is indicative of the provisional nature of the assessment methods presented. Given that fixed standards cannot yet be set for nanoparticles, it has been suggested that the governance of those risks should be adaptive (Klinke & Renn 2012), responding to new information and changing views on nanoparticles. This is a call for a form of trial-and-error learning that underlies the framework of responsible experimentation that Van de Poel and colleagues have been developing (Jacobs et al. 2010; Van de Poel 2009; Van de Poel 2015).

Others have argued that we should take a more precautionary approach towards nanoparticle risks to minimize the potential harmful effects (Gezondheidsraad 2008; Van Broekhuizen & Reijnders 2011; Weckert & Moor 2007). The basic idea of precautionary thinking – the precautionary principle – states that a lack of knowledge about risks is not an acceptable reason for not taking precautions (Steel 2014; Ahteensuu & Sandin 2012). In the case of technologies that could potentially be harmful, this principle does not allow for experimentation, that is, it does not permit exposing people and the environment to uncertain risks. This, however, has led to concerns about the overly strict regulation of nanoparticles. The precautionary approach is essentially a risk-averse approach to uncertain risks and may lead to moratoria or bans on many nanoproducts. This would also prevent society from profiting from the social and economic benefits of applications such as nanoparticle-enabled drug delivery, land and water remediation and filtration technologies, or the many coatings and paints that diminish environmental burdens in the construction industry.

Of course, one may be skeptical of overly positive depictions and visions of what nanoparticles may offer (see, for example, the appeal by the European Chemical Industry Council, Cefic, that we need these technologies to optimally make use of natural resources; Cefic 2014), but there are definitely applications thinkable that would contribute to the wellbeing of people (Beumer 2016). Challenges in the application of the precautionary approach pertain to establishing whether the concern leading to the taking of extra precautions is reasonable. Ironically, the same uncertainty that justifies invoking the precautionary principle often impedes establishing what amounts to a "reasonable concern" (Grunwald 2012).

All these difficulties in managing uncertain risk entail a more fundamental question concerning what should be done about uncertain risks. If we want to continue developing and making use of nanoparticles, what are the responsibilities in managing their uncertain risks?

1.4. Uncertain risks and responsibility

Hans Jonas (1984) recognized some time ago that technological innovation enables humans to generate effects that extend beyond their current place and time. This, he argued, requires a new kind of ethics, an ethics of responsibility, which demands that people take responsibility for the futures they create. Discussions concerning responsibility for risks can be seen in this light. Risks require a forward-looking rather than a backward-looking notion of responsibility. In backward-looking notions of responsibility, the focus is on assessing whether particular activities deserve praise or blame, and under what kind of conditions one can be held accountable for past actions. Forward-looking responsibility focuses on what agents should be doing now to prevent morally undesirable outcomes from occurring (for more on the distinction between backward-looking and forward-looking notions of responsibility see Van de Poel 2011). The idea is to proactively take *responsibility*[1] for nanoparticle risks, rather than establishing after the fact whether the way the risk was managed is praiseworthy or blameworthy.

Van de Poel and Nihlén Fahlquist (Poel & Nihlén Fahlquist 2012, p. 118) list four forward-looking responsibilities with respect to risk:

(1) Responsibility for risk reduction
(2) Responsibility for risk assessment

1 In this section I only describe forward-looking responsibility with respect to uncertain risks. A more general notion of forward-looking responsibility has been debated in several academic papers and government reports under the notion of Responsible Research and Innovation (RRI). Most of the scholars in this field emphasize the importance of innovation practices being responsive to public and environmental needs. For example, Von Schomberg suggests that responsible innovations are directed at solving the Grand Challenges of our time, such as global warming and energy and food security (Von Schomberg 2013). Van den Hoven takes a more methodological angle and proposes Value Sensitive Design as a methodology for making product design more responsive to widely held values (Van den Hoven 2013). Value Sensitive Design implies a re-orientation of the design process through an empirical and conceptual reflection on values. Owen and colleagues describe Responsible Research and Innovation in terms of process requirements: innovation processes should be attentive, inclusive, responsive and deliberative to ensure a proper embedding of technological products into society (Owen et al. 2013). I will engage with this body of literature in Chapters 4 and 5 and in the conclusion. For now, I take from this literature that there is an unease with the way technologies are currently being developed. This is, in my view, at least partly due to the fact that we are not able to predict how and to what extent new technologies may become harmful.

(3) Responsibility for risk management
(4) Responsibility for risk communication

These four responsibilities are still very generally defined, and in practice they will entail a number of different activities. For example, the responsibility for risk reduction could entail both a concerted effort to minimize the release of and exposure to nanoparticles (see additional discussion in Chapter 3) and a limitation on the use of nanoparticles (e.g., for luxury products). The responsibility for risk assessment presupposes conducting laboratory risk research and assessing the likelihood of risks emerging in particular practices and uses of products. Responsibility for risk management suggests the existence of (or building of) organizational structures that are adequate and flexible enough to respond when hazards occur/emerge (see also Chapter 5). Responsibility for risk communication entails the sharing of knowledge along the production chain and with wider society.

These responsibilities all are important, but as we saw in the previous section they may be difficult to act upon in the case of uncertainty. For example, when risk assessment methods fail, long-term societal monitoring and knowledge-sharing become more important. Furthermore, risk management may, in the case of uncertain risks, not always imply the reduction or mitigation of risks, but rather the management of exposure to risky products. Risk communication is much harder when it comes to uncertain risks, and may imply an open debate about ignorance and the limits of our knowledge. Nonetheless, the creation of risks demands a general responsibility to deal with them. Who should take this responsibility? The easy answer may be: those who are developing the technology (and thereby changing the world). However, we will see in the next section that it may be hard to identify one single actor who should take responsibility for uncertain risks.

1.5. Allocating forward-looking responsibilities

In Engineering Ethics, responsibility for risks, and any ethical issue concerning the products of technological innovation, is often allocated to individual engineers. For example, ethics codes for engineers advise individual engineers on how to be a good engineer, be loyal to employers and be socially responsible. Langdon Winner has argued that ethics education often focuses more on solving individual dilemmas than engaging with the wider social implications of one's profession (Winner 1990). Herkert has identified a similar focus on what he calls "micro-ethics," that is mostly "concerned with individuals and the internal relations of the engineering profession" (Herkert 2001, p.403). A prime example of this may be the discussion on whistleblowing, considered as a way to act individually in relation to a systemic problem that imparts a heavy moral load upon individual engineers (DeGeorge 1981). This is not to say that individuals do not matter. On the contrary, ultimately responsibility in innovation processes comes down to the behavior of individual people (Van den Hoven 2013).

However, it has been recognized that the collaborative nature of scientific projects creates problems concerning the allocation of responsibility for the impact of technology to the individual scientists and engineers that develop these technologies. Innovation processes are complex and widely spread; they take place in multiple locations, combine insights from several disciplines and extend over long periods of time. This means that it is very difficult to know beforehand the extent to which one is contributing to the production of risk. Even if it is clear that a person is part of the causal chain of production, the decisions and actions of that individual will only contribute in part to the risk that could be associated with the final product. Such problems[2] generally arise when attempting to assign responsibility for any outcome of an innovation process, as Swierstra and Jelsma have argued (2006). This is even more the case when allocating forward-looking responsibility, as future processes are open-ended and it is difficult for individual researchers to foresee their effects.

Another way to approach the problem is through a more collectivist notion of responsibility. A collective understanding of responsibility holds that we can allocate moral responsibility to groups of people to prevent potential future harms to occur or to hold them responsible for past harms. In the context of this thesis one could argue that those involved with the development and use of nanoparticles jointly share responsibility for their uncertain risks; this means they have to collectively ensure that these uncertain risks are dealt with adequately. There are theoretical objections that challenge the moral agency of groups. For instance, one may argue that it is not possible for groups as a whole to have intentions and act ethically, rather what is seen as an expression of group

2 There is a class of problems in Engineering Ethics dedicated to these kinds of situations: problems of many hands are characterized by an inability to allocate responsibility to particular individuals because of the distributed nature of many innovation processes (Doorn 2012).

agency is an aggregate of individual agency. Here, however, I do not want to go into the possibility of group agency as a transcendent phenomemon, but rather explore whether it is possible to develop a less demanding notion of collective responsibility, which assumes that collective responsibility arises out of the aggregate activities and responsibilities of individual members of that collective. For instance, because one is part of an innovation process, a specific technological project, works for a specific company, or within a specific research field, one contributes to a collective venture which creates responsibilities for the impact of that project, company or field.

There are different ways in which such a notion of collective responsibility has become important in the context of technological development. For example, in the literature on responsible innovation, it is depicted as a collaborative effort. Stilgoe and colleagues state that responsible innovation means "… taking care of the future through collective stewardship of science and innovation in the present" (Stilgoe 2013, p.1570). For Von Schomberg, it is a "transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)" (Von Schomberg 2011). Within this framing, the engagement of scientists with society and the engagement of society with science become vital in innovation. Mutually responsive societal actors and innovators are expected to interact and share in the innovation process that results in technologies with the "right kind of impacts" (Von Schomberg 2014). Responsible innovation is then the outcome of a process in which a collective of individuals interact and engage with each other.

One of the problems with this view on collective responsibility is that its understanding of collectives is too general to allocate responsibility to. It suggests that everyone in society can be responsible for innovation processes in some way, when there are some important distinctions between people in terms of expertise, control and access to resources that determine whether we can allocate responsibility to them for ensuring innovation processes lead to desirable outcomes.

A related view on allocating collective responsibilities to scientists and engineers is that responsibilities follow from a social contract between science and society. "Science" as a whole has a contract with "Society" as a whole to act in society's interest (Glerup & Horst 2014; Hessels et al. 2009; Douglas 2003).

The basic tenet is that researchers and citizens differ significantly in terms of knowledge, skills and influence in relation to scientific and engineering research. Moreover, researchers only become experts because society supports them. Therefore, they have an (often implicit) social contract with society because the institutions of science depend to a large extent on the state, that is, on taxpayers' money and government institutions and infrastructure, and should therefore respond by contributing positively to society.

The social contract view offers an understanding of responsibility for the outcomes of science and technology that is more fine-grained than the responsible innovation view with respect to the allocation of responsibilities based on diversity (e.g. differences in expertise and access to resources). However, this view brings to the fore another challenge for collective responsibility; the demarcation of the collective. As we will see in chapter 4, the allocation of responsibility to collectives is often based on the possibility to demarcate a group or community based on shared goals, decision-making structures or another form of organization that structures the collective.

A problem with the social contract view is that the science-society relationship is portrayed as one between unified groups of people. However, both Society and science consist of a variety of different groups and individuals who all benefit from each other in different ways. For example, government funding from tax revenues is not evenly spread over scientific disciplines. Furthermore, scientists are part of society; the two are not mutually exclusive. The view also offers too much of a generalization, and, more importantly for the argument in this thesis it assumes the existence of clearly demarcated groups that we can allocate responsibility to.[3] The idea of social contracts between science and society offers an interesting heuristic for discussions on a societal level. However, if one wants to determine who should act upon uncertain risks within the broad categories of "Science" and "Society" it gives little to go by to identify particular groups or individual actors. This problem looms even larger in nanoscience and nanotechnology, as the identity of this field is only beginning to take form. No clear community, for example, in the form of an established research field or professional association, can be demarcated and assigned responsibilities (Spruit et al. 2016).

3 There are several authors who oppose the idea of a social contract for other reasons: they argue that a contract implies an active process of constructing a contract and an agreement or decision. This is typically not the case for social contracts.

The foregoing shows that it is not only difficult to fairly allocate responsibility to individuals, but that allocation of responsibility to collectives poses problems as well. My problem with allocating collective responsibility is not with the possibility of having a responsible collective *per se*; rather, the problem is that it needs some sort of structure that enables the sharing of responsibility and legitimizes allocating responsibility to that particular group of individuals. This suggests that in order to determine a viable allocation of responsibility for uncertain nanoparticle risks, it is necessary to reflect on the way people interact and collaborate in the field, and how this influences the capacity of individuals and groups to take responsibility for emerging hazards.

1.6. The social nature of responsibility

The previous section showed that it is often difficult to allocate responsibility for risks to individuals in innovation processes because they have a limited capacity to act or because their actions make little or no difference, while, at the same time, collective notions of responsibility are often too generalizing (as in the case of collective responsibility for responsible innovation) or assume the existence of unified groups (as in the idea of a contract between science and society), which hinders their use as a basis for allocating responsibility to the members of more diverse or loosely connected groups. This seems to suggest that the social context in which we act and the way we relate to each other is somehow only a hindrance to the allocation of responsibility. That, however, would be too hasty a conclusion. It would deny the social nature of responsibility itself.

May has argued that the notion of responsibility itself already takes into account the social context in which it functions; what somebody does and deems responsible is shaped and guided by the relationships we have with other people, and the groups of which we are part (May 1996). For example, he argues that the responsibility of a parent to take care of a sick child can override a more general responsibility towards society to educate university students (even though more people may benefit from this). What justifies overriding the teacher's responsibility with parental responsibility is the special relationship between parent and child. Responsibility is, according to May, also shaped by group identity. Being affiliated to a group or community not only shapes what a person perceives as their responsibilities but also shapes the moral expectations we have concerning that person's behavior. Nevertheless, different roles come with different moral expectations and the responsible person has to balance these expectations. One example is the responsibilities that an engineer has, as a member of a profession (to deliver good-quality work), towards their employer (to be loyal) and towards wider society (to produce products that are not harmful). These have to be balanced when a person is developing engineering products. In balancing their relationships and identities, individuals come to express responsibility.[4] In practice, this implies that what it means to take responsibility is multivocal and established in interaction with one's context. Additionally, acting responsibly is partly discretionary; it is up to the acting person to determine the appropriate way of responding to a situation. For example, we will see in this thesis that there are multiple strategies that are appropriate to respond to risks. It is precisely because the notion of responsibility entails responsiveness to the context in which one acts that makes it a valuable notion to use in discussions concerning uncertainty. Responsibility and uncertainty both require that one keeps track of the particularities of any given situation.

Responsibility thus seems to be established in the interaction with one's social environment. As May argues, individuals are "*both* passive recipients *and* active participants in the social milieu" (May 1996, p. 4). What responsibility individuals are allocated is thus also a product of the interaction between them and their social context.

1.7. Relationships and the allocation of responsibility

Much of May's book, *The Socially Responsive Self*, discusses responsibility as something that is constructed by individuals based on their group affiliations. Individuals have to respond to the values of the communities of which they are part. May discusses cases in which individuals take responsibility that seems counter to such group values, such as in the case of whistleblowing. Such actions may undermine solidarity with a specific group, but allow an individual to act on responsibilities towards other groups (e.g., to wider society). I do not want to

4 Indeed, this ultimately presupposes a more individualist notion of responsibility, as it assumes that ultimately only individuals have moral agency and can exert responsibility in managing their relationships and identities. I realize I disregard ample literature on the existence of collective agents. I do not want to go into discussion about the nature of agency and collective intentionality here, but simply assume that to deal responsibly with nanomaterial risks individuals need to act. However, this can be as part of an group as we have seen in the section 1.5.

explore the interaction between individual responsibility and group identity in this thesis, rather I want to follow up on May's second[5] suggestion: that responsibility is somehow responsive to the relationships we have with other people.

There is already literature in moral philosophy that reflects on the interaction between relationships and responsibility. For example, there is ample debate about whether duties can arise out of special relationships with people (Jeske 2014), such as duties of care stemming from the relationship between parents/carers and children. However, this often does not take into account the more interactive nature of responsibility that May is describing: that responsibility and relationships somehow shape each other. To be able to grasp this social shaping of responsibility, this thesis explores a relational view of responsibility inspired by the Ethics of Care. The Ethics of Care is a form of relational ethics that has mainly developed in Western philosophical literature (Metz & Miller 2016). Scholars working on an Ethics of Care have provided an account of how responsibilities are shaped and negotiated in relationships of dependency, power and vulnerability (Tronto 1993). Exploring the meaning of caring relationships (see Chapters 3 and 5), this body of literature has focused on the ethical issues surrounding relationships in family contexts (Ruddick 1980), education (Noddings 1985) and care for the disabled (Kittay 2011), as well as in democratic societies (Tronto 2013).

In this thesis, I do not aim to develop a comprehensive framework in line of the Ethics of Care, rather I use relational lens as a novel way to address the allocation of responsibility in engineering ethics: The view that determining whether someone is responsible does not solely require an *a priori* examination of their duties towards other people, it is established *in the interaction* with the person or object being cared for.

5 Social environments can encompass many more different aspects that may influence responsibility, such as political aspects, class differences, institutional elements, but for the sake of clarity I will focus on only one aspect within this thesis: the relationships an individual has with other people.

1.8. Research approach

1.8.1. Problem statement

Given the observations of May and Ethics of Care scholars, this thesis builds on the assumption that relationships play a role in the allocation of responsibility for the uncertain risks related to nanoparticles. It will explore how relationships and responsibilities interact and shape each other in the context of nanoparticle use and development. For example, there may already be specific relationships in place in a particular situation. In such cases, the allocation of responsibility could be based on these relationships; for example, that we allocate the responsibility to inform workers about the uncertain risks of nanomaterials to labor unions because they already have an established relationship, rather than, for example, allocating these responsibilities to governments. Another option may be to adjust or build relationships in order to be able to meet the responsibilities we would like to allocate to certain individuals. As nanoscience and nanotechnology constitute a relatively new field, institutional channels for knowledge-sharing about new risk information or about new best practices for handling nanoparticles may not yet be in place. In such cases, new relationships may allow, or may be needed for, the meeting of those responsibilities. In this thesis, I want to explore both directions (from relationships to responsibilities and vice versa), as well as consider the option that relationships and responsibilities can be mutually attuned to each other. Therefore, the main question of this thesis is:

> *How can relationships and responsibility be aligned in managing the uncertain risks of nanoparticles?*

Before we can align relationships and responsibilities, we must first examine how relationships may influence the allocation of responsibility for uncertain risks associated with nanoparticles. More specifically, we need to know whether there are particular qualities of relationships that play a role in the way we deal with uncertain risks, for example, how we manage them or make decisions about them. The first subquestion aims at establishing this:

> (1) *In what way do relationships matter when dealing with uncertain risks?*

The next question moves beyond the view that relationships, and the social environment we act in, are only a context in which responsibility is enacted. In such a view relationships may be seen as a hindrance to the allocation of individual responsibility; for example, that because the social environment in which someone lives limits individual actions, it therefore also limits the extent to which we can expect them to act responsibly. Instead, relationships can be approached more constructively. Relationships can be built and shaped in order to foster responsibility. Therefore, the second subquestion explores whether there may be a moral imperative to build relationships in light of the need for responsible management of uncertain risks associated with nanoparticles:

> (2) *Is there an obligation to build relationships in order to take responsibility for uncertain risks?*

If this question is answered positively (which it is under certain conditions, as we will see in Chapter 5), and we expect people to build relationships in order to take responsibility for uncertain risks, one has to wonder what these relationships might look like. This leads to the third and final subquestion:

> (3) *What characteristics should relationships have to foster responsibility for the uncertain risks of nanoparticles?*

Answers to these subquestions provide the building blocks in our response to the main question and will describe how relationships should be aligned in order to promote responsibility for the uncertain risks of nanoparticles.

1.8.2. Method

The aim of this thesis is primarily normative; however, its normative analysis is strongly empirically informed. Philosophical analysis is complemented with empirical insights from two case studies (Chapters 2 and 5). In Chapter 2, interviews, document research and observations are used to support a philosophical argument for the use of relational criteria in precautionary thinking. Chapter 3 systematically reviews the empirical literature on the qualities of relationships that are important in risk decisions, drawing from the fields of bioethics, the social sciences and psychology. Chapter 4 is based on a collaborative form of research with two ethically engaged nanotechnology researchers at the University of California, Berkeley. Using collaboration as a form of research (see

Calvert 2014), this chapter explores whether an absence of relationships in the working environments of the two collaborating researchers gives rise to a duty to collectivize, that is, a duty to form relationships in order to act upon any emerging risks.

This thesis also uses literature from feminist philosophy, in particular the literature on the Ethics of Care. In relation to the sharing of responsibility, in particular, it uses notions of collective responsibility. These concepts are applied to problems and ideas in science and engineering ethics. For example, Chapter 2 develops the thinking on the precautionary principle – which is a well-established principle in environmental policy – on the basis of an Ethics of Care. Something similar is done in Chapter 5, which explores the possibility of caring relationships in science and engineering contexts. Chapter 3 brings the concept of relational autonomy from feminist philosophy into engineering ethics and nanoethics, while Chapter 4 is based on general theories of individual and collective responsibility applied to an engineering setting.

1.8.3. Actors and relationships in nanoparticle innovation

What kinds of relationships are relevant when it comes to managing the uncertain risks of nanoparticles? As discussed above, nanoparticles are used in a variety of products and applications. Therefore, the uncertain risks of nanoparticles are dealt with by a variety of people in a variety of relationships, ranging from researchers and developers to end users. This section will give a brief overview of the actors that play a role at various stages of nanomaterial development and what relationships they have.

Researchers: Typically, research in the field of nanoscience and nanotechnology[6] takes place in universities. A study from 2013 shows that the United States, China and Japan rank high in terms of research impact in this field, with the Netherlands listed fourteenth worldwide (Leydesdorff 2013). Much of the research work has been interdisciplinary (Guston 2010), with research often not taking place in a nanoscience or nanotechnology department, and often being dispersed over university campuses and different engineering fields (see Chapter 4).

6 Some of the data and references in this section concern nanoscience and nanotechnology more generally, as nanoparticle-specific data are sometimes lacking, but I take it that these provide an indication with regard to the nanoparticle context.

Research funders: Research in nanoscience and nanotechnology has been heavily supported by national governments. This has led to dedicated research efforts in this field, such as the National Nanotechnology Initiative in the US (National Science and Technology Council 2014) and the Dutch NanoNextNL program (Cunningham & Werker 2012). Such programs have often generated high research outputs (Wang et al. 2015).

Nanoparticle developers: The European office lists more than 10,000 patents on nanotechnology products worldwide, 5,292 of which have nanoparticles as their main component, and/or make use of or provide a precursor for nanoparticles.[7] These patents have been filed by both public (university, government) institutions and companies.

Nanoparticle producers: Several multinationals are known to develop nanoparticles, such as DuPont (Krabbenborg 2013), BASF (BASF 2013; BASF n.d.) and DSM (DSM 2013). Many of the production activities that take place within universities have been on a relatively small scale (Aitken et al. 2006), although recent numbers are lacking. Within organizations that develop and produce nanoparticles, workers may be exposed to occupational health and safety risks due to longer term exposure to nanoparticles.

End-users: Nanoparticles are often not stand alone products, but are applied in all sorts of contexts. There are several known applications of nanoparticles in consumer products such as clothing, cosmetics, kitchen utensils and electronics (see, for example Danish Consumer Council et al. 2013). In addition to end-users and producers, it is expected that there are a number of business-to-business traders also involved in this field.

Not-for-profit organizations: Not-for-profit organizations such as labor unions and environmental organizations have been actively involved in discussions concerning the risks of nanoparticles; for example, the Environmental Defense Fund has been involved in the drawing up of a risk framework for nanoparticles (Krabbenborg 2013), while the labor unions have been involved in discussions concerning the exposure of workers to the alleged risks of nanoparticles (see Chapter 3 of this thesis).

Citizens: As consumers, citizens are confronted with the potential risks of the products they buy (see discussion in Chapter 2), or they may be exposed to risks

7 Search via https://worldwide.espacenet.com on June 30, 2006. Search keys: Cooperative Patent Classification B82Y, keyword ‘nanoparticle’ in abstract and/or title.

by other people who use or develop products with nanoparticles (Van de Poel & Spruit 2013).

Regulators: There are several governmental bodies regulating nanoparticle risks at the national and international levels. Nanoparticles currently fall under several existing regulations at national and international (EU) levels: the environmental and health risks of nanoparticles are part of the European REACH framework; European biocides regulation covers particular biocidal nanomaterials; in general, the safety of consumer products falls under product liability regulations; and occupational risks fall under OHS regulations (see Chapter 3). As a result, there are many different regulating and supervising organizations.

Risk assessors: Significant attention to nanoparticle risks in early phases of nanotechnology development has led to research programs, for example, the above-mentioned NanoNextNL, focusing on identifying and assessing those risks. In this context, while some programs mainly conduct laboratory or other forms of research, other programs are active in relation to the management and governance of these risks. For example, the Dutch KIR-Nano centre has been active in exchanging information and building a network around nanotechnologies (see Chapter 3).

Given the wide range of actors involved in this field, it can be expected that there is considerable variation in the ways that these people relate to each other. For example, some actors actively share information, with risk scholars sharing information with regulators and nanoparticle users, while researchers and developers share information about risks along the value chain. Others have more financially based relationships, with researchers relying on funders, while producers and users (consumers) have market-based relationships. Within companies, workers will have labor relationships with their employers. In this thesis, I do not want to limit my analysis to one particular type of relationship. Rather, I want to explore how qualitatively different relationships will require different alignments with responsibility. Within this thesis, I will focus in particular on: relationships between producers and consumers of products deemed to have risks (Chapters 2 and 5); relationships between employers and employees who work with risks (Chapters 2 and 3); relationships amongst researchers and innovators (Chapter 4); and relationships between developers and the wider society (Chapter 5). These specific kinds of relationships are highlighted at various moments in the thesis. However, the conclusion presents a discussion at a more general level, concerning the alignment of relationships and responsibility in managing uncertain risks associated with nanoparticles.

1.9. Outline

The four research chapters of this thesis were written as journal articles. The abstracts of these articles are presented below. Chapters 2, 3 and 4 have been published (citations are provided in the footnotes), while Chapter 5 is currently under review. Chapters 2 and 4 are the result collaborations and are therefore co-authored. For both of these chapters, the majority of the text and the main philosophical idea were produced by the author of this thesis.

Chapter 2: Informed consent in asymmetrical relationships: An investigation into relational factors that influence room for reflection[8]

In recent years, informed consent has been suggested as a way to deal with risks posed by engineered nanoparticles. We argue that while we can learn from experiences with informed consent in treatment and research contexts, we should be aware that informed consent traditionally pertains to certain features of the relationships between doctors and patients, and researchers and research participants, rather than those between producers and consumers, and employers and employees, which are more prominent in the case of engineered nanoparticles. To better understand these differences, we identify three major relational factors that influence whether valid informed consent is obtainable, namely dependency, personal proximity, and existence of shared interests. We show that each type of relationship offers different opportunities for reflection, and therefore poses distinct challenges for obtaining valid informed consent. Our analysis offers a systematic understanding of the possibilities for attaining informed consent in the context of nanoparticle risks, and makes clear that measures or regulations to improve the obtainment of informed consent should be attuned to the specific interpersonal relations to which it is supposed to apply.

8 This chapter has been published as Spruit, S.L., Van de Poel, I. & Doorn, N., (2016). Informed Consent in Asymmetrical Relationships: An Investigation into Relational Factors that Influence Room for Reflection. NanoEthics. Available at: http://link.springer.com/10.1007/s11569-016-0262-5

Chapter 3: Choosing between precautions for nanoparticles in the workplace: Complementing the precautionary principle with caring[9]

Workers who develop and use nanoparticles are on the front line of exposure to the purported risks of nanoparticles. Employers have a legal duty to protect their employees against any work-related harm. However, it is difficult to perform the required risk assessment and management when dealing with uncertainty. Risk ethicists have therefore argued for using the precautionary principle to guide such decisions on uncertain risks. This paper argues that if we want to make use of innovative products, such as nanoparticles, but lack the knowledge and shared standards for choosing between protective measures, the precautionary principle is underdetermined. For the use of nanoparticles in work environments, there are several guidelines that suggest different precautionary strategies for dealing with their purported risks, but choosing between these guidelines proves difficult in the absence of a clear, scientific decision principle. Therefore, the paper explores the Ethics of Care to develop a complementary decision criterion for the precautionary principle. From this perspective, the caring qualities of work relationships are key in comparing precautions with each other. Three conditions for assessing risk management strategies are proposed based on 1) the existence of a mutual concern for employee health and safety, 2) the connectedness and continuity of the relationships between employer and employee, and 3) the responsiveness of employers to employee needs. Using these criteria will support choosing between precautions, by shifting attention from the acceptability of imposing a risk to creating a social context in which the imposition of the residual risks can be considered acceptable.

Chapter 4: Just a cog in the machine? The individual responsibility of researchers in nanotechnology is a duty to collectivize[10]

Responsible Research and Innovation (RRI) provides a framework for judging the ethical qualities of innovation processes; however, guidance for researchers

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9 This chapter has been published as Spruit, S. L. (2015). Choosing between precautions for nanoparticles in the workplace: complementing the precautionary principle with caring. Journal of Risk Research, 1-21. doi: 10.1080/13669877.2015.1043574

10 This chapter has been published as Spruit, S.L., Hoople, G.D. & Rolfe, D.A., (2016). Just a Cog in the Machine? The Individual Responsibility of Researchers in Nanotechnology is a Duty to Collectivize. Science and engineering ethics. Available at: http://www.ncbi.nlm.nih.gov/pubmed/26538353.

on how to implement such practices is limited. Exploring RRI in the context of nanotechnology, this paper examines how the dispersed and interdisciplinary nature of the nanotechnology field somewhat hampers the abilities of individual researchers to control the innovation process. The ad-hoc nature of the field of nanotechnology, with its fluid boundaries and elusive membership, has thus far failed to establish a strong collective agent, such as a professional organization, through which researchers could collectively steer technological development in light of social and environmental needs. In this case, individual researchers cannot innovate responsibly purely by themselves, but there is also no structural framework to ensure that responsible development of nanotechnologies takes place. We argue that, in such a case, individual researchers have a duty to collectivize. In short, researchers in situations where it is challenging for individuals to achieve the goals of RRI are compelled to develop organizations to facilitate RRI. In this paper, we establish and discuss the criteria under which individual researchers have this duty to collectivize.

Chapter 5: Taking care of innovation: a framework for characterizing caring relationships and networks in RRI

Several authors have suggested rethinking the notion of responsibility as a form of care in Responsible Research and Innovation (RRI). This paper explores an aspect of care that has been touched upon by some of these authors, but that is underdeveloped in RRI discourse: the relational nature of care. A comprehensive framework is lacking that describes what characteristics relationships in RRI should have if they are to be considered caring. Therefore, this chapter takes a first step in developing a framework to assess caring relationships in innovation practices. To this end, it discusses the role of relationships in moral theory, with a view to deepening our understanding of the moral significance of relationships. It then introduces the notion of caring relationships from the Ethics of Care literature. To move beyond a simplistic dyadic view on caring relationships that is unfitting for innovation contexts, a framework for describing networked caring relationships is developed that enables us to analyze networks of innovators in terms of the role they play in caring (i.e., the role of care-giver, care-receiver, provider, claimant and doulia). Next, the paper develops a way to describe particular relationships using six characteristics derived from the Ethics of Care literature that are important for assessing whether relationships can be considered caring: dependence, power, attention, responsiveness, emotional engagement and availability. The usefulness of this framework is tested in an empirical case study: the use of nanoparticles for land remediation. Three conceptual challenges were identified: (1) the limitations of the relational characteristics with respect to relationships between people who have roles other than the care-giver and care-receiver; (2) the fact that care is a side-constraint rather than a goal of innovation practices; and (3) the scope of caring networks.

Chapter 6, the concluding chapter, will respond to the main research question and discuss in principle how relationships and responsibility can be aligned. The generalizability and limitations of the findings will be discussed and the implications of my findings for policy on Responsible Research and Innovation will be reflected upon.

2 Informed consent in asymmetrical relationships: An investigation into relational factors that influence room for reflection[11]

The aim of this thesis is to investigate how the responsibility for the uncertain risks of nanomaterials can be aligned to the relationships in which those risks arise. However, it is often unclear how relationships matter when dealing with the uncertain risks of nanomaterials. Therefore, the aim of this chapter is to describe how relationships influence decision-making about acceptable exposure to uncertain nanomaterial risks. This will be explored in the light of suggestions made by Shrader-Frechette (2007) and Jacobs, Van de Poel and Osseweijer (2010) to use informed consent as a principle to decide about the acceptability of exposure of individuals to uncertain nanomaterial risks. As we will see in Section 2.2, informed consent is a principle that originated in a medical context. This means that the relationships in which informed consent traditionally functions, that of the doctor-patient and researcher-research participant relationships, differ from market and labor relationships that are important when it comes to nanoproducts. Therefore, Section 2.3 develops a framework to describe the differences between different kinds of relationships in terms of three relational factors: dependency, personal proximity and the existence of shared interests. Section 2.4 explores how these relational factors manifest themselves in relationships between consumers and producers and employers and employees who come into contact with nanomaterials. The chapter concludes with a reflection on how informed consent can accommodate such differences between relationships in the context of nanomaterial risks.

11 This chapter has been published as Spruit, S.L., Van de Poel, I. & Doorn, N. (2016) Informed Consent in Asymmetrical Relationships: An Investigation into Relational Factors that Influence Room for Reflection. NanoEthics. Available at: http://link.springer.com/10.1007/s11569-016-0262-5

2.1. Introduction

The notion of informed consent has major significance when dealing with the risks associated with medical treatment and experimentation. The main idea behind informed consent is that individuals should be able to make their own knowledgeable and voluntary decisions concerning their exposure to potential dangers, thereby emphasizing the importance of individual autonomy and responsibility for balancing risks and benefits. In this paper, we discuss the application of informed consent to engineered nanomaterial risks. To do justice to the different social context in which nanomaterial risks emerge, we explore how social relations influence the validity of informed consent.

Toxicologists, risk assessors, and environmental scientists have not yet reached consensus on the alleged hazardous effects of newly engineered nanoparticles and nanostructured materials (from now on "nanomaterials"[12]). Innovation in fields such as material sciences, chemistry, and physics has led to the possibility to create and manipulate matter on the nanoscale. This has led to the production of nanomaterials with economically promising new traits such as a higher reactivity, different polarity, and increased mobility. However, the identification and evaluation of these materials is problematic due to a general lack of knowledge about them and of how they interact with the environment. Furthermore, limitations in measurement techniques have made formulating occupational exposure limits difficult (Schulte et al. 2010). Nevertheless, caution is advised, especially in the occupational context, due to the potential risk to human health and safety (Van Broekhuizen & Reijnders 2011; Gezondheidsraad 2012; Spruit 2015).

In response to this uncertainty about hazards, several authors have suggested that informed consent may be applied to decisions on the desirability of new nanomaterials. It has been argued that nanomaterials are experimental in the sense that the impact of these risks may become fully clear only after these new materials have been introduced into society (Van de Poel 2009; Jacobs et al. 2010). Although there is much uncertainty about the risks posed by nanomaterials, they are now regularly introduced into the environment and society (Dekkers

[12] This paper focusses on nanomaterials that are intentionally produced as active nano-sized materials. We acknowledge that there is strong overlap in the toxic properties such materials may have with naturally occurring or process generated nanomaterials, therefore much of the discussion that follows will be applicable to these materials as well.

et al. 2007; Danish Consumer Council et al. 2013). In that respect, informed consent may be an interesting model to judge the acceptability of such social experiments with nanomaterials. And indeed, proponents of informed consent in the context of nanomaterials argue that it would be better to obtain some form of consent from citizens, allowing them to decide whether they are willing to be exposed to the risks posed by these technological products. Shrader-Frechette considered this one of the primary duties of government in regulating nanomaterials, arguing that they must "… help citizens attain their rights to free informed consent to nano-related risks (Shrader-Frechette 2007, pp 49)." Similar suggestions were made by Jacobs and colleagues (Jacobs et al. 2010), who considered the absence of genuine consent in relation to the risks posed by nano titanium dioxide to be a topic of ethical concern.

Informed consent is an established principle to deal with risks in the field of medicine (Faden & Beauchamp 1986; Weindling 2001; Manson & O'Neill 2007), but its translation to the use of nanomaterials is not straightforward. An objection to the use of informed consent for nanomaterials may be the uncertainty that accompanies these materials. Consent cannot be informed if it has no solid knowledge base, something that seems to be exactly missing in the case of nanomaterials. Without sufficient knowledge about what the risks of nanomaterials are it may be hard to balance them against their alleged benefits and come to valid informed consent. Each medical product will have gone through extensive testing before it enters the market, whereas risk assessment of nanomaterials is hardly sufficient to cover all products developed in this emerging technological field (Choi et al. 2009). However, at closer examination the differences are less clear. After introduction to the market, many drugs present unexpected side-effects and unanticipated interactions (Wieczerzak et al. 2015), making informed consent in a treatment context sensitive to uncertainty as well. Participants in clinical trials are confronted with even more uncertainty when they decide to be subjected to experimental drugs. Therefore, uncertainty accompanying nanomaterials is in our view not a principled reason to refrain from the implementation of informed consent in the governance of nanomaterials. Rather, dealing with uncertainty requires an open dialogue about potential side-effects and the limitations of knowledge thereof, that is central in informed consent procedures.

Nevertheless, the context in which informed consent is traditionally used and developed – namely the medical field – differs from the context in which most nanomaterials are used (Asveld 2006). Drug use and medical research is more highly regulated than the production and application of nanomaterials that are characterized by regulatory gaps (Beaudrie et al. 2013; Godwin et al. 2015; Falkner & Jaspers 2012). Additionally, while the need for medical treatment and the development of new drugs is often taken for granted, the benefit of nano-enabled products is less evident (Gupta et al.). Furthermore, in medical treatment and research the application of potentially hazardous materials is relatively contained; medicines are administered to individual humans, whereas nanomaterials may be used in a variety of consumer products and settings ranging from sports equipment, building materials to shoe polish (Woodrow Wilson International Center for Scholars 2013; Danish Consumer Council et al. 2013). Unlike individual risk-taking in medical contexts, exposure to nanomaterials is more collective in nature which renders informed consent unsuitable (Hansson 2006). However, this is not the case for all exposure to risky nanomaterials. In this paper, we look at individual market transactions and workplace exposure to risky nanomaterials both of which are situations that Hansson identifies as those in which informed consent could potentially be obtained (Hansson 2006).

Our focus is on one specific difference between the medical context of treatment and research and the wider context in which nanomaterials are applied: the relationships between those who produce risks and those who are exposed to them. We assess how differences in relationships may affect the obtainment of informed consent. We look at the risks posed by nanomaterials and the main challenges for achieving informed consent in two settings in which nanomaterials are handled. Workers are amongst the first people to be exposed to new nanomaterials, and their relationship with their employer influences the voluntariness of that exposure. Although a consumer's decision to buy a product containing nanomaterials may be considered a form of consenting to nanomaterial risk, the quality of the relationship with the producer – for example, whether the relationship is transparent or more distant – influences the transfer of information about risks. By exploring the characteristics of the producer–consumer and the employer–employee relationship, and the opportunities these relationships provide to obtain informed consent as well as the constraints they place on doing so, we are able to say more about how informed consent may, or may not, be obtained for the risks posed by new technologies.

We build on the idea that, in practice, the qualities of interpersonal and social relationships[13] influence the obtainment of valid informed consent. Differences in power, knowledge, and influence may require a different interpretation or operationalization of informed consent in non-traditional contexts Several authors acknowledge the importance of the relational setting for informed consent (Schuck 1994; Mills et al. 2006; Burgess 2007; Bell & Ho 2011; Kamuya et al. 2011). A detailed analysis of exactly which characteristics of relationships influence the obtainment of valid informed consent outside of treatment or research relationships is, however, lacking. Recognizing the relational influences on informed consent may assist us either to conclude that informed consent is not feasible in the context of technological risks, or to adapt the notion of informed consent to certain contextual constraints while maintaining its normative core.

In this paper, we first discuss informed consent in terms of its various components: competence and voluntariness, the transfer and understanding of information, and the ability to make an individual choice. We then expand this view by presenting informed consent as functioning in and being the product of a particular relationship. We draw from academic literature to identify which aspects of relationships (mainly in medical or research settings) are known to affect informed consent. Based on these findings, we present a more detailed characterization of the relationships between producer and consumer, and between employer and employee. We conclude with a discussion about how best to take such relational aspects into account when conceiving of informed consent in the context of the risks posed by nanomaterials.

2.2. Informed consent in context

The practice of informed consent has its roots in the medical context. Informed consent refers to the process of getting permission before a healthcare intervention can be conducted on a person. It is one of the fundamental ethical principles in both clinical treatment (medical ethics) and clinical research

13 In social scientific literature, the term "social relations" is often used to refer to more abstract notions of relationships, e.g. relations between classes and social groups. Personal relationships are more direct, and often imply informal connections. This paper uses "relationship" to refer to relationships broadly construed, including both formal and information, and distant and proximate relationships.

(research ethics). Informed consent functions within a broader regulatory framework as a legal safeguard to protect the patient's individual autonomy (Dolgin 2010). However, this paper focuses on informed consent as an answer to the moral intuition that many people share, namely that people have the right to know what risks they are being subject to, and the right to freely choose which risks they are willing to be subject to and which ones they do not wish to be subject to.

In medical and research ethics, attempts have been made to define the elements that constitute informed consent. Although there are different classifications, the following elements are generally considered to capture the basic notion of informed consent: a "threshold component," an information component, and a consent component (Meisel 1981; Meisel et al. 1977; Berg et al. 2001). The threshold component indicates the preconditions for informed consent, including the competence of patients and research participants for independent decision-making and the voluntariness (i.e., the absence of coercion) of their decisions. The information component comprises standards for disclosure of information by doctors, as well as patients' understanding of that information. Discussions concerning the consent component include the conditions under which a decision can be considered valid. For example, is a procedurally correct decision sufficient, or does it refer to "an individual's *autonomous authorization* of a medical intervention or of participation in research"? (italics in original; Beauchamp & Childress 2001, pp 78)

These components of informed consent set conditions for reasoning capacities, information transfer, and control thereby ensuring individual capacity to autonomously choose medical procedures or research participation. However, the literature on the various components of informed consent reveals that the ideal case of a "purely autonomous individual" – one who independently informs herself and makes an independent decision based on her own assessment of the desirability of her exposure to risks – often does not exist in practice. For Buehler (Buehler 1982), this is a case of "wishful thinking," since patients primarily make medical decisions in close consultation with their doctors. The professional is also strongly involved in the information component as she has to ensure that the patient has received sufficient information and reached a full understanding to make an autonomous decision (Beauchamp & Childress 2001). But also framing effects or informational manipulation may lead to patients being influenced by doctors when information is presented or framed in such a way that the patient is directed toward a particular choice thereby threatening the possibility of voluntariness (Malenka et al. 1993; Edwards et al. 2001). Such influence is not, of course, only internal to the doctor–patient relationship. Third parties, social expectations, and pressure may also pose a threat to the validity of informed consent (Millum 2014). For example, expectations about gender roles have been shown to influence women who consented to gynecological interventions even though they did not really agree with the medical procedures (Dixon-Woods et al. 2006).

Most, if not all, decisions are not the mere result of individual reasoning based on individual capacity but are shaped by a social context consisting of personal, family, and professional relationships. This observation has led people to argue that we should conceive of autonomy not as an individual capacity but as a relational notion (Mackenzie & Stoljar 2000), shifting attention to the interpersonal dynamics that underlie individual decision making. Certain kinds of relationships may impede with individuals' ability to make independent decisions, whereas others facilitate and foster voluntary and informed decision-making. This goes beyond direct interference. Proponents of this notion of relational autonomy have argued that even our conception of autonomous choice is itself shaped by, and is the product of, a specific social context in which we live. Relationships with parents, teachers, friends, etc. shape our identity, our capacities, and our understanding of ourselves as autonomous individuals (Nedelsky 1989). If socialization is oppressive this may be detrimental to the ability of people to reflect on their options. McLeod and Sherwin for example argue that being members of oppressed groups, such as immigrant communities, in the long run leads to reduced self-trust and can undermine group members' capacities for autonomous choice in medical settings (McLeod & Sherwin 2000).

If we take seriously the claim that social relationships shape autonomy to a great extent, then we need a conception of informed consent that is sensitive to the relational context in which it functions. Therefore, the remainder of this paper will be a first step in developing a relational approach to informed consent for nanomaterial risks. We maintain that the quality of informed consent can be assessed not only in terms of individual capacity, but also as the product of a specific relationship and the characteristics of the relationship in which it functions.

A key notion here is reflection: the validity of informed consent depends on the room for individuals to reflect on the influence of their surroundings, and the quality of that reflection. Christman argues that as long as a person

"... maintains the ability to adequately reflect on ... [her] conditions and embrace them ... we should continue to label her autonomous" (Christman 2011, pp 155). This means that compliance with a social setting, with its norms and values, or even obedience to others, can be considered autonomous as long as an individual makes this choice after having reflected on it. This, of course, presupposes that an individual has an actual choice and the liberty to make that choice (Berghmans 2011). Reflection cannot compensate for an absence of alternatives. However, we know that reflection itself is susceptible to socialization. The focus of our discussion here will not be on what makes up qualitatively good reflection, and what influence socialization should or should not have, this goes beyond the scope of this paper. Nonetheless, our discussion will show that several characteristics of relationships can contribute positively to empowering individuals that may have been silenced or rendered powerless.

Indeed, we will develop a more procedural approach with a focus on the context of decision-making rather than a substantive approach that would define what autonomy actually entails and what type of behavior or thoughts are necessary for autonomous choice[14]. Several authors have argued for something similar (Mackenzie & Stoljar 2000; Bell & Ho 2011) but not in the context of nanomaterial usage. In the following, we expand this procedural relational approach to informed consent with a view to informing a debate about the desirability of informed consent for dealing with nanomaterial risks. The next section discusses a characterization of relationships in order to examine in more

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14 This chapter builds on an conception of autonomy as self-rule or self-governance. In the literature there are two ways in which this notion of autonomy can be assessed (Christman 2011); (1) by assessing one's competencies, for example to assess whether one has the cognitive abilities to make independent choices, and (2) by assessing the authenticity of the decisions one make, for example by assessing whether the decision is in some way "one's own" and not externally influenced. Whereas some approaches to autonomy side with one of these approaches (either describe individual abilities that make up autonomous behavior or set limits to external influence), the notion of relational autonomy developed in this paper incorporates elements of both the competency and the authenticity view. It recognizes that one's relationships with other people may both support an individual's ability to make her own decisions, for example through education, as well as constrain the authenticity of that person for example by imposing values or oppressing views. However, in linking to different components of Informed Consent (competence and voluntariness, the transfer and understanding of information, and the ability to make an individual choice), it also includes elements from the competency view.

detail the ways in which relationships affect room for reflection and thereby the validity of informed consent in consenting to risks.

2.3. Informed consent decisions in different types of relationships

A range of relationships may be at play in informed consent decisions. Here, we model these relationships as an example of a dyadic relationship between a risk-imposer and a risk-bearer. The basic idea is that one party (the risk-imposer) introduces a risk that is borne by another party (the risk-bearer). At present, informed consent means that the risk-imposer is allowed to introduce a risk if, and only if, the risk-bearer has given her informed consent to the introduction of the risk. This is obviously a simplification of the various relationships that are at play in informed consent. However, this approach is helpful in establishing some of the structural differences between relationships in which informed consent has already been studied extensively – that is, those between doctor and patient and between researcher and research participant – and relationships in which informed consent is less studied, namely those between producers and consumers and between employers and employees, and that are relevant to the case of exposure to nanomaterial risks.

This section proposes a framework for characterizing the relationship between risk-imposer and risk-bearer that is based on the literature on doctor–patient and researcher–research participant relationships. We also discuss how structural differences between relationships allow for more or less room for reflection, and thereby influence the validity of informed consent. In section 5, we use this framework to characterize the relationships between producers and consumers and between employers and employees.

2.3.1. Ideal-typical relationships in medicine and research settings

Although many authors emphasize the importance of relationships in arriving at autonomous decisions, they have largely left the nature of these relationships undiscussed. Nevertheless, some typologies have been proposed to capture the structural differences between the relationships in which informed consent decisions are made. The ideal types discussed in this section refer to various forms and dimensions of control between patients and doctors, and investigators and subjects. In these models, actors exert influence at different levels and in different ways in relation to different expressions of autonomy.

	Paternalism	**Informative/ consumer**	**Interpretive**	**Deliberative**
Who has control over the informa-tion?	Doctor	Doctor actively shares all information with patient	Doctor about medical information, patient about own values	Both share and exchange information, although doctor has medical expertise
Who makes the decision?	Doctor	Patient chooses; doctor has to accept pa-tient's preferences	Doctor helps patient as consultant to discover own preferences and values	Patient and doctor deliberate together, although the patient makes the final decision

Table 2.1. The table summarizes the models of medical treatment relationships, based on the work of Emanuel & Emanuel (1992). The columns represent different ways of dividing responsibilities for medical decision-making. Even though some models, such as the informative model, ascribe a smaller role to doctors in making the decision, they may still highly influence it by presenting information in a particular way.

Ezekiel and Linda Emanuel offer a well-known typology that distinguishes four models of the doctor–patient relationship (Emanuel & Emanuel 1992). The first, the “paternalistic” model, describes a doctor who is considered the patient’s guardian, treating the patient in a way that is deemed medically correct, with the patient simply assenting to the doctor’s decision. In the “informative” or “consumer” model, the doctor provides the patient with all the relevant information and leaves the decision-making to the patient. This model offers more autonomy than the paternalistic model as patients are seen as actively making decisions rather than simply following the doctor’s advice. There have been objections to this model, however, because it makes the role of the doctor too technical and lacks a “caring approach” (Oprea 2013). This objection is overcome in the “interpretive” model, where the doctor helps the patient to reflect on her own values and decide what she wants. In this case, the doctor acts more as a consultant or therapist. Emanuel and Emanuel's fourth model, the "deliberative" model, is more symmetrical: the doctor actively discusses treatment with the patient, who uses the doctor's expert knowledge but also actively engages in her own treatment process.

The main distinguishing factor between the ideal types described by Emanuel and Emanuel seems to be the level of control over medical decisions (see Table 2.1). More paternalistic models leave little room for patient agency whereas the interpretive and informative models emphasize patients' individual freedom of choice. Even though some models, such as the informative model, ascribe a smaller role to doctors in the actual making of a decision, they may still be highly influential through the way they present information. These "framing effects" can be very powerful sometimes even creating anxiety and harming patients (Wells & Kaptchuk 2012).

Other ideal types that have been developed in research environments show that differences in the relationship between researcher and research participant are multidimensional and potentially asymmetrical in various ways. Philosopher Joan Cassel (Cassell 1980) developed a typology of research relationships to assess the appropriateness of ethical principles in those relationships (Table 2.2). She distinguished between research relationships in different fields showing how they vary in terms of the researcher's power and control over the research setting and context as well as the direction of the research interaction. Experimental biomedical researchers have a lot more power and control over their research participants compared to anthropological field workers who use such methods as participant observation. In biomedical experimentation, researchers define the experimental setting and determine what the participant should do. This is much less the case in social sciences research in which the research participants have much more agency because the research takes place in their own social settings, and methods of participant observation require minimal interference by the researcher (for example (Mulder et al. 2000). Finally, the direction of interaction in research is a further important distinguishing factor. Participants in biomedical, psychological, and survey research have very limited interaction with the researcher (they basically provide answers and/or information) while in anthropological fieldwork the participants often actively steer the research and have a much more equal role in communication. A limitation of this typology is that it does not specify what characteristics of relationships allow for more or less control or more or less power on both sides.

Dimension of control	**Biomedical experi-mentation**	**Psychological experi-mentation**	**Survey research**	**Fieldwork (participant observation)**
Investigators' power as perceived by participants	High	High-medium	Medium-low	Equal
Investigators' control over research setting	High	High-low	None	Negative control by participants
Investigators' control over context of research	High	High	Medium-low	Equal
Direction of research interaction	One-way: investi-gator examines research participant	One-way: investigator examines research participant	Limited two-way: in the case of unstructured surveys (inter-views), participant can interact more freely with investigator	Two-way: investigator and partici-pant strongly influence each other

Table 2.2. An overview of influence and control in research relationships, adopted with minor adjustments from Cassel (1980).

2.3.2. Relational factors that influence informed consent

To clarify which characteristics of relationships allow the risk-bearer to be more autonomous, we need a more detailed conception of what constitutes these relationships. Therefore, this section presents empirical literature from bio-ethics, the social sciences, and law on the relational characteristics that influence informed consent practices or similar kinds of decisions. We look at three types of relational factors: (1) dependency, (2) personal proximity, and (3) shared interests. This information can provide us with insight into the relationship between informed consent and the social context of its application, in general, as well as deepen our understanding of which aspects of relationships may be supportive of or disruptive to relational autonomy.

Dependency

Asymmetry in expertise and knowledge concerning the risks associated with products and treatments makes risk-bearers dependent on risk-imposers for disclosure and an understanding of the information. Risk-imposers and risk-bearers often do not have the same information about the risks of an intervention or drug or about exposure to dangerous substances. According to Faden and Beauchamp (Faden & Beauchamp 1986), the main obstacle to informed consent in the medical context is informational manipulation which occurs when information is presented or framed in such a way that the patient is directed toward a particular choice (Faden & Beauchamp 1986; Bromwich 2012; Burrow 2012). This can be done because there are often great inequalities in the information available to patients and doctors – this is known as "informational asymmetry" (Schuck 1994) – with patients often depending on doctors for access to, and the interpretation of, risk information. Aside from dependency in the provision of information, there may also be a difference in the capacity of risk-bearers to understand the information provided by doctors and researchers (Fortney 1999), for instance due to illness (Benson et al. 1988; Behrendt et al. 2011) or simply the patients' lack of expertise.

Dependencies – such as informational asymmetry and risk-bearers' dependency in understanding risk information – may give rise to situations in which the obtainment of informed consent is strongly influenced by the power relation between risk-imposer and risk-bearer. The existence of power is almost by definition relational: Power exists only by virtue of there being somebody to influence or control with that power. In medical practice, doctors can exert considerable influence over medical decisions by, for example, imposing their values. Coercion is not at all uncommon in medical practice (see, for example Bauduin 2004; Zigmond 2011; Burrow 2012; Farnan et al. 2010). Furthermore, doctors are important gatekeepers for medical treatment and medical resources.

Personal proximity

The ties between the risk-imposer and the risk-bearer have become increasingly closer in research and medical practice. According to Miller and Boulton (Miller

& Boulton 2007), research relationships in the social sciences have become much more personal and conversations have become more dialogical. Researchers sometimes develop what are known as “fake friendships” with participants, immersing themselves in the field through participant observation resulting in very open contact.

A similar phenomenon can be seen in the medical field, where doctors and patients need common ground to discuss the course of treatment. For example, shared values are said to be very important in meeting patients’ physical and psychological needs (Veatch 1995). It may also be important for doctors to become familiar with their patients’ frames of reference and values to understand why their patients turn to alternative treatments that, medically speaking, may not be the best choice. Additionally, close bonds also seem to positively influence information transfer and genuine understanding as a personal and trusting relationship positively influences the understanding of medical information (De Melo-Martín & Ho 2008).

Furthermore, the continuity of therapeutic and research ties may interfere with the validity of consent. Doctor–patient interactions can be seen as long-term commitments rather than as one-off decisions to arrive at a form of consent (Schuck 1994). These relationships are built over time: a doctor monitors a patient’s health and may change the treatment regime as required. Something similar is seen in sociological and anthropological research. For example, in participant observation there is an ongoing interaction between the researcher and the participant (Thorne 1980). On the one hand, building strong and long-term bonds in the field is often inherent in being a good social researcher. On the other hand, individuals may feel pressured to make choices that maintain their relationship with, for example, health professionals thus threatening the voluntariness of their consent (Kamuya et al. 2011).

Therefore, informed consent procedures must achieve a balance between closeness and distance. Informed consent is often presented as an alienating, formalized practice that can be very impersonal and highly bureaucratized. For instance, according to Clarke (Clarke 2003), many informed consent procedures have become formalized decisions that may leave little room for questions and dialogue. Miller and Boulton (Miller & Boulton 2007) also observed a strong standardization of ethical and informed consent procedures in the social sciences. However, this does not always need to be an issue. For instance, in social science research there is often no clear moment of initiation or involvement in a study (Mattingly 2005). Especially when using participant observation, a research participant is unlikely to be directly asked for her informed consent (Burgess 2007). There seems to be no clearly demarcated moment for doing so and, in this respect, increasing formalization may assist the actual obtainment of informed consent. This indicates that maintaining the right distance is key to making informed consent decisions.

Shared interests

The relationships in which informed consent decisions are made differ in the degree to which there is some sort of shared interest between the risk-imposer and the risk-bearer. This shared interest is most obvious in the treatment relationship between doctor and patient: Here, the doctor has a fiduciary duty toward the patient which means having to act according to the interests of the patient (Dyer 1982; Schuck 1994). Thus, a doctor must not only inform patients about risks and allow them to make a decision but also tell them about alternative treatments. This is not to say that patients' interests are always entirely clear: Research has shown that there is strong variation between patients' preferences in medical decision-making (Arora & McHorney 2000). Patients may also form and shape their preferences during the decision-making process in line with the interpretative model of Emanuel and Emanuel (Emanuel & Emanuel 1992) in which doctors help patients to discover and order their values to come to medical decisions.

However, patients or their guardians may misinterpret the intentions of doctors due to the social status of medical institutions. For example, in academic hospitals doctors are often also researchers who have an interest in high rates of participation in trials (De Vries et al. 2011). This has consequences for the obtainment of informed consent: Parents may misinterpret activities that are experimental as being therapeutic and think that the doctor is only acting in their child's best interest. Something similar can be seen in the social sciences, where researchers often engage with politically loaded or sensitive topics. In these settings, researchers may be mistakenly perceived as advocates or activists whereas their primary loyalty is to the academic community in providing a theoretically sound, objective account – though various forms of engaged anthropology seem to merge these two roles (Low & Merry 2010).

Room for reflection

As argued in section 3, relationships influence the room for reflection that is crucial for obtaining valid informed consent. The previous section discussed the characteristics of relationships in which informed consent decisions are made. Depending on their characteristics, relationships may offer different opportunities for reflection. For instance, in a relationship in which there is strong dependency because of informational asymmetry, risk-bearers have less capacity to genuinely reflect on their options. Strong personal bonds, on the other hand, may enhance reflection as is revealed in the deliberative model of the doctor–patient relationship. The existence of conflicting interests may prompt reflection as conflict enables us to see differences in the values that guide risk decisions.

The relational factors identified in the previous section enable us to evaluate the validity of informed consent from a relational perspective (see Table 2.3 for an overview) not only because these individual factors themselves influence the reflection of risk-bearers on the information and decisions with which they are confronted but also because these factors help the risk-bearer to reflect on her relationship with the risk-imposer: One can only be really autonomous by reflecting on the characteristics of the relationship one is in, and how those characteristics may influence the decision one makes.

Factor	Evaluated in terms of:
Dependency	• Dependency on risk-imposer for information • Understanding-dependency due to differences in level of education, knowledge, and cognitive abilities between risk-bearer and risk-imposer • Dominance of one actor's view in decision • Existence of visible and invisible coercion
Personal proximity	• Level of anonymity, intensity if contact, and sharing of personal information • Relational continuity, duration of the contact (multiple meetings) • A balance in formalization/informalization of contact (e.g., as a result of standardization and bureaucratization)
Shared interests	• Similarity between the interests of the risk-bearer and those of the risk-imposer, as well as the extent to which one can rely on another to act in one's interests • Existence of legal and moral duties of one party to protect the other party's interest • Presence of commercial or other conflicting interests

Table 2.3. Relational factors that may influence the autonomy of informed consent or similar decisions

2.4. Characterizing employer–employee and producer–consumer relationships

Relationships need to meet certain levels of independence, shared interests, and proximity to allow for reflection and the obtainment of valid informed consent. This section explores two relationships that are prominent in decisions concerning nanomaterial risk: the relationship between employer and employee, and that between producer and consumer. We characterize these relationships in terms of the characteristics introduced in the previous section, that is, in terms of dependency, personal proximity, and the existence of shared interests. Next, we discuss what room for reflection these relationships offer.

2.4.1. Relational factors

The characterization we present describes the employer–employee and producer–consumer relationships, in general, in ideal-typical terms.

Dependency

The relationship between producers and consumers is often considered to be one in which the consumer is fairly independent. In an ideal market, market transactions are, by definition, similar to informed consent decisions: For a market transaction to be considered genuine, all decisions have to be made knowingly and willingly. Producers and consumers are fairly autonomous in their decision to partake in a specific market transaction: they can buy from or sell to whomever they choose. Nevertheless, in many cases there may also be some form of dependency among consumers because, for example, there are not enough alternatives to make a free choice, or a producer has a monopoly on certain products (such as the near monopoly of Microsoft in the 1990s).

In ideal market transactions both the producer and the consumer have complete information about the product and its possible hazards, which would suggest we can see it as a form of informed consent. In practice, of course, complete information is never available. In many jurisdictions, therefore, the producer has a legal duty to inform buyers about any known negative effects through labeling thus making the informational position of consumers somewhat similar to that of the patient in the doctor–patient relationship. One difference from the doctor–patient relationship, however, is that a producer is not expected to offer consumers information about alternatives that may better suit their needs – which would obviously be against the producer's economic interests. Moreover, there is usually no personal contact between the risk-imposer (producer) and the risk-bearer (consumer), unlike in the doctor–patient relationship. This may make transferring knowledge of the risk more difficult, with the risk-imposer unable to verify whether the risk-bearer has really understood the risk. As a result, informational asymmetry threatens the risk-bearer's opportunity to reflect on the desirability of being exposed to that risk. Also, consumers often have little or no say in design processes (despite all the participatory initiatives that have emerged in recent years), so in this respect, too, they very much depend on the efforts of producers to make less risky products.

The presence of free choice is much less obvious in working environments. The hierarchy in working environments means the employer is responsible for the working conditions of her employees: employees depend greatly on their employers to make the right decisions concerning exposure to risks, and employers are in many countries legally responsible for organizing a safe working environment. The individual choice of employees is limited, making this type of relationship rather asymmetrical in terms of power. It must be noted, though, that the academic environments in which nanomaterials are used and produced, are typically characterized by more independence and self-determination in working practices.

Personal proximity

The strength of ties in both employer–employee and producer–consumer relationships may vary considerably depending on the context. In some markets and for some products, there may be strong and enduring ties between producers and consumers; in other cases (e.g., consumer products that can be bought at a supermarket) the ties may be much looser: Consumers may be anonymous to producers and a personal bond may be absent. Employer–employee relationships are, in general, less anonymous as there is often interaction on a daily basis and these relationships usually last longer than producer–consumer relationships. Again, however, there may be quite some differences between employees who are hired on a temporary basis through an employment agency and those who spend their entire working lives with the same employer which leads to strong personal bonds between them.

When we focus on nanomaterials, the following ideal-typical picture arises. Companies that develop and use nanomaterials often employ skilled workers who, we assume, work there for at least a number of years making the ties between employer and employee stronger and distances (e.g., in hierarchy) easier to bridge. Although this may lead to shared interests (see also the following section), long-term bonds may also pose a risk and lead to self-sacrificing behavior by employees out of loyalty to an irresponsible employer or in order to hold on to a valuable job. Phenomena such as group think – a tendency to prefer harmony within the group over the right or best outcomes – suggest that stronger social ties may also diminish the space for reflection (Janis 1982). Similarly, we know that shared decision-making processes may lead to group polarization (Sunstein 2002) where a groups comes to hold more extreme views than the individual members of the group held initially.

Market transactions are, in general, much more distant. As is the case in biomedical research settings, producers and consumers do not have contact on a regular basis, and any contact there tends to be relatively brief and instrumental. Furthermore, market transactions often go through sellers and re-sellers, leading to large distances between the risk-producer and the consumers who are exposed to the risks. This limits the opportunity for consumers to communicate with producers about the risks posed by new technological products with the contact rather unidirectional. This is especially the case for one-time buyers although some consumers are loyal to particular brands. The latter may be in a better position to make informed decisions because of this stronger connection.

Shared interests

If we assume that producer–consumer relationships are guided by the market, then producer and consumer have a shared interest in the transactions they agree on, but apart from that there need not be a shared interest. In comparison, employer–employee relationships seem to be characterized by stronger shared interests, as both have, at least in principle, a shared interest both in the performance of the company and in some minimally decent working conditions. Nevertheless, the history of labor movements suggests that these shared interests have not always been recognized and acted upon by the parties involved.

If we focus on nanomaterials, it is particularly interesting to look at the extent to which there is a shared interest in safety and protection against potential occupational health and safety risks. The extent to which safety in this field is a shared interest depends not only on the ideal-typical characteristics of the producer–consumer and the employer–employee relationship but also on relevant laws and regulations. Relevant to the producer–consumer relationship is the fact that under current product liability regulation in the EU, there is a strict liability for risks (European Parliament & Council of European Communities 1985). It prescribes caution and requires rigorous testing for products introduced to the market and holds companies liable for any undesirable effects of the products (in the case of normal use). For the employer–employee relationship, it is relevant that most Western countries have established a legal duty for employees to, guarantee the safety of the work environment for employers by, for example, implementing risk management and preventative measures. This means that, as is the case with product liability, the health and safety of the risk-bearer (in this case, the employee) is a concern for both the risk-bearer and the party exposing that person to a risk (here, the employer). It is a shared interest according to the law.

However, the extent to which interests overlap is more encompassing in the case of the employer–employee relationship. Producers are primarily concerned with the safety of a specific product while employers are concerned with the health of personnel in their working environment. Thus, employers have a duty of care to their employees and, perhaps not surprisingly, the employer–employee relationship exhibits similarities to the more paternalistic doctor–patient relationship. The producer–consumer relationship, on the other hand, leaves much more room for personal consideration and is much more similar to an informative or consumerist relationship model (to use Emanuel and Emanuel's typology). In general, we do not expect producers and commercial players to look beyond the safety of their products in meeting the needs those products are intended to meet. This would not be in the commercial interest of companies and would entail a level of engagement of producers with their clients that is rarely seen. Depending on the level of shared interest, it is to be expected that risk-bearer and risk-imposer are more engaged in supporting the risk-bearer's decision-making strategy thereby enabling autonomous reflection.

2.4.2. Room for reflection

The relationship between employer and employee and that between producer and consumer vary in terms of dependency, strength of bonds, and level of shared interests. Since autonomy is shaped by the characteristics of relationships, the validity of informed consent is contingent on these characteristics. The discussion in this section suggests that employer–employee relationships and producer–consumer relationships provide different amounts of room for reflection. In working relationships, strong bonds with and dependency on the employer may limit opportunities for critical reflection and autonomous risk decisions. Conversely, in the producer–consumer relationship, room for reflection is particularly threatened by too loose bonds and the absence of shared interests. Thus, the framework developed in the previous section helps us to see that it might be hard to achieve valid informed consent in producer–consumer relationships and in employer–employee relationships albeit it for quite different reasons. This also means that what we can, and maybe should, do to improve the obtainment of valid informed consent is quite different for these different types of relationships.

2.5. Discussion

In an ideal world, informed consent is given under optimal conditions of voluntariness, complete disclosure, and understanding of information. However, informed consent functions within the dynamics of a particular relationship between a risk-imposer and a risk-bearer. This relationship should preferably be symmetrical in order to decrease the dependency of the risk-bearer on the risk-imposer. A certain level of personal contact is needed to ensure proper information disclosure and to create a space for genuine discussion about the risks and benefits of a particular product in order to increase understanding. At the same time, the personal ties should not be so strong that the risk-bearer feels forced to act in accordance with the risk–imposer's proposal without proper reflection – making it effectively a power relation. A strong overlap of the interests of the risk-imposer and the risk-bearer prevents conflicts of interests and deception or exploitation but some conflict of interest, or of values, between risk-imposer and risk-bearer may be instrumental in prompting reflection.

The world, however, is not perfect. Relationships between doctor and patient and between researcher and research participant, as well as those between producer and consumer and between employer and employee, differ in various ways from the ideal-typical relationship that is presupposed in informed consent. Dependency seems to be more asymmetrical in medical treatment and working relationships. The extent to which shared interests exist varies: doctor–patient relationships are typically characterized by strong overlapping interests whereas this is less obviously the case for the other relationships. Furthermore, the proximity in these relationships is very different: Market relationships and research relationships (in particular biomedical relationships) may be rather impersonal and distant whereas employees and employers may sometimes build upon long-term and often personal ties that are similar to those in treatment relationships. Of course, this characterization is based on a rather generalized image of what these relationships look like, and there may be many variations. There is a certain range, however, within which these relationships operate.

Factor	**Doctor–patient**	**Researcher–research participant**		**Producer–consumer**	**Employer-employee**
		Biomedical research	**Social science research**		
Dependency of risk-bearer	High: great informational asymmetry; doctor is gatekeeper	Medium: great informational asymmetry, but participation in research is voluntary	Low: researcher depends on research participant for cooperation	Low	High: although employee may have some agency
Personal proximity	Strong: long-term	Weak: but with personal contact	Medium-strong	Very weak: distant and incidental	Strong: long-term and intensive
Shared interests	Substantial: health is shared interest	Limited	Medium: success of research is in interests of both	Limited: product safety	Substantial: safety is shared interest
Challenge to room for reflection	Informational and understanding asymmetry Too close bonds	Limited shared interest	Too proximate personal relationships	Absent or very distant ties	Power asymmetry

Table 2.4. Overview of differences between relationships in which types of informed consent decisions play a role.

Different relationships pose different challenges when it comes to room for reflection and achieving valid informed consent. Much of the literature on informed consent identifies information dependency in the doctor–patient relationship as one of the major challenges in achieving informed consent. Our paper also argues that the close bonds in these relationships may also pose a risk to the capacity for reflection and autonomous choices. Highly proximate relationships leave little room for patient independence and may invoke paternalism. The relationship between employer and employee appears challenging in a different way. The hierarchy between them impedes the making of a genuinely voluntary decision. While there may be a degree of equality in the working relationship, the employee always depends on the employer to ensure the safety of the work environment and the security of her job. It is therefore unlikely that an employee will be in a completely symmetrical relationship with her employer which may threaten the voluntariness of risk decisions. In research relationships, and primarily in biomedical research relationships, the limited overlap in interests also creates problems for informed consent. There is often no immediate need for research participants to be part of a research project although history shows that deception has led to participation in research. In social science, the personal proximity poses more of a challenge.

Finally, the sheer distance between consumer and producer leads to informed consent being obtained rather indirectly. It is unlikely that producers will develop very strong ties with their consumers, and as a result, the risk-imposing producer cannot monitor whether the consumer has received and genuinely understands the information provided. Marketing departments could play a role in this[15] but still the consumer can only consent through a market transaction and this hardly offers an opportunity to ask for further clarification. Consequently, different relationships provide different amounts of room for reflection both on the information available for making decisions and on the way such relationships shape the autonomy of the risk-bearer.

Considering the variations in these relationships, we conclude that informed consent would not function in the same way in different types of relationships. Institutional changes that may be useful in the doctor–patient relationship may have a detrimental effect in the employer–employee relationship, and vice versa.

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15 Developments such as the conscious consumerism movement show that consumers feel increasingly connected to certain brands on ethical grounds. This allows brands to build relationships with their costumers and establish a stable clientele.

In other words, any implementation of informed consent must take into account the particularities of the relationship in which the consent functions. Our systematic analysis is a first step toward improving the conceptualization of informed consent in a way that does justice to these relational differences by providing a more fine-grained account of the conditions under which valid informed consent can be obtained. The following subsection discusses the implications of this for the feasibility of obtaining informed consent for exposure to nanomaterial risks.

Implications for informed consent as a way to deal with nanomaterial risks

Informed consent has been proposed as a way to deal with the risks and benefits that products containing nanomaterials pose to consumers. These efforts have typically focused on providing better information to consumers and on addressing the information asymmetry between producers and consumers (cf. Shrader-Frechette 2007). Such efforts include, for example, the labeling of nano-content in cosmetics (European Commission 2013), additional product information, and the provision of online databases with voluntary application and risk information from the manufacturers (Danish Consumer Council et al. 2013; Woodrow Wilson International Center for Scholars 2013; Vance et al. 2015). Both citizen panels and participatory risk assessment bring citizens' knowledge level closer to that of developers (Guston 2011), and give citizens influence on future technological developments (Godman & Hansson 2009). NGOs often play a role in facilitating knowledge transfer, for instance by increasing the visibility of nanomaterial use and by encouraging informed public debate.

Although we know from experience with informed consent in doctor–patient relationships that it is important to address asymmetries in information and understanding, our analysis suggests that the weak ties between producers and consumers also present a major barrier to acquiring valid informed consent in producer–consumer relationships. These weak ties are a threat to the correct interpretation and understanding of information, and may also result in very limited shared interest. Our findings suggest that if we want to strengthen informed consent in producer–consumer relationships, we should also focus on these aspects, rather than just on overcoming information dependency. This is, to some extent, already happening. NGOs do not only provide risk information but can also help establish relationships, for instance by starting a joint inquiry into the acceptability of risks (Krabbenborg 2013). Current trends in responsible innovation and design studies aim to create even closer ties between consumers and producers through means of participatory design and user-oriented design (Nieusma 2011). However, most consumer-producer relationships are still very distant, especially in an international context. Some argue that current developments in the field of nanotechnology create even more dependency from the global South to the global North (Maclurcan 2011).

When it comes to employer–employee relationships, we are not aware of attempts to explicitly use informed consent as a way to deal with nanomaterial risks to employees. Nevertheless, there are several ways in which European Occupational Health and Safety regulation promotes informed consent-like decision making. For instance, EU Directive 89/391/EEC on the introduction of measures to encourage improvements in the safety and health of workers requires the provision of information, training of workers, and shared forms of decision making (e.g. through consultation and participation). Something similar is prescribed in Council Directive 98/24/EC on the Protection against Chemicals Risks at Work. Such measures, empower individual workers and ensure that information sharing becomes a mutual interest for both employer and employee.

More informal guidelines that have been developed to deal with nanoparticles at the workplace, emphasize the need for direct communication between employer and employee (Spruit 2015; Cornelissen et al. 2012; Van Broekhuizen & Reijnders 2011). The rationale behind this is that the uncertainty concerning nanomaterials risks has made the application of existing risk-management strategies in workplaces particularly tricky. Conventional workplace exposure scenarios do not apply to nano-sized materials, and there is an absence of occupational exposure limits for most nanomaterials (Schulte et al. 2010). If employers do not know whether they can take adequate protective measures against uncertain risks, it seems reasonable to at least ask employees whether they mind being exposed to them. Yet, it must be noted that an obstacle is still the asymmetrical power relation between employers and employees which is also maintained in most Western labor laws. Here labor unions play and have played a role in decreasing dependency of the employee on the employer (Foladori & Lau 2011; European Trade Union Conferederation 2011). All in all, it seems that while the information component is increasingly addressed in employer-employee relationships, employees are often not in a formal position to make a decision regarding their own use of nanomaterials.

Much more research should be done on how the characteristics of relationships interact and could compensate for each other and facilitate room for reflection. A potentially more constructive, but speculative, approach to informed consent would be to see the three relational aspects we identified as communicating vessels. Mechanisms that point in this direction can already be observed. For instance, a high degree of dependency on employer's decisions concerning the use of nanomaterials can to a certain extent be compensated for by a higher level of shared interests as is the case in labor law. More distant consumer relationships can also be partially compensated for by providing consumers with information about nano-content in their products as this decreases informational dependency. More research is needed to establish how these different relational factors could and should compensate for and interact with each other to achieve genuine informed consent for using, working with, and handling products containing nanomaterials. We hope that our discussion of informed consent provides a fruitful starting point for such an analysis.

3 Choosing between precautions for nanoparticles in the workplace: Complementing the precautionary principle with caring[16]

While informed consent presupposes that people make voluntary decisions concerning their own exposure to risks, many risks are imposed upon other people without their explicit consent. In such cases, the relationship between the person imposing and the person bearing the risk may be relevant to risk decisions. With a specific focus on the relationship between employer and employee, this chapter examines how the qualities of relationships can inform decisions concerning the imposition of uncertain nanomaterial risks upon other people. The chapter starts with a discussion of a commonly used decision principle for uncertain risks: the precautionary principle (Section 3.2). It shows how, in practice, this principle is underdetermined as a decision criterion due to limitations in risk assessment and management methods under conditions of uncertainty (Sections 3.4 and 3.5). It is proposed that in such cases the precautionary principle should be complemented with a caring approach (Section 3.6). To this end, three relational conditions for assessing risk management strategies are developed based on (1) the existence of a mutual concern (between employer and employee) for employee health and safety, (2) the connectedness and continuity of the relationship between employer and employee, and (3) the responsiveness of employers to employee needs. Section 3.7 concludes that in cases where scientific uncertainty limits the application of the precautionary principles, we should shift the discussion from the acceptability of scientific risks to creating a social context in which the imposition of the residual uncertain risks is deemed acceptable.

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16 This chapter has been published as Spruit, S. L. (2015) Choosing between precautions for nanoparticles in the workplace: complementing the precautionary principle with caring. *Journal of Risk Research*, 1-21. doi: 10.1080/13669877.2015.1043574

3.1. Introduction

History teaches us that the hazards of technological innovation, such as the production of new nanoparticles, are often uncertain in the early stages. Over the years, the potentially devastating effects of several technological innovations have become clearer. Scientific fields such as physics, chemistry, and engineering have produced technologies that initially seemed harmless, but proved to be harmful to humans and the environment on a large scale. For instance, CFCs were presented as the safe alternative to existing flammable and toxic refrigerants, and only later were found to be devastating for the ozone layer. Asbestos was used for multiple purposes before its toxicity to humans led in most countries to a ban on its production. This has given rise to a chronic unease concerning the safety of innovative technologies and materials (Fruhen et al. 2013), and has prompted scientific risk assessment and governance (see, for example Hassenzahl 2005; Klinke & Renn 2011).

In the context of nanotechnologies, the limitations of measurement techniques and exposure scenarios, or unforeseen interaction effects, make it difficult to measure and predict potential hazards caused by nanoparticles (K Clark et al. 2012; Levard et al. 2012). A range of scientific recommendations and papers have been produced on the potentially hazardous effects of nanoparticles in working environments (Borm et al. 2008; Kaluza et al. 2009; Pronk et al. 2009; SER 2009), but toxicologists and risk scientists have not reached consensus on the hazardous effects of exposure to nanoparticles in the workplace. There are indications that the use of nanoparticles may cause health problems, but the indications are not conclusive (Gezondheidsraad 2012; Song et al. 2009). The scientific information is not sufficient to make straightforward decisions on the safety and health risks posed by these materials. We also lack longer term observational studies on the adverse effects of nanoparticles that would allow, for instance, the collection of data on the accumulation of particles in specific body parts, or what happens in interaction with other chemical substances (Gezondheidsraad 2012).

Despite the uncertainties pertaining to the purported risk of working with these materials, nanoparticles are being developed and used in universities, industry, and workplaces. Although the exact number of producers using nanoparticles is hard to ascertain (Öko-Institut et al. 2014), the use of nanoparticles in production and industrial processes is expected to increase in the years to come (Aitken et al. 2006). The Dutch National Institute for Public Health and the Environment observed a six-fold increase in consumer products containing nanoparticles between 2007 and 2010, namely from 143 to 858 products (Wijnhoven et al. 2011).

As a result, people who develop and work with such new materials are among the first to be exposed to their purported risks. In 2011, an estimated 3000 people were coming into contact with nanoparticles in their working environments in the Netherlands alone (Pronk et al. 2011), and the expected increase in nanoproducts will coincide with an increase in the handling of nanoparticles in the workplace. Thus, the people working with these particles may or may not be exposed to hazards, as the risks posed by these new materials to the human body (and the environment for that matter) are uncertain. Therefore, organizations such as the Health Council and various civil society organizations have proposed gaining more knowledge of the risks of working with nanoparticles, by setting up an extensive registration and monitoring scheme in workplaces (Gezondheidsraad 2012), and making other reporting and communication efforts to build capacity for adequate risk communication along the value chain (Van Broekhuizen & Reijnders 2011).

Employers are legally required to ensure safe working conditions for their employees. The Dutch Civil Code states that: "The employer is obliged to arrange and maintain rooms, equipment, and tools used for labor, as and to give instructions to prevent harming the employee during his or her working activities"[17] (BW 7: 658, clause 1, my translation). Hence, employers are legally responsible for the quality of the working conditions when working with dangerous substances. To fulfill this duty, employers must, for example, ensure that exposure to hazardous materials is limited by making a risk assessment and management plan for working with chemical substances (Arbeidsomstandighedenbesluit, Chapter 2, Section 2). In this risk inventory and evaluation, an overview should be given of potential hazards and the measures already taken to secure the safety, health, and well-being of employees. These risks should also be evaluated and prioritized in order to devise a coherent strategy to deal with them.

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17 Original text: "De werkgever is verplicht de lokalen, werktuigen en gereedschappen waarin of waarmee hij de arbeid doet verrichten, op zodanige wijze in te richten en te onderhouden alsmede voor het verrichten van de arbeid zodanige maatregelen te treffen en aanwijzingen te verstrekken als redelijkerwijs nodig is om te voorkomen dat de werknemer in de uitoefening van zijn werkzaamheden schade lijdt' (BW 7: 658, clause 1).

However, uncertainty concerning the risks involved with working with nanoparticles makes the operationalization of this duty of care problematic. Since occupational health and safety (OHS) risks of nanoparticles are hard to quantify, formulating occupational exposure limits (OEL) for nanoparticles has proved to be difficult (Schulte et al. 2010). Furthermore, many exposure measurement techniques in working environments are still based on the mass of substances used, as is commonly done in assessing the risk of larger particles, but these are less appropriate for assessing nanoparticles since a small mass may still consist of numerous active nanoparticles. Additionally, worker exposure scenarios based on larger particles might not take into account the fact that nanoparticles can easily enter the body through the skin. Most occupational risk assessments focus on risks through inhalation. As a result, the legal requirements for protecting workers who are using these particles are unclear under the current working conditions.

How, then, should employers care for their employees in the absence of clear, scientific information about the hazards of nanoparticles on which to base a risk management strategy? Several risk scholars have argued for a precautionary approach to uncertain risks, like those involving nanoparticles (Van Broekhuizen & Reijnders 2011; Rogers 2001; Stirling 2007; Van Asselt & Vos 2006). In this paper, I reflect on the application of the precautionary principle (PP) to this case, and argue that the PP proves to be underdetermined when choosing between the several precautionary strategies for working with nanoparticles that are available. In the following section, I give a brief introduction to the PP, arguing that its validity depends at least partly on its practical application. In Sections 3 and 4, I describe the methods and findings of an inquiry into the current regulation and risk management of nanoparticles in the Netherlands. I then discuss (Section 5) the limitations of the PP in this context when guiding decisions concerning the uncertain OHS risks of nanoparticles, and suggest a complementary decision criterion for choosing between precaution strategies that is based on the caring qualities of the relationship between employer and employee (Section 6). In my conclusions, I briefly reflect on the implications and generalizability of my proposal to complement the PP.

3.2. The precautionary principle

The PP is a widely discussed decision principle in the governance and risk management of uncertain environmental, health, and safety risks (Groso et al.

2010; Klinke et al. 2006; Van Asselt & Vos 2006). Originally developed in the context of environmental hazards (UNCED 1992 subclause 15), it calls for timely action in the face of uncertain health and environmental hazards. It has also been proposed to help guide decisions on the risk management of new technological innovations, such as the uncertain risks posed by using and working with nanoparticles (Van Broekhuizen & Reijnders 2011; see for instance; Höck J. Krug H., Lorenz C., Limbach L., Nowack B., Riediker M., Schirmer K., Som C., & Stark W. von Götz N., Wengert S., Wick P.: 2008; Kessler 2011; SRU 2011).

Although the principle has been formulated in many different ways (Ahteensuu & Sandin 2012; Sandin 1999), key to the idea of the PP is that it rejects uncertainty as an excuse for not taking action in the face of uncertainty (Steel 2014). On the one hand, it can be seen as a direct response to cases of paralysis or inaction in the absence of clear, scientifically established measures to avoid great harms; on the other hand, it can be presented as a demonstration of humility (Stirling 2007), since invoking it acknowledges the limitations of science and risk assessment methods in predicting risks. Most formulations of the PP, however, seem to boil down to a relatively simple idea, namely "If there is (1) a threat, which is (2) uncertain, then (3) some kind of action (4) is mandatory" (Sandin 1999, p.891). This formalization demonstrates the epistemic side of the principle, which is concerned with having knowledge of a potentially hazardous future event (1 and 2), and the normative side of the principle that is concerned with the appropriate response to such uncertain risks (3 and 4).

The normative component of the PP requires us to take action in the face of scientific uncertainty. But not just any kind of action is sufficient. Since uncertainty can make it hard to predict both the exact manifestation of the threat and the adequacy of the measures taken, the default response to uncertain risk under the PP is cautiousness. A very demanding version of the PP, at least in terms of precautions, may argue for avoiding technological innovation altogether, given its inherent unpredictability. Many assert that such conservatism can backfire, as the PP may block beneficial innovative measures, such as those necessary for preventing environmental hazards (e.g., in the context of climate change)[18] – a paradox that has led to charges of incoherence and irrationality. A more moderate formulation of the PP demands that, when confronted with uncertain

18 For instance, Cussen argues that in popular formulations of the precautionary principle, there is little consideration of the utility of innovation or any other risky activities (2009).

threats, precautions should be taken. This means that decision makers must choose those actions that err on the side of caution. As such, invoking the PP is an expression not only of humility, but also of care: it identifies an organism, a person, or another object that has to be additionally protected or restored in light of a potential future threat.

For the PP to function as a decision rule in practice, it needs to be action-guiding in the face of uncertainty. Since the main reason why this principle is invoked is a response to a history of inaction when faced with technological and scientific threats (Harremoës et al. 2002), its validity at least partly depends on its practicability. Using the PP as a decision rule should provide decision makers with useful criteria with which to compare options. Several authors have stated that the PP is ill-defined, however, and that either vagueness or a multitude of competing definitions stand in the way of its straightforward application (Sandin et al. 2002). In this paper, I identify and reflect on a different problem that arises in the application of the PP: when various precautions are possible within the framing of the PP, how can one choose between them? One may argue that any choice is justified, since the precautions conform to the PP. This means, however, that it functions merely as a selection mechanism, and not as an action-guiding decision rule. The following sections will illustrate this problem by presenting a situation in which the PP is very useful for selecting a subset of risk management strategies that are considered precautionary, but still underdetermined as a decision rule, since it does not give guidance when choosing from several precautions.

3.3. Materials and methods

The argumentation in this paper is illustrated by a study on the current discussions concerning the use of nanoparticles in working environments, and informed by document research, complemented with a series of interviews. The documents studied are reports and guidelines that are currently available in the Netherlands (sources listed in the references). Governmental websites, such as that of the Ministry of Social Affairs and Employment, provided valuable information on OHS legislation and about nanoparticles in particular. Furthermore, as several advisory organizations, such as the Health Council of the Netherlands and the Social Economic Council, have been influential in this debate, their reports are also integrated in the text. This research led to the identification of several guidelines that provide information on what precautions could be taken when working with nanoparticles. Three of them are described in more detail below.

During the summer and fall of 2012, I conducted twelve interviews to supplement the document research and for further clarification. Eight of the interviewees had been participants in a workshop organized by the Health Council of the Netherlands on the report 'Working with Nanoparticles' (Gezondheidsraad 2012). The other four interviewees were identified using a snowballing method. This ensured that the interviewees were all well-informed and active in the discussion concerning OHS risk of nanoparticles in the Netherlands. I obtained a wide range of perspectives by interviewing actors from a variety of fields, including two respondents working in risk research, three respondents specialized in OHS risk assessment and management in workplaces, two representatives of industry, three government officials (including officials from the labor inspectorate), and two respondents who are closely involved with the labor union. The interviews were held at the respondents' workplaces. They took on average 45–60 mins and were recorded. During the interviews, I invited the respondents to talk about the uncertainty and risks concerning the use of nanoparticles in working spaces. Topics included the hazards of nanoparticles, uncertainty about these hazards, questions as to optimal strategies to deal with them, and the available guidelines and recommendations, as well as the respondents' own role in the debate about risk management strategies for working with nanoparticles.

In addition, I observed two events. The 'Chemicals Day' (*Stoffendag*) that took place on 7 October 72012 was an informative meeting for occupational health and safety specialists, companies, and industry, about working with chemicals and what safety measures to use. It was organized by the Netherlands Organisation for Applied Scientific Research (TNO) on behalf of the Netherlands Ministry of Social Affairs and Employment. Nanoparticles were the topic of two well-attended sessions, during which the guidelines for working with nanoparticles were discussed. I carried out a second observation during a smaller gathering of OHS specialists working at Dutch universities, organized by Leiden University, the Foundation for Fundamental Research on Matter (FOM), TNO, and Delft University of Technology. This meeting was arranged to inform these experts about a new project aimed at harmonizing, or at least adapting, the available guidelines to a research setting.

3.4. Regulation of OHS when working with nanoparticles in the Netherlands

Nanoparticles are accompanied by uncertain risks, and even though there are expectations that there may be hazards involved in working with them, it is still largely unclear how hazardous they might be. Before going into a more theoretical discussion of how to make decisions in the face of uncertainty, this section gives an overview of the regulatory context in which the OHS issues related to nanoparticles are put on the table. This serves as an example for exploring an ethics of care perspective as complementary to precautionary thinking in the subsequent sections.

3.4.1. Regulation of OHS

Over the past decades, the Dutch government has increasingly emphasized that voluntariness and self-regulation should be the cornerstone of regulating OHS (Plomp 2008; Popma 2013b). In a letter to the Social Economic Council, the secretary of Social Affairs and Employment at that time, Piet-Hein Donner, stated that “working safely is primarily a topic for employers and employees” (Donner 2008, p.2, my translation), arguing that the government should not be too closely involved in formulating and issuing rules. According to a government representative, one of the reasons for this is that governments often lack the necessary expertise and speed to effectively respond to new technologies such as nanoparticles. Concerning nanotechnology, the government does not have in-house scientific expertise; it largely makes use of external knowledge institutes such as the National Institute for Public Health and the Environment (RIVM). Furthermore, industry is often engaged in developing new technologies over long periods of time. The government is not ready when products come to market. It takes time to assess the risks of such products and respond to this as a government by, for instance, introducing new regulations. Therefore, self-regulation is believed to provide a timely response to new technologies, as well as prevent the enactment of unsuitable or inadequate forms of regulation.

Self-regulatory arrangements are common for work-related matters in the Netherlands. Discussions are not limited to individual employers and employees. Instead, a variety of organizations are involved in the debate on the use of nanoparticles in the workplace. For example, a workshop organized by the Health Council of the Netherlands that led to the report ‘Working with Nanoparticles’ (Gezondheidsraad 2012), included participants from a variety of fields, such as the labor inspectorate, OHS advisors from several universities, risk research institutes, and consultancy and industrial organizations. Furthermore, labor unions, such as CNV and FNV Bondgenoten, have taken an active stance on the safety of nanoparticles (FNV 2010). Collaboration between these actors in this field was not a one-off event: most of these stakeholders are part of a negotiation tradition, (*polderen*) through which work-related social matters such as pensions and wages are discussed. This tradition also offered a forum for discussing the quality of working conditions, such as those for working with nanoparticles (SER 2009). At the same time, employers are legally obliged to consult experts in order to comply with these standards, making it more likely that they will encounter the wide range of reports published by the above-mentioned societal actors.

Additionally, the Dutch labor inspectorate has shrunk considerably (Popma 2013b). Popma reports a decrease from 400 FTE personnel in 1994 to 221 FTE in 2012, and a decrease from 87,000 inspections to 20,000 inspections over that same period. According to an employee of the labor inspectorate, only about 2% of companies are inspected each year (Interview B2). Furthermore, especially concerning the inspectorate's specialized medical expertise – which would be needed to adequately assess the risk posed by nanoparticles– the Netherlands was said to lag behind other European countries. Popma reported in 2011 that the Dutch labor inspectorate was severely understaffed and, for instance, employed only one company doctor (*bedrijfsgeneeskundige*), whereas before 1987 these doctors had played an important role in intervening in cases of occupational disease (J. Popma, 2011). A representative of a labor union commented on this decrease in oversight by the labor inspectorate: 'It seems the government expects us to check on working conditions' (Interview C9, my translation) – a task this representative was not very keen to perform. Thus, in practice, the management of nanoparticles in workplaces is shared by several private parties.

3.4.2. Precautions for working with nanoparticles

Focusing on the debate concerning nanoparticles, we see that a precautionary approach is advised when using nanoparticles in workplaces (Gezondheidsraad 2008). The Health Council of the Netherlands advises to 'use nanoparticles of any substance in the workplace in *the same way as dangerous chemicals*' (Gezondheidsraad 2012, p.38, my translation, my emphasis). Many of the documents and respondents even specifically mentioned the PP as a guiding principle for decisions concerning exposure to nanoparticles in the workplace. In practice, this means that it is considered best to keep exposure to these particles as low as reasonably achievable (following the ALARA principle that is used for dangerous substances), at least until there is more scientific knowledge of the risks of being exposed to nanoparticles (SER, 2009). Several online tools and guidelines offer strategies for employers to assess and manage the uncertain risks of nanoparticles. In the following, I briefly compare and discuss three of these strategies as different understandings of what it means to take precautions in relation to working with nanoparticles.

Stoffenmanager Nano 1.0

Arbo Unie, a company specialized in OHS-related issues, developed the Stoffenmanager Nano 1.0 online tool in collaboration with TNO – a Dutch research organization for applied scientific research – and BECO, a company that specializes in sustainable development (TNO et al. 2011).[19] The Stoffenmanager Nano is designed to perform a qualitative risk assessment for substances whose toxicity and degree of exposure are not yet quantifiable (Van Duuren-Stuurman et al. 2012). It is based on a control-banding method (Brouwer 2012), whereby hazards and exposure are both categorized in a one dimensional band (from less to more severe hazards or exposure). The hazard categories are based on such characteristics as shape (are they fibers?), solubility, and size. For instance, particles that are smaller than 50 nm are considered more hazardous than larger versions of the same material, because of the likelihood of the occurrence of nano-specific effects, such as increased reactivity. The degree of exposure is based on the use and kind of control measures that could be implemented in the workplace. Setting both bands off against each other in a matrix provides an indication of riskier and less risky working situations.

19 Cosanta B.V., a spin-off of company of TNO and Arbo Unie, is working on developing a new version of Stoffenmanager Nano.

Hazard band / Exposure band	A	B	C	D	E
1	3	3	3	2	1
2	3	3	2	2	1
3	3	2	2	1	1
4	2	1	1	1	1

Table 3.1: Example of risk prioritization in Stoffenmanager Nano 1.0 (derived with permission from Buuren-Stuurman et al. 2011): Stoffenmanager Nano 1.0 combines five hazard categories with 4 types or levels of exposure. This leads to a prioritisation of risks, those in red are likely to pose greater risks than those in the orange category (3).

This risk categorization helps employers to assess the impact of protective measures on the exposure of employees to risks, as they reduce exposure that would lead to a decreased risk prioritization. However, the effectiveness of such measures in reducing exposure to nanoparticles is often not entirely clear (Van Duuren-Stuurman et al. 2012).[20]

Provisional nanoreference values

In collaboration with a platform of occupational hygiene specialists, the Knowledge and Information Point on Nanotechnological Risks (KIR-nano) of the National Institute for Public Health and the Environment (RIVM)[21] evaluated in 2010 the usefulness of provisional nano-reference values (Dekkers & de Heer 2010), and derived provisional nanoreference values for 23 frequently used nanomaterials, such as carbon nanotubes and nanosilver. The nano-reference values are based on a method developed in Germany that makes a risk categorization based on known properties that influence the toxicity of nanoparticles, such as bio-persistency, density, and particle size. The nanoreference values are presented as temporary because, unlike the legally established exposure limits

20 At the time of writing (fall 2014), one of the respondents indicated that many uncertainties about the effectiveness of protective measures, such as facemasks, have largely been resolved.

21 The KIR-nano is a working group within the RIVM primarily aiming at informing and advising the government on the risks of nanotechnology.

for hazardous substances, they are not based on complete and established toxicological or medical data, and when further data are available the necessary no-effect levels (DNEL) or OEL should be derived in order to establish more precise limits.

The nanoreference values do not guarantee employees' safety, since the uncertainty about the characteristics of nanoparticles that influence their toxicity is simply too great. However, one interviewee particularly involved with composing these nanoreference values, emphasized that they are generally more conservative than OEL of the non-nano chemical substance (Interview I5). In addition, a comparison of the benchmark exposure limits recommended by the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA), with the OEL for titanium dioxide and fullerenes proposed in the risk analysis literature, showed that in all cases the former limits were significantly lower than the latter limits (Dekkers & de Heer 2010).

Guidance on working with nanoparticles

The Dutch labor organizations FNV and CNV came up with their own guidance on working with nanoparticles (*Handleiding veilig werken met nanomaterialen*), together with the Confederation of Dutch Industry and Employers (Cornelissen et al. 2012). This guideline was formulated by three experts from the Dutch research and advisory organizations IVAM and Industox, which support societal stakeholders such as companies, governments, consumers, and labor organizations in dealing with nanomaterial-related issues. Like the Stoffenmanager, this guideline also presents a control-banding type risk categorization that incorporates hazards, exposure, and technical characteristics of the work done. Similarly, it gives advice on activities aimed at controlling exposure, following the widely used OHS strategy.[22]

Besides a scientific debate, this guideline also embodies a social consensus between many stakeholders: "The guideline was written by employers and employees [together]" (Cornelissen et al. 2012, p.3, my translation) and its development was supervised not only by a risk assessor from RIVM (the organization that composed the provisional nanoreference values), but also by

22 The OHS strategy (in Dutch: Arbeidshygienische Strategie) is a legally established risk minimization strategy, which aims to first remove exposure at the source, then at a collective level, and only as a last resort count on individual protective measures (this order is legally mandated in Arbowet, article 3, sub clause 1b).

representatives from the labor organizations FNV and CNV, the industrial organization VNO/NCW, a representative from the labor inspectorate, and a representative from the Department of Social Affairs and Employment. As such, the guideline is also a result of political negotiation: it embodies trade-offs of interests between all the above-mentioned parties.

3.4.3. Choosing between precautions

The guidelines discussed offer strategies for dealing with the uncertain risks for employees working with nanoparticles. However, they all have different characteristics: one prioritizes risks, one formulates maximum exposure values, and one is the product of deliberation between various stakeholders. If employers want to continue using nanoparticles, and are to comply with their duty to care for their employees, the challenge is for them to select a risk-management strategy.

In a recent study, a risk assessor at a physics research institute compared the guidelines and found that it is difficult to say which is better (Vervoort 2012). He applied the guidelines in several research settings and found that they resulted in different risk assessments and management strategies for similar cases. Due to the uncertainty concerning nanoparticles, it is unclear how these guidelines rank in terms of safety. We do not know whether one of the guidelines leads to more protection than the others, and can thus be considered safer. In the absence of a clear scientific criterion to choose between them, they seem to be on a par in terms of precaution.

Nonetheless, employers are expected to choose their own strategy, even though there are no clear scientifically established selection criteria to determine which guideline is 'better.' During the 'Chemicals day' in October 2012, this proved to be the key issue for employers. Participants (mainly companies and OHS advisors) sought a more decisive statement on the available tools during the two workshops organized. "Which one is the best?" (my translation) one of the participants asked.[23] As a result, the availability of all these options for precautionary strategies creates a situation where the possibilities for action are increased rather than decreased for employers. Thus, even with the best inten-

[23] Note that there was no obligation to choose one of the guidelines; drawing up a new safety strategy was also an option.

tions, or perhaps especially for those employers with the best intentions, choosing a precautionary strategy is anything but straightforward.

3.5. The limitations of the precautionary principle in nanopractice

The case presented in this paper is an illustration of the PP in practice. I argue in this section that, although specifically developed to deal with uncertain risks such as those involving working with nanoparticles, the PP is ultimately underdetermined if we want to make use of these innovative materials, but lack the knowledge and shared standards required to select the most suitable precautions.

As argued in Section 2, a very precautionary response to the uncertainty concerning nanoparticles would be to not expose workers to them. This view is reflected in the (quite stringent) decision-rule formulated during a workshop on precaution in the context of nanoparticle risk, namely 'No data □ No exposure' (Van Broekhuizen & Reijnders 2011, p.1651). However, even the most conservative stakeholder in the present study acknowledged that some benefits would justify exposure to uncertain risks, as long as it concerned the production of necessary, not luxury, products.

If we reason from a more moderate version of the PP and we want to benefit from the application of nanoparticles, some sort of trade-off has to be achieved between avoidance of and exposure to uncertain risks in fulfilling the duty of care. However, as my empirical inquiry demonstrates, especially in cases where there is less experience with new materials, there are no shared standards or a common notion of what can be reasonably expected in terms of protective measures and/or acceptable exposure. As a result, we see the co-existence of three risk-management strategies, all of which are different ways of operationalizing a moderate version of the PP:

> *Moderate PP: When exposing employees to nanoparticles that pose uncertain risks, precautions should be taken.*

All three strategies take a precautionary approach to nanoparticles, in the sense of being more conservative with respect to the scientific evidence needed to warrant protective measures. And all three aim to limit exposure to nanoparticles in order to avoid jeopardizing employees' health.

However, this moderate PP proves underdetermined to guide the choice between precautions: employers would still have to find a way of making a choice between the available guidelines, and the PP only argues that it is best to choose one of these strategies. As there is no scientifically established way to discern between these precautions, they are on a par in terms of precaution. The PP primarily calls for discussion about precautions in response to the level of scientific knowledge of hazards, but in the absence of a clear scientific criterion, choosing between them becomes an arbitrary affair. In addition, the availability of several precautionary strategies creates less clarity for employers; the choice concerning safety measures becomes more complex, since more options, in the form of guidelines, are available. This makes the PP vulnerable to the same critique to which it is a response, namely that it may be susceptible to paralysis by not being sufficiently action-guiding.

3.6. Caring relationships as a decision criterion for choosing between precautions

In the previous section, I showed how applying the PP ultimately runs into problems when confronted with uncertain risks. This is because of the difficulty in making a trade-off between risk avoidance and exposure in the absence of scientific criteria on which to base such a decision. Therefore, in this section I argue for a strategy complementary to the PP that bases risk decisions not only on scientific information, but also on the social context in which risk decisions are being made. I discuss the notion of care as a complementary decision-making criterion for the management of uncertain risks. More specifically, I argue that we should reflect on the quality of the working relationships between employer and employee as a factor to assess the desirability of risk impositions.

Care is increasingly recognized as an important concept in thinking about the way people should treat each other. The practice of care in private settings – such as the care of a mother for her child – and in professional settings in nursing and education, has inspired scholars of philosophy, political theory, and the social sciences to reflect on what constitutes 'good care' and to develop a normative perspective that puts personal engagement and relationships at the core of moral thinking. Scholars who are involved in developing the ethics of care, seek to describe moral responsibility in terms of care-giving and care-receiving (see, for example Engster 2007; Held 2006; Noddings 2002). To care for someone means a commitment to the well-being of that other person, and in its most basic formulation care entails the meeting of the needs of other people. In the words of Noddings (Noddings 2002, p.32): "When we care, we want to respond positively to the needs of another, and a primary need is protection from harm." Good caring requires a certain attentiveness and responsiveness to other people's needs, as well as the willingness and competence to act upon those needs (Tronto 1993; for an elaboration of similar caring qualities see; Fisher & Tronto 1990).

Caring is not limited to personal relationships, as several authors have extended the reach of this notion beyond the private realm, arguing for 'caring' political and societal institutions (Engster 2007; Tronto 1993). Their argument follows from the recognition of the interrelatedness of activities in contemporary societies. Since in the fulfillment of our basic needs, we all build on the activities of other people – such as bakers, doctors, and constructers – everybody is in some way or another dependent on each other. This means we share a common fate with many other human beings, who all actively make and shape their own and our lives and futures at the same time (Adam & Groves 2011). But this results in a situation where everybody is in a vulnerable position; dependency is a fact of contemporary life for everyone, and not only for those that we traditionally single out as particularly vulnerable, such as disabled people or minorities (Kittay 2011). The interrelatedness of human existence justifies a need for caring and cooperation, since "all humans have needs that others must help them meet" (Brugere 2014, p.1). So, to be really caring, one would have to take the needs of many, more distant actors into account (or build a political system that takes care of them). This would provide the social glue that is necessary for safeguarding the quality of our common fate.

Caring is not embodied in one decision or action; it is a particular way of relating to each other. The previous paragraph discussed caring as a desire to improve our coexistence, to collaboratively construct each other's well-being. Following the work of Virginia Held (2006), the ethics of care differs from other normative ethical theories in its focus on the relationships between people, rather than on moral rules or the utility of actions. We have expectations of the moral behavior of people depending on their relationships. For instance, it is worse to be lied to by a friend than by a stranger. The correctness of certain behavior is thus contingent on the relationship it is practiced in. Indeed, this shows similarities to more role-based notions of responsibility, and the quintessential caring relationship of a mother towards a child is often described in terms of a parenting role. But a key difference is the acknowledgment that the person cared for is not passive. Being in a relationship means that there is an interaction between actors and the views and experiences of the care receivers, which is the key to finding out what good care is. This goes against a more paternalistic notion of caring. Good caring is about fostering and developing human relationships, and not only about guiding individual moral behavior.

Given the above discussion of care, it becomes clear that relationships need to have some common structural features in order to be called 'caring relationships'. These are relationships in which (1) people share a mutual concern, namely each other's well-being; (2) respond to each other's needs and ask the care receiver about the desirability of responding to those needs; and (3) express a sense of connectedness, also in more distant relationships, and acknowledge that the bond has certain continuity.

3.6.1. Caring in nanopractice

In the following, I explore how the caring perspective sketched above could take shape in the context of the risk management of nanoparticles in the Netherlands. I discuss what aspects of the relationships between the actors in our case should at least be taken into account in order to arrive at a caring way of dealing with the uncertain risks of nanoparticles. I also demonstrate that some caring qualities are already present in the Dutch situation, but should be expanded to fulfil the requirements of caring relationships.

Safety as a mutual concern

The position of employees vis-à-vis their employers is typically asymmetrical. Employers have the power to make decisions about the type of work to be done, the materials to be used, and the resources necessary to organize protective measures. As a result, employees largely depend on their bosses not to expose them to hazards (not letting them do jobs that are too dangerous) at work. This section discusses how from this asymmetrical relationship a mutual concern arises that can be considered one of the cornerstones of a caring relationship.

The asymmetrical relationship between employer and employee gives rise to a rather formalized form of care (Tjong Tjin Tai 2006). Dutch labor law requires employers to take a protective stance towards their employees by ensuring there is a safe working environment. The employee has a duty to comply with safety standards and regulations, in other words, to also take care of his or her own safety. Still, it is the employer who is primarily responsible for safety, and would have to prove negligence or intentional misconduct on the part of his or her employees to be exempt from liability. As a result, safety is, at least legally, of mutual concern to both employer and employee. This is, however, more complicated in the case of the uncertain risks posed by nanoparticles. In this case, the safety – or rather, the potential lack of safety – of these materials is not yet known, which makes it harder to legally enforce this mutual concern.

Additionally, self-regulatory practices for hazardous working environments seem to assume the existence of caring relationships, or at least demand some sort of shared responsibility, which is a starting point for caring behavior. For instance, the registration and monitoring system proposed by the Health Council should be considered an acknowledgement of this mutual concern, as it requires employers to register any health effects related to nanoparticles in order to allow the early identification of future employee health and safety concerns. The emphasis on establishing safety cultures in working environments is another example of how mutual concerns are evinced (Guldenmund 2000; Kastenberg 2014). However, even with the acknowledgement of a mutual concern, the way caring relationships manifest themselves may vary considerably.

Connectedness

Employees in the Netherlands are often only involved in risk decisions through formal representations. Most discussions concerning risk management are held by experts and employer and employee representatives; employees are rarely directly involved (Popma 2013a). Because the caring relationships of the type envisaged above are more demanding in terms of interaction, in this section I discuss what type of connections are in place in our case and to what extent we can call them 'caring.'

The guidelines imply different ways of interaction between employer and employee in their application. The nanoreference values are constructed in such a way that they are merely applied in work settings. Using them requires some sort of measurement of exposure, which then justifies a go/no-go decision. The Stoffenmanager seems to leave more room for negotiation, since the risk prioritization that is made through control-banding is contingent upon the practical existence of (and compliance with) protective measures. This means that the outcome of this process needs to be adapted to work floor practices, and is therefore more likely to spark interaction on the work floor. The guidance on working with nanoparticles is presented as a shared product of employers and employees, and suggests creating opportunities for discussing them on the work floor during "toolbox meetings" or work meetings, or through information leaflets. Compliance with this guideline would include the active creation of workplace relationships to deal with nanoparticles.

It must be noted, though, that experts play a powerful role in supporting the caring practices of employers. Employers, many of whom do not have OHS expertise, have a legal obligation to seek expert advice and support in order to ensure that they are using state-of-the-art information in their OHS decisions. This means that employers depend to a large extent on experts in interpreting scientific information and in making decisions concerning the identification and containment of hazards. These experts can be employees of independent companies, such as Arbo Unie (which was involved in constructing the Stoffenmanager Nano), or in-house OHS personnel. Depending on their position, they may be more or less effective in embodying the mutual interest of employer safety. Additionally, experts, and various other actors, are influential in setting standards for good conduct in handling nanoparticles. First of all, the government may fund organizations – such as RIVM (which derived the nanoreference values), TNO (the co-creator of Stoffenmanager Nano 1.0), or IVAM (who helped establish the guidance on working with nanoparticles) – to create tools for dealing with nanoparticles responsibly. Also the practice of *polderen,* and self-regulation in general, presupposes active collaboration between labor organizations and industrial organizations. If it were not for the existence of all these connections, the guidelines would not exist.

It thus seems that the legally, rather simplistically presented, dyadic caring relationship between employer and employee is in practice much more complicated: the standards of care that are set in practice, arise from all kinds of interactions and relationships. And this may complicate risk decisions, because more players join the discussion.

For risk management strategies to be truly caring, not only must they be characterized by strong connections, but these relationships should also be of a certain quality. Given the complexity of the interactions presented above, there is a possibility that employees become overpowered by other actors in the debate. In response to this, experts could, for instance, ensure that working practices are safe despite the power dynamics between employer and employee, industrial organizations, and labor unions. At the same time, we should not be naïve about the influence that experts themselves exert when giving advice and developing risk management strategies. For employees, there is a big risk of being lost in the communication, as their views may be neglected or dismissed as those of laymen. Thus, for experts to support caring practices, it may be preferable for them to play a role as a third party guarantor (Bachmann & Inkpen 2011), or as an ombudsperson, rather than merely a scientific advisor.

Responsiveness to needs

Given the vulnerable position of employees, not only recognition of a mutual concern and a level of connectedness, but also responsiveness to employees' needs are essential to a caring approach. Because of the uncertainty concerning nanoparticles, there is still much to learn about both the risks and the effectiveness of protective measures. Workers are in the best position to have first-hand experience with nanoparticles and are able to assess the practicability and viability of risk management strategies,[24] that is, if they know that they are working with nanoparticles.[25] Therefore, working relationships should have an ongoing opportunity for feedback in the design of risk management strategies. From an ethics of care perspective, these guidelines should ideally be 'living documents' – on-going learning processes – rather than be presented as a final product.

All three guidelines have been developed with the physical needs of employees in mind; the aim is to not expose employees to dangerous materials in their working environment. It is, however, less clear how the use of the guidelines leads to more direct responsiveness to voices on the work floor. To what extent are workers' voices really heard, and to what extent are risk management strategies adjusted in response to their needs? Perhaps the most developed guideline in this respect is the one that calls for clear communication and workplace meetings about risks and uncertainties on the work floor.[26] However, even the

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24 Indeed, workers are also often in some way responsible for creating risks; for instance, their cleaning behavior may very much influence the spread of nanoparticles through working spaces.

25 Because nanoparticles are not formally classed as dangerous materials, products containing nanoparticles do not have to be labeled as such. Workplace labeling is mandatory when supplying and handling "regular" dangerous substances; for instance, warning labels are placed on the packaging of products and materials. This means that in some instances people may not even know that they are working with nanoparticles, which makes it harder to pick up on any nanoparticle-related health effects.

26 This guideline provides limited suggestions on how to actually organize and feed the experiences of employees back into risk management practices on the work floor. However,

availability of the different guidelines may spark discussion. A developer of Stoffenmanager Nano 1.0 argued that the use of this tool already makes people see the potential risk of nanoparticles and can function as a starting point to make these risks discussable.

From a caring perspective, responsiveness to the needs of stakeholders should include not only physical health and safety, but also a broader range of concerns. As argued, the PP calls for discussion about hazards in terms of risk and uncertainty, but the desirability of exposure to new materials and the precautions to take do not depend only on the knowledge of the physical effects they may cause. Studies on the acceptance of new and emerging technologies, like nanotechnologies, show that people may be concerned about or fearful of the societal and sometimes very transformative effect technologies may have. These may be fears that, from a precautionary perspective, do not legitimize a change in working practices, but can legitimate such changes from a caring perspective. For instance, nanotechnologies are arguably part of a new industrial revolution, transforming working practices and production processes. This may create fear of job losses on a vast scale. Such concerns are not directly the result of a change in the scientific status of the risks of nanoparticles, but are part of a normative and social debate on the role of technologies in our lives. From a caring perspective, some sort of response to these kinds of concerns is demanded from employers as well.

In addition, employers (as well as all the actors involved in the debate about nanoparticles) should not assume that they know what employees' needs actually are, because it may be the case that employees do not mind facing certain risks during their work. Perhaps employees are willing to run these risks because it is part of their job. For instance, two university researchers I spoke with accepted uncertain risks as part of their job in highly innovative surroundings. In these cases, caring and responding to needs does not automatically mean the reduction of exposure, as long as employees have a say in it; a need for respecting employees' autonomy can be greater at times than the need for physical well-being. This would, however, require a certain level of agency and room for reflection that may not always be present in employer–employee relationships.

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the absence of specification in the guidelines does not imply that there is no opportunity for employees to communicate their needs.

This is exactly why it is important to look at the relational configurations of such relationships.

To enable the attentiveness and responsiveness to employees' needs that is so valued from a caring perspective, the social relationships on the work floor must meet certain standards: the distance should not be too great in order to lower the threshold for employers to speak up; they need to express a certain continuity to create a dialogue on these matters, for instance, by establishing fixed times for discussion, or establishing recognizable channels of communication. This can prove difficult because of all the uncertainty surrounding nanoparticles. For example, during the Stoffendag a member of the audience said that he had difficulty discussing nanoparticles because of the great uncertainties and the fact that he did not want to scare his personnel. Tackling this kind of communication hurdle is essential in order to create room for workers to share their needs. But of course, communication without action is futile; the needs of employees require some sort of response from an ethics of care perspective, for instance, by changing risk management strategies or, perhaps, by simply acknowledging that an employee is in a precarious situation.

3.6.2. Care as a decision criterion complementary to the precautionary principle

I have discussed several characteristics of caring relationships and how they may inform a discussion about the risk management of uncertain risks. Most of the characteristics were recognizable to some extent in the case, which suggests that the ethics of care could be applied as a way to support decisions when choosing between precautions against uncertain risks. In this section, I make a first proposal for a decision criterion based on these characteristics in order to complement a moderate version of the PP. Given my concern with the applicability of the PP, any attempt to complement the PP will be ineffective unless one at least tries to operationalize it into a practicable decision criterion, otherwise it will be just as susceptible to the paralysis objection. Therefore, based on the discussion in this chapter, I suggest that the moderate version of the PP be complemented with the following decision criterion.

> *Moderate PP: When exposing employees to nanoparticles that pose uncertain risks, precautions should be taken.*

Complementary criterion: If there are multiple precautions available and they are on a par in terms of precaution, then:

(1) *Choose either a precaution that is an expression of a mutual concern (legally, financially, or otherwise) between risk-imposer [in this paper: employer] and risk-bearer [in this paper: employee] for the safety of the risk-bearer, or a precaution that leads to the sharing of a concern for the risk-bearer's safety.*

(2) *Choose either a precaution that is the product of an ongoing direct contact between risk-imposer and risk-bearer (e.g., a collaboration with regular contact), or a precaution that results in more connectedness between risk-imposer and risk-bearer.*

(3) *Choose either a precaution that is a result of a responsive relationship between risk-imposer and risk-bearer (e.g., a risk-imposer showing a demonstrable interest in the risk-bearer's needs and acting upon it), or a precaution that results in greater responsiveness of the risk-imposer and the risk-bearer.*

Working relationships should ideally meet all criteria; however, as to the relationship between these conditions, there is still some work to be done. Conditions 1 and 2 seem to be constitutive of the responsiveness condition described in condition 3. They are necessary, but not sufficient, conditions for creating a responsive relationship. Given the rationale of working conditions regulation to protect the interests of employees vis-à-vis their employers, it appears logical that the achievement of the third responsiveness condition should be at least decisive in comparing precautions that do not meet all three conditions.

3.7. Conclusion

I argued in this paper that when deciding on risk management strategies for exposure to nanoparticles in workplaces, the precautionary principle is underdetermined. Through this inquiry I demonstrated that in situations where we want to make use of these new materials, a moderate PP version fails to be action-guiding in terms of providing a way to choose from the available precautionary strategies. There are multiple strategies to deal with the risks posed by nanoparticles in the workplace, but due to a lack of scientific knowledge and shared standards for comparing protective measures, there is no clear criterion to decide which strategy is best in terms of precaution. This problem might not be limited to the nanoparticles case, as many technological and scientific products are surrounded by similar uncertainty. In these cases, too, an absence of knowledge can impede the comparison and choice of precautions. Even more so, this study focused on the relatively 'simple' case of the threat of a new substance to a single body. However, in more complex cases – such as devising precautions that take into account the interaction effects of nanoparticles in the environment, or user behavior – it is more likely that several precautionary strategies co-exist and are seemingly on a par.

I therefore proposed complementing the moderate PP in such situations with a decision criterion that judges the relationship between risk-imposer and risk-bearer, based on the ethics of care. In a sense, the PP provides only a narrow conception of care that urges risk minimization (if not avoidance). In this paper, however, I argue for a more comprehensive view of care. I contend that we should reflect on the social context in which risk impositions occur in the absence of scientific criteria on which to base risk decisions. Focusing on the social relationships in which risk decisions are made teaches us to judge the caring qualities of those relationships by assessing three conditions, namely (1) the acknowledgement of mutual concern, (2) whether there is a sense of connectedness, and (3) the responsiveness to employees' needs. At first glance, this approach may seem contradictory to the idea of precaution, as it does not aim to preclude the imposition of risk. However, if we accept a moderate version of the PP, we have to accept that there is always a small chance that hazards will occur as a consequence of risky working practices. Since we lack the scientific criteria to determine which precaution is more or less risky, I suggest that we should shift the discussion from the acceptability of scientific risks, to creating a social context in which the imposition of the residual uncertain risks is deemed acceptable, that is, a situation in which the needs of employees play a central role and there is room for employees to express those needs.[27]

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27 One may even argue that if exposure to uncertain risks takes place after taking precautions and within caring relationships (thus, in work settings or in other kinds of innovative practices that

A next step in research is needed to see whether and, if so, how the characteristics of caring relationships, as they are discussed in the ethics of care literature, translate to other situations. It may help in other cases of technological or scientific development in which the precautionary principle is invoked, but has led to a multitude of incomparable precautions. However, especially when applying the decision criterion to cases where relationships are less proximate – such as with societal actors or, when no direct feedback can be expected, in the case of the environment or future generations – more work remains to be done.

can be genuinely considered caring), harm that would occur as a result of workplace exposure to uncertain risks is not necessarily irresponsible or a breach of the duty of care, but rather a tragic consequence of unforeseeableness and risk of working with new materials and technologies.

4 Just a cog in the machine? The individual responsibility of researchers in nanotechnology is a duty to collectivize[28]

The previous chapters focused on existing relationships and how the qualities of those relationships influence the way we deal with the uncertain risks of nanomaterials. However, there are situations in which relationships are not already in place. The nanotechnology field is still emerging and remains very dispersed. For example, there are no professional associations that could back or support moral discussion about the ethics of and decisions concerning uncertain nanomaterial risks. Therefore, this chapter explores whether there is a moral imperative to build relationships to ensure that uncertain nanomaterial risks are dealt with adequately. More specifically, the chapter examines the building of relationships in the light of recent discussions on the topic of Responsible Research and Innovation (RRI).

Literature on RRI places great responsibility in the hands of scientists and engineers to quickly act upon any emerging unwanted effects (Section 4.1). By means of collaborative research (Section 4.2), two nano-engineers and myself have explored the meaning of responsibility in the development of nanotechnologies. However, acting upon such responsibility cannot be done alone (Section 4.3.1): it requires information sharing and collaboration. At the same time, there is no collective organization that could bear this responsibility because of the dispersed nature of the nanotechnology field, with its many and diverse range of actors (Section 4.3.2). Therefore, Section 4.4. argues that individual researchers in such situations should organize themselves; they have to build relationships in order to form communities that *can* carry responsibility. While there are still some challenges to be faced if one wants to take such an

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approach (Section 4.5), this approach will be valuable beyond the discussion of responsibility in the nanotechnology field (Section 4.6).

4.1. Introduction

Responsible Research and Innovation (RRI) is emerging as one of the leading paradigms for discussions concerning the governance of new technologies. Broadly speaking, research and innovation following the RRI praxis should lead to the development of technologies that promote social and environmental values (Owen et al. 2013; Van den Hoven 2013), and respond to the grand challenges of our time (Von Schomberg 2013). While few engineers and scientists would disagree with the goals of incorporating social and environmental values into research and innovation, how to accomplish such lofty goals is not so clear. Consider technological innovations that are characterized by a high degree of uncertainty. In the early stages of development it is difficult to predict the impacts of the technology, whereas in later stages the ramifications may be more difficult to rectify due to entrenchment and technological lock-in (Collingridge 1981). Scholars involved in the discussion concerning RRI aspire to provide an answer to this 'dilemma of control' by developing RRI as a framework that is both flexible and responsive, in order to be able to adapt to new (scientific) information and changing ethical perspectives on technological impacts (Nordmann 2014; Owen et al. 2013).

RRI is characterized by a shift from assessing the desirability of the *outcome* of innovation processes, such as evaluating harmful product outcomes in court under liability law, to assessing the qualities of the innovation *proces*s. Drawing heavily on ideas like constructive technology assessment (Rip & Te Kulve 2008), midstream modulation (Fisher et al. 2006; Schuurbiers 2011) and anticipatory governance (Guston 2013; Sarewitz 2011), several authors have proposed methodologies for assessing the responsibility of research and innovation. The RRI paradigm proposed by Stilgoe, Owen, Macnagten and their colleagues has four dimensions (Owen et al. 2013; Stilgoe et al. 2013). They propose that research should be: anticipatory, exploring in advance and anticipating potential technological impacts; reflective, by examining goals and purposes of technologies as well as the uncertainties in risk assessment; deliberative, the idea that public and diverse stakeholders' perspectives are actively considered during design processes and, lastly; responsive, the actual alteration and shaping of technological trajectories in response to deliberation and reflection. Jeroen van den Hoven

(2013; 2009) proposes Value Sensitive Design as a methodology for RRI; conceptual and empirical research with the aim of value identification, and a value-directed design methodology would be needed in order to make innovation more responsible. Van de Poel writes about the responsibility of innovation processes in terms of responsible experimentation (2009; Van de Poel & Royakkers 2011). Since research and innovation in new and emerging technological fields are prone to uncertainty, we should perceive them as forms of social experimentation. Van de Poel argues that such experiments should be governed by normative requirements drawn from the realm of bioethics and medical experimentation.

The process orientation that is integral to RRI is predicated on some form of organization. The abovementioned approaches all assume that technological development trajectories are actively steered in light of new information perspectives on technological risks, or other socially or environmentally undesirable impacts. This is a core tenet of RRI. It follows that we must then ask: who is actually doing RRI? Processes cannot be responsible, nor can they reflect on or account for what they do and make intentional choices. In the end, responsibility should rest with a particular agent. RRI refers to a collection of individual agents that perceive, reflect, and act together in such a way that this leads to technologies being designed with certain values in mind. While it may make sense to set process level requirements when designing a governance structure, when it comes down to allocating responsibility we must focus on individual agents since individuals, not processes, can be the subject of responsibility claims. They are the ones who, under the header of RRI, should "either feel responsible, or can be held or can be made responsible" for the course of innovation processes (Van den Hoven 2013, p.81).

The purpose of this paper is to elaborate the responsibilities of individual researchers in RRI. We argue that, for engineers and scientists to successfully implement RRI, they have a *duty to collectivize* and must develop organizations to facilitate RRI since this is so difficult for individual agents to achieve on their own. We use nanotechnology as a case study to develop our argument, in part because the National Nanotechnology Initiative in the United States has identified supporting the responsible development of nanotechnology as one of its four primary goals. We focus on the nanotechnology field at the University of California, Berkeley (UC Berkeley), a world leader in nanotechnological research. We first explore how the emerging and enabling nature of nanotechnology makes it difficult for individual researchers to contribute to RRI. We examine how the limited individual capacity of researchers to control and foresee nanotechnological development impedes the allocation of responsibility. Next, we argue that there is no collective agent within the nanotechnology field that could be capable of RRI. Then, we turn to a more theoretical discussion on how the dispersed nature of the nanotechnology field impacts individual responsibility. We develop a set of criteria to argue that researchers involved in nanotechnology have a duty to collectivize, to organize themselves into a collective that can innovate responsibility. This framework offers a new perspective on individual responsibility for RRI.

4.2. Research Approach

This paper is the product of a collaborative study, or rather a collaborative reflection, on the ethical dimensions of nanotechnologies. From the summer of 2013 to the spring of 2015, a group consisting of two PhD students in engineering from the UC Berkeley and one PhD student in ethics from Delft University of Technology participated in the jointly organized program Global Perspectives (Hoople 2014; Rolfe 2014; Spruit 2014; Sunderland et al. 2014). During this program, the authors were sensitized to each other's work and encouraged to come up with joint research projects, using collaboration as a form of research (Calvert 2014).

Nanotechnologies are a central theme in the work of all three the authors, though GH and DR are involved in it from an engineering perspective and SS from an ethical perspective. We easily engaged in discussions concerning ethical issues in engineering work; however how to operationalize ethics in nanoscience and technology was not at all obvious. For instance, after reading nanoethics texts for the Global Perspectives, DR and GH felt the field was often too speculative and inclusive of non-nanotechnologies. We all experienced the field as ambiguously defined and found its terminology heavily skewed by the external pressures of funding and networking activities (Nordmann 2007). Furthermore, little work seemed to address DRs immediate concerns about nanotechnologies, such as the use and risks of nanomaterials in working environments and the effect of nanoparticles on the environment. At the other end of the spectrum, SS was surprised by how little room was reserved for discussions of such topics within daily research practices at UC Berkeley. Along the way we realized that, for engineers and ethicists to find each other's work relevant, it is critical to develop a shared understanding of what the field of nanotechnology entails as well as what responsibilities come with being a member of the nanotechnology community. This paper is a first attempt to develop such a shared understanding, and can be read as a self-reflection and a result of the position that we take within the field: PhD researchers.

The empirical sections of this paper are based on the local contexts of UC Berkeley, and describe the academic setting experienced by GH and DR. UC Berkeley is an academic leader in nanotechnology with over 100 faculty across ten departments researching in this area. That said, we think our analysis is generally representative; we take it that the dispersed structure around nanotechnology research is fairly representative of the way nanoengineering research is conducted at top research institutions in the United States and sheds light on the more general topic of how converging fields with no clear and monolithic institutional space (such as a stand-alone department) impede individual responsibility-taking.

4.3. Responsible Research and Innovation in Nanotechnology

In 2000, Bill Clinton launched the National Nanotechnology Initiative (NNI), a research program devoted to advancing understanding and control of matter at the nanoscale (Sargent Jr. 2014). Since then, the United States federal government has invested $19.4 billion in the program. The initiative has led to a wide range of innovations, ranging from breakthroughs in battery technology to nanoscale transistors. Nanotechnology may be thought of as a range of tools that enable advancements in other fields, including biology, electrical engineering, materials science, and physics. Nanotechnologies are of great interest to scientists and engineers because the physical nature of matter and energy changes as we reach the nanoscale. When matter is constrained to the scale of nanometers in at least one dimension, roughly 10^{-9} meters, it exhibits novel physical, electrical, and optical properties. The most notable of these changes is the presence of quantum effects that cannot be seen in larger materials. These properties allow scientists and engineers to create improvements across disciplines such as surface interactions, molecular biology, semiconductor physics, and microfabrication. Nanotechnology research extends from fundamental science to consumer applications, which makes it difficult to develop an overall approach for enabling nanotechnological researchers to evaluate and address the ethical risks posed by their work. This is particularly true for researchers of fundamental nanoscale physics and cutting-edge nanofabrication technologies. Research in these fields seeks to understand the physical phenomena and fabrication techniques that may later serve as tools for a wide range of disciplines. These approaches are often implemented into applications that the initial researcher had never imagined.

One of the four stated goals of the NNI program is to "support responsible development of nanotechnology" (National Science and Technology Council 2014). While this seems to suggest that nanotechnology is a uniform and distinct field, posing a unique set of ethical concerns, in practice, nanotechnological research is interdisciplinary, dispersed, with many actors and structures governing the funding of and research in this field. Nanotechnology research has advanced widely, but only a single major research institution (UC San Diego) has created a stand-alone nanotechnology department. Elsewhere, researchers are spread across many departments based on the applications of their nanotechnological research. So most nanotechnological research exists within an application discipline. This structural arrangement facilitates collaboration between experts in nanotechnology and experts in application fields. Interactions between actors within nanotechnology are limited to more informal structures such as shared research spaces, funding initiatives, seminar groups, and certificate programs. In practice, this limits the forums for nanotechnological researchers to discuss ethical responsibilities that may be unique to nanotechnology. Thus the key question is: given the state of the nanotechnology community, how can individual researchers achieve the NNI's goal of supporting responsible development of nanotechnology?

4.3.1. Limitations on the Capacity of Individual Researchers to Steer Nanotechnological Development

By working with materials and devices at the nanoscale, scientists and engineers are able to make significant advances in a wide range of industries, including drug delivery, transportation, weaponry, and microprocessors (Lin & Allhof 2007). Here we argue that this structure makes it challenging for individual researchers to steer nanotechnological development, because it impedes their capacity to control and foresee how nanotechnologies will be developed and applied.

A key characteristic of nanoscience and nanotechnologies is that they play an enabling role in other fields. The enabling effects of nanotechnology can be broken down into two basic categories: sustaining innovations and disruptive innovations. Computer processors are an excellent example of how nanotechnology enables sustaining innovation. In 1965, Gordon Moore, co-founder of Intel, predicted that the number of transistors on a computer processor would double every two years. Maintaining this pace over the last five decades has forced engineers to constantly find ways to reduce the size of transistors. Without the enabling effects of nanotechnology, Moore's law would have failed long ago. While the process for making computer components has not fundamentally changed, the ability to manufacture at smaller and smaller sizes has made new chipsets possible. In other fields, nanotechnology has acted as a disruptive innovation, enabling previously inconceivable discoveries. Biological systems are inherently nanostructured and nanofunctional, so the advent of nanotechnology allows for a literal quantum leap in medical systems. Some of the most promising early applications of nanomedicine have come in the realm of drug delivery. Polymer-drug nanoparticles and nanodrug delivery devices with variable diffusivity allow drugs to be delivered to targeted regions of the body (LaVan et al. 2003). In applications such as anti-cancer drugs, such technology could target tumors while protecting healthy cells from toxic exposure. Nanotechnology has also allowed for the synthesis of tissues that might 1 day become implantable organs (Griffith & Naughton 2002).

A consequence of developing an enabling technology is that inventors must relinquish control of their inventions to those who use the technology. The emergence of nanoscience and nanotechnology has created, and continues to create, opportunities for research and technological development beyond the scope of the nanotechnology community. The capacity of individual scientists and engineers to steer or adjust nanotechnological developments is strongly determined by their influence on the fields in which their technologies are going to be applied. Although most nanotechnological research occurs in a university setting, the resulting ideas are commercialized by corporate entities that license the intellectual property. In such cases the capacity of the basic researcher to influence nanotechnological applications could be even more limited.

Furthermore, as researchers in nanotechnology do groundbreaking work they may be unwittingly laying the scientific framework on which applications will later be based. In a way these nanotechnologies are like hammers looking for nails; their effects only materialize because of their enabling effects. Researchers may have a particular application in mind during the development phase, but often it is the unexpected or unanticipated discovery that produces the most interesting technology. Consider the case of quantum dots. Energy level confinement was first discovered in 1974, with the name 'quantum dot' first applied in 1988 (Reed et al. 1988). Forty years later, the initial discovery has led to transistors, solar cells, LEDs, and diode lasers. In 2013, a flat-panel television became the first example of a commercial technology incorporating quantum dots (Bullis 2013). Nearly 40 years passed before the initial innovation resulted in a commercial application.

Consequently, it seems unreasonable to expect individual researchers to bear the responsibility and to be able to steer nanotechnological trajectories resulting from their enabling work. Scientists and engineers working on nanotechnology are only able to oversee a relatively small part of the innovation process. This is, of course, not a new critique; a similar argument has been made by Swierstra and Jelsma who render individual accountability for technological development problematic because of the collaborative nature of science (Swierstra & Jelsma 2006). Parallels can also be drawn with discussions of 'many hands problems' in engineering contexts, in which a group of actors cause harm through their combined behaviors rather than individual wrongdoing. In such cases the distribution of labor also means that individuals lack the capacity to prevent major harm single-handedly.

While the challenges of steering technological trajectories are indisputable, does this absolve enabling scientists and engineers of all moral responsibility for how their technology is used? We think not, since nanotechnology researchers have still contributed to the innovation processes, even though their individual impact takes place over large spans of time. In a sense, individual researchers share a responsibility with all those involved in nanotechnological developments. While they may not be individually responsible, by contributing to a shared innovation trajectory they seem to play a part in a larger collective that may be a reasonable candidate for bearing this forward-looking responsibility (Miller 2006). Next, we will explore the extent to which the nanotechnology community as a whole could serve as a vehicle for allocating forward-looking responsibility to individuals.

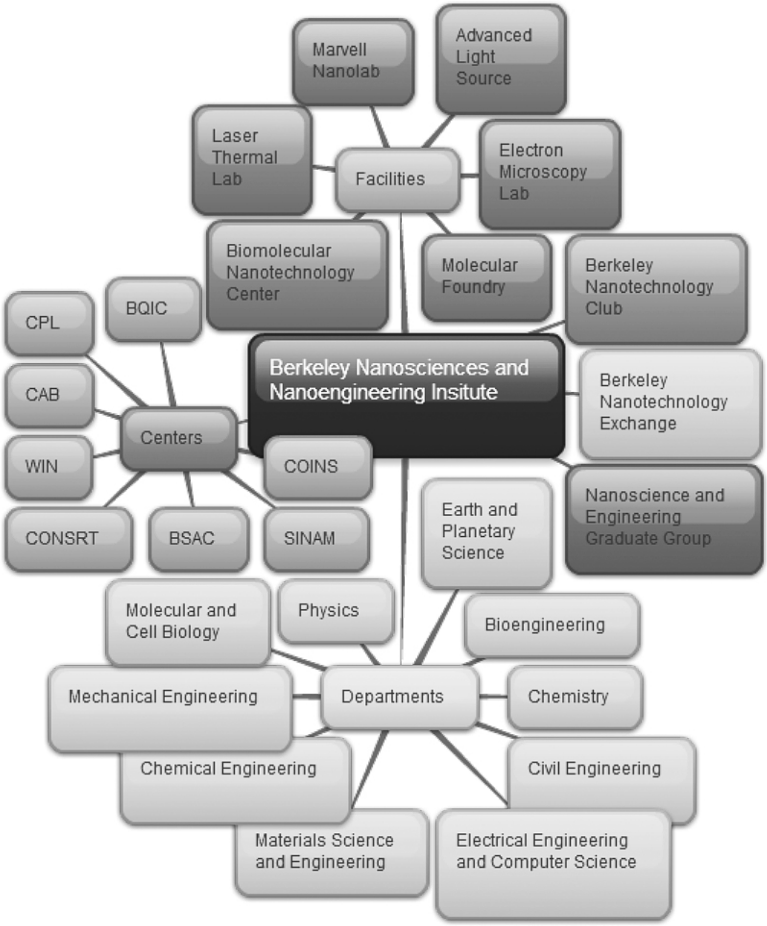

Figure 4.1. Overview of Nanoscience and Nanotechnology at University of California Berkeley. On top you can find the shared facilities that fall under the header of nanotechnology, (on top) such as the Marvell Nanolab discussed in the text. The academic departments involved in the Berkeley Nanosciences and Nanoengineering institute are listed at the bottom. On the left several specialized research centers are listed (in counter-clockwise order); The Berkeley Quantum Information and Computation Center (BQIC), The Cell Propulsion Lab (CPL), Center for Analytical Biotechnology (CAB), Western Institute of Nanoelectronics (WIN), a DARPA-funded research center in nano-opto-electronics (CONSRT), Berkeley Sensor and Actuator Center (BSAC), the Center for Scalable and Integrated Nanomanufacturing (SINAM) and Center of Integrated Nanomechanical Systems (COINS). On the right handside you can find The Nanotechnolgoy club, which organizes events for graduate students and undergraduates to educated them about nanotechnology. The graduate nanotechnology group directs the special emphasis in nanotechnology that is part of doctoral education, and is responsible for cross-listing classes in the Department of Nanoscience and Engineering (which has no professors, labs or majors). The nanotechnology exchange is an industrial outreach program, that lets corporate sponsors find research and labs that they are interested in.

4.3.2. The problem with defining a collective agent in the nanotechnology field

We have concluded that, if we want nanotechnology to be developed responsibly, individual researchers must in some sense share this responsibility with others involved in the nanotechnology research and development process. Because of their higher level of organization, such groups of people may constitute a collective that can bear forward-looking responsibility. Collective agents are generally distinguished from mere aggregates of people acting in parallel by (1) the existence of some sort of group decision mechanism, (2) the achievement of, or aspiration to achieve, certain common aims, and (3) the assignment of roles and tasks to group members in order to achieve those aims (Collins 2012; Pettit & Schweikard 2006). Given the fact that individual researchers have a limited capacity to act, this section will explore the extent to which the field of nanotechnology constitutes a collective or group agent structure with the capacity to steer nanotechnological development.

Nanotechnology is a highly interdisciplinary field; scientists in many fields have sought and found ways to understand, manipulate and create matter at the nanometer scale. As many nanotechnologies are broadly applicable, one of the other ways nanoscientists and nanoengineers interact is around particular research thrusts. Consider again the example of quantum dots. These dots are a topic of study for many researchers at UC Berkeley, including physicists, chemists, materials scientists, and engineers. Among them are Stephen R. Leone, Professor of Chemistry and Physics, and Paul Alivisatos, Professor of Chemistry and Materials Science & Engineering, who have been cross-appointed to a total of four different departments, illustrating how their research transcends traditional disciplines. Professor Leone's research page lists a wide array of topics relating to physics and chemistry, including "ultrafast laser investigations and soft x-ray probing of valence and core levels" and "nanoparticle fluorescence intermittency" (Department of Chemistry Berkeley 2014b). Professor Alivisatos' biography states that his "research concerns the structural, thermodynamic, optical, and electrical properties of colloidal inorganic nanocrystals" (Department of Chemistry Berkeley 2014a). Despite different research thrusts, both professors are interested in quantum dots. They have independently published several papers concerning quantum dots and have also collaborated on one publication (Vura-Weis et al. 2013).

While these two researchers and their research groups are certainly part of a community, they are housed in different departments and pursue different research goals. They do not seem to meet the definition of a collective agent.

Unlike computer science or electrical engineering, nanoengineering is not its own discipline, with a common sense of direction, such as the build up of a shared methodology and body of knowledge. At UC Berkeley the footprint of the nanotechnology collaboration is literally spread over the entire campus. There are over 100 faculty working in nanoscience and nanotechnology, with a multitude of different research thrusts, centers, and collaborations. While describing the full network of actors is beyond the scope of this paper, Fig. 1 gives an overview of the complexity of the network.

In terms of distributing roles or providing a shared decision-making procedure needed for collective agency, the community of scientists and engineers involved in nanoscience and engineering is not a strong organizing force. Researchers involved in nanotechnological development are not part of an institutional framework comparable to those offered by professional organizations in other engineering fields. The UC Berkeley-based Berkeley Nanoscience and Nanotechnology Initiative (BNNI) aims to be "the umbrella organization for expanding and coordinating Berkeley research and educational activities in nanoscale science and engineering" (BNNI 2007, see fig. 1). The organization's website lists researchers working on topics ranging from nanomanufacturing, quantum information and computers to analytical biotechnology. While the BNNI provides a framework for collaboration at UC Berkeley, participation in the nanotechnology community is largely voluntary. Faculty members belong to a home department, such as materials science, but do not share a common nanoengineering department and may choose to participate in some or none of BNNI's activities. In practice, the type of informal interaction between Leone and Alivisatos discussed above is exemplary for the nanotechnology community at UC Berkeley.[29]

Although nanotechnology researchers are unified by the fact that they have all found different ways to understand, manipulate, and/or create matter at the nanometer scale, this does not mean that they can be regarded as one collective

29 The absence of a professional nanoengineering identity is confirmed by the absence of a standalone nanoengineering undergraduate or doctoral program. The BNNI organizes a designated emphasis in Nanoscale Science and Engineering for PhD students. UC Berkeley defines a designated emphasis as "an area of study constituting a new method of inquiry or an important field of application relevant to two or more existing doctoral degree programs. It is not a free-standing degree program, but must be added as an additional major along with an existing doctoral degree program" (BNNI 2014).

or one professional group. The ad-hoc nature of the field of nanoscience and nanotechnology, with its fluid boundaries and elusive membership, does not establish a collective agent through which scientists and engineers could steer technological development together in light of any unwanted outcomes of nanotechnological innovation.[30] This causes a paradoxical situation, in which individual researchers cannot innovate responsibly purely by themselves, while there is also no structural framework to ensure that responsible development of nanotechnologies takes place.

4.4. Reframing the Responsibility of Nanotechnology Researchers as a Duty to Collectivize

The nanotechnology field clearly poses a problem for RRI. While RRI requires some sort of synchronized action, this is challenging due to the dispersed nature of the field. It has been convincingly argued, however, that this does not provide sufficient reason for scientists and engineers to avoid or be excused from responsibility (Davis 2012). Nanotechnology researchers are not just a cog in the machine; they are integral contributors to the invention of nanotechnologies. This section explores a solution to this paradoxical situation, by arguing that these researchers may have a *duty to collectivize*.

Unorganized groups of people pose a problem for allocating responsibility. In the previous section we saw that the level of organization and distribution of roles, the presence of a shared decision-making structure, and shared aims all play a role in determining whether or not we can consider a group a collective agent. We do not presuppose a holistic definition of a group agent. In our view a group is basically an organized set of individuals. Our goal is not to focus on the ontological underpinnings of collective agents. Instead we depart from a fairly uncontroversial assumption that a group's level of coherence and structure

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30 Currently, much of the ethical debate about nanotechnologies takes place outside of the nanotechnology community, in applied ethics or social scientific journals, such as the journal NanoEthics. Alongside the development of scientific advances in nanotechnology has come extensive research into the ethical aspects of nanotechnology, specifically in the field of nanoethics, and more generally in STS and engineering ethics. Discussions concerning nanotechnology have ranged from debates on practical considerations related to chemical hygiene to dystopian scenes of world destruction (Drexler 1986; Gordijn 2005; Lin & Allhof 2007). However, many of the findings that SS shared from her field of ethical inquiry were novel to DG and DR.

influences the extent to which that group of people can be expected, within reason, to be responsible for the behaviors of other group members. Even if no clear group agent exists, we may have the intuition that some sort of shared responsibility is in place. Held (1991) argues that groups that lack the structural organization needed in order to be considered an agent can sometimes be held accountable for collective omissions. For instance, consider strangers on the beach who are confronted with somebody drowning. These strangers have a certain obligation to work together to save the individual from drowning. In such cases we may not hold individuals accountable for the drowning person, but, as Held argues, we would blame these groups of bystanders for not teaming up to save the drowning person. This implies that a random collection of bystanders may perhaps not be a collective agent in the strict sense (having a shared decision-making structure or structural organization), but as group of individuals they have some sort of collective capacity to act.

Collins (2012) builds on Held's idea and proposes a more formalized account of the intuition that, in some cases, individuals have a responsibility to create a collective agent . In short, Collins argues that, in cases where there is a morally pressing issue that could be resolved by a group, but no group agent exists to resolve it, individual agents may have a duty to create a group, a collective agent, that is capable of resolving the issue concerned. For this duty to collectivize to apply, Collins suggests the following Criteria for Collectivization Duties (CCD), which we will discuss and apply to the context of nanotechnology research (CCD-Nano).

4.4.1. Criteria for Collectivization Duties

Collins starts off with five conditions that describe the situations in which collectivization duties are invoked. The first condition defines the moral problem at hand: "φ is morally pressing" (Collins 2012, p.244), which means that there is an activity φ, that must be performed because it is morally valuable in itself or because it brings about a certain morally desirable outcome. In the debates concerning RRI we can recognize both meanings of morally pressing: the incorporation of multiple values into science and engineering is seen as a democratic goal in itself, while it would also lead to the development of technologies that are socially and environmentally acceptable. This then leads to a reformulation of this criterion that overlaps with the stated goal of the NNI: Responsible Research and Innovation of nanotechnology is morally pressing.

The next condition declares that there is nobody, either an individual person or a collective, who actually has a duty to perform the activity φ (in our case: responsible development) that would bring about desirable outcomes: "at t_1, either: no (collective or individual) agent/s have duties, either to φ or to take responsive actions with a view to there being the morally desirable outcome that φ produces; or too many agent/s with such duties default" (Collins 2012, p.244). Two kinds of duties are mentioned in this condition. The first is a direct duty to φ and the second is a duty to take responsive actions to φ, thus a duty to contribute to φ taking place. We interpreted the first direct duty as the duty of RRI, for which we know there are no individuals who can do this independently, and for which there is also no clearly identifiable collective agent. The second duty to "take responsive steps towards φ" implies that agents can take independent steps that lead to the performance of action φ, meaning individual scientists and engineers or groups of people whose combined activities lead to responsible nanotechnological development. Based on this we propose the following reformulation of Collins second criterion: "there are no individual researchers or group agents, such as professional organizations or authorities, that bear the duty of RRI, or take independent steps that would lead to RRI, or too many agents with such duties default."

The third criterion relies on a counterfactual conditional, deriving a duty to create a collective from the statement that a collective would be able to bear a duty once it exists: "if, at t^1, [individual agents] A, . . . , N each took responsive steps towards there being a collective-that-can-φ, then, at t^2, that collective would incur a duty to φ" (Collins 2012, p.244). So, if individual researchers took steps towards forming a collective agent that *can* responsibly develop nanotechnology than that collective agent would be bestowed with a duty to develop responsibly. Collins does not elaborate on the normative basis for this duty; why it would suddenly emerge once the collective exists. We choose to interpret this as a duty derived from the collective's capacity to act; since a collective would be able to facilitate responsible development of nanotechnology, this collective would bear this obligation. As this may seem a heavy burden, we will discuss this obligation in more detail in the next section. The reformulation of this criterion becomes: "if researchers organized themselves into a collective that can do RRI, then this collective, once established, would have a duty of RRI."

The fourth criterion sets limits on the burden that may rest on individual agents to organize themselves: "at t^1, [individual agents] A, . . . , N are each able to take responsive steps towards there being a collective-that-can-φ at a reasonable expected personal and moral cost." We translated this into: "researchers involved in nanotechnology development are able to take steps towards organizing themselves without considerable personal and moral costs," limiting the demanding nature of the collectivization duty for individual researchers.

The fifth criterion states that "other individuals will not successfully take responsive steps towards there being a collective that will incur a stronger duty to φ." The key idea here is that an individual's collectivization duty is contingent upon the activities of other individuals, who, if they collectivized (a) would fulfill the morally desirable activity, and (b) would as a collective have a stronger duty to φ than other collectives. Collins does not specify what constitutes a stronger duty to φ for collectives. However, given the action-oriented nature of Collins proposal we assume that collectives with a stronger capacity to φ would have a stronger duty to φ. Other considerations could also play a role in determining the strength of this collectivization duty. An example is the extent to which the collective has benefited from the situation in which the morally pressing issue emerged. This will be addressed in more detail in the discussion. We propose the following formulation: "there is no reason to believe that other individuals will collectivize into a group that would have a stronger duty to do RRI."

If these five criteria are met, then this would give individual agents a duty to collectivize, meaning that: "at t^1, [individual agents] A, . . . , N each have a duty to take responsive steps towards there being a collective-that-can-φ," which means that individual researchers have to take steps towards organizing themselves into a collective that can develop a mechanism for responsible innovation. Once such a collective is formed, it has a duty to facilitate responsible innovation. As follows from the translation of Collins' seventh CCD: "at t^2, once a {A, . . . , N} collective-that-can-φ is formed, that collective has a duty to φ." This is essentially a confirmation of the third criterion in the antecedent. Next: "at t^3, once the collective has distributed φ-related roles, each member with a φ-related role has a duty to perform that role" (Collins 2012, p.244). Once a collective is formed with the aim of developing responsible innovation methods, and all of the individual researchers understand their roles within this collective, the individual researchers have a duty to perform their individual roles.

This leads to the nanotechnology-adjusted version of Collins proposal for collectivization duties: CCD-Nano:

If:

- (1) *RRI of nanotechnology is morally pressing, and*
- (2) *there are no individual researchers or group agents, such as professional organizations or authorities, that bear the duty of RRI, or take independent steps that would lead to RRI, or too many agents with such duties default, and*
- (3) *if researchers organize themselves into a collective that can do RRI, this collective, once established, would have a duty to do RRI, and*
- (4) *researchers involved in nanotechnology are able to take steps towards organizing themselves without considerable personal and moral costs, and*
- (5) *there is no reason to believe that other individuals will collectivize into a group that would have a stronger duty to do RRI*

then:

- (6) *individual researchers have to take steps towards organizing themselves into a collective that can do RRI, and*
- (7) *once this collective is formed, it has a duty to do RRI, and*
- (8) *once this collective has distributed roles to individual researchers, each member has to perform his or her individual role*

This idea of collectivization duties fundamentally shifts the discussion about how to implement RRI in the case of nanotechnology. Rather than focusing on particular harmful impacts and risk impositions that may be difficult to prevent due to limited power or ignorance concerning future developments, it presents something that is within reach of individual researchers: the *duty to organize themselves*. Researchers at all levels in nanotechnology have the individual agency to contribute to this goal, though their activities depend on their position and power within the field (as secured in criterion 4). Individuals know how to create structures and procedures and allocate tasks to create a collective, which can in turn ensure that technological development proceeds in a responsible manner.[31] Similar work was done during the nascent years of computer science. Individuals in this group collectivized in order to form a new professionalism in their field. They formulated codes of practice and ethical guidelines to describe acceptable ways of practicing software engineering (Gotterbarn 1997). If our argument holds, individuals who do not take adequate responsive action with a view to creating a collective would be taking an irresponsible moral risk.

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[31] The result of this may be alliances with people external to the research field (like the alliance between the authors of this paper), such as nanoethicists who help analyze what responsible development of nanotechnologies actually entails.

4.5. Discussion: Challenges in Applying the Duty to Collectivize in the Nanotechnology Context

Before we can unambiguously apply the criteria for collectivization duties that we modified for the nanotechnology context (CCD-Nano), there are some challenges to overcome. Only then can we use CCD-Nano to establish whether researchers working on nanotechnologies have a duty to collectivize. We will discuss these challenges with a view to improving our approach for future use.

The first objection one could raise to a collectivization duty in nanotechnology is that it is unclear when an issue is morally pressing enough to justify a need for forward-looking responsibility. Held's example of a person drowning seems morally clear; it is obvious that some sort of action would have to be taken in life or death situations. Something similar can be said for preventing known risks. We can reasonably expect a certain duty to prevent health and environmental risks or negative social impacts. This would, of course, be proportional to the magnitude and likelihood of that particular risk. In the case of uncertain risks, however, this is much more difficult. In the case of nanotechnology, something may have the potential to cause harm due to unforeseen technological developments, but we have no certainty about what exact threats may emerge and no way of calculating probabilities of these events occurring. In such cases a duty to take action is much harder to justify.

Therefore, the key to developing CCD-Nano is to reflect on what would constitute a sufficient reason to expect people to organize themselves. Which concerns warrant collectivization duties and which do not? One way of addressing this issue in the case of nanotechnology could be to take the precautionary principle as an indication of the urgency of the matter. Several scholars have argued in favor of a precautionary approach to uncertain nanotechnological risks (Ahteensuu & Sandin 2012; Spruit 2015; Weckert & Moor 2007; Van Broekhuizen & Reijnders 2011). This means that when there is reason to expect potential harmful impacts, but solid scientific risk information is lacking, precautions would have to be taken to prevent further harm. If invoking the precautionary principle is seen as a way of establishing the urgency of a matter, this would demonstrate that the nanotechnology field is morally pressing enough to justify a duty to collectivize, or at least to meet criterion 1 of CCD-Nano.

Another issue that emerges is the demarcation of the collection of individuals who have collectivization duties. Who should organize themselves or, in Collins' terms, who are agents A through N that have to collectivize? We have deliberately avoided talking about 'nanoengineers' in this paper as it is quite difficult to demarcate this group. The nanotechnology label is often applied to make research more appealing to funding agencies or publishers, but the individuals using the label do not identify themselves as members of a nanotechnology community. Conversely, some researchers working on nanotechnology eschew the label entirely, believing it to be irrelevant. For example, during the Global Perspectives program, one faculty speaker at UC Berkeley explicitly did not refer to himself as a nanoengineer, even though he was working at the nanoscale, because he thought it was a useless category. This demonstrates that actors may not feel part of this community at all, even though they may do technically similar work, simply because they label their work differently.

However, the ambiguity of the nanotechnology label is no excuse to avoid responsibility. Researchers in the field of nanotechnology may be what May and Hoffman call a 'putative group', a group of people that could organize themselves once they recognize that they share responsibilities (May & Hoffman 1991, chapter 6). Fortunately, Collins' proposal is not contingent upon the recognition of a shared identity, but on the recognition of a shared problem. Collins argues in a consequentialist fashion that those people who *"are each able to take responsive steps towards there being a collective-that-can-φ"* (Collins 2012, p.244) are our target group, the bearers of collectivization duties. The idea is that those people who can reliably establish an effective group—a group that can reliably perform the morally pressing action—should be expected to organize themselves.

This demarcation based on an efficacy argument is appealing but brings us to a third challenge: how do we know a collective will reliably ensure RRI? Given that it is a key feature of this technological domain that uncertainty and unpredictability impede the construction of adequate risk management strategies, the question remains how one would know beforehand if a collective of researchers can effectively steer technological development and do RRI. The efficacy criterion is underdetermined in this sense. A suggestion could be to add a fairness criterion to the efficacy criterion that is common in consequentialist notions of responsibility, as suggested by Doorn (2012). Many individual scientists and engineers benefit from using the ambiguous 'nanotechnology' as a label. It provides them with access to funds and resources. It is not a new idea that such a benefit of membership in a particular group could also give rise to responsibilities towards that group (May & Hoffman 1991). Funding may provide a discerning criterion to distinguish between all individual researchers who *can* collectivize and those who *have a duty* to collectivize because of the benefits they got from the ‘nanotechnology’ label.

4.6. Conclusion

In this paper we established the conditions under which individual researchers have a duty to collectivize in order for research and innovation to be done responsibly. We focused on the field of nanotechnology—specifically on the research setting at UC Berkeley—in order to understand how individual capacity to do RRI is limited, especially in the absence of a collective that can provide a framework for RRI. As an answer to this situation we have proposed a conception of individual responsibility in RRI based on a duty to collectivize. We have explored how this could be a fruitful approach for nanotechnology while acknowledging there are still hurdles to overcome, namely: deciding what concerns provide sufficient grounds to expect people to collectivize, determining the reasons to demarcate groups of individuals who should constitute the collective, and establishing whether a collective can be expected to do RRI in a reliable manner.

We expect our approach to be valuable not only in discussions concerning responsibility in the nanotechnology field. Other emerging and converging research fields will face similar struggles in establishing a professional and ethical identity. Especially in the early days of a new field of science and engineering, the ethical concerns and fears that emerge may have to be dealt with quickly and adequately. Our proposal for the duty of collectivization encourages individuals to build structures that can steer technological development in directions that make a positive contribution to our world, while maintaining a situation in which this new field of research and innovation can flourish.

5 Taking care of innovation: a framework for characterizing caring relationships and networks in RRI

Chapter 4 argued that in some cases people should build relationships with each other in order to be able to adequately respond to uncertain risks. Thus far, we have not specified what such relationships would look like, that is, what qualities they would have with respect to the management of uncertain risks. This chapter takes a first step in this by developing framework for identifying and describing morally relevant features of relationships in the development of nanoparticles.

This chapter shifts from a narrow notion of responsibility focused on dealing with risks to a broader conception of responsibility that takes into account both risks and benefits. It considers the literature on Responsible Research and Innovation (RRI) that argues that we should think about responsibility for new and emerging technologies in terms of care (Section 5.1). In this section the notion of caring relationships is identified as a promising but unexplored concept in RRI. However, a comprehensive framework that describes what characteristics these relationships in RRI should have if they are to be considered caring is lacking. Therefore, this chapter aims to develop a framework to describe caring relationships in innovation practices. To this end, Section 5.2 presents the different roles that relationships play in normative ethical theory. Next, the Ethics of Care (EoC) literature on the notion of caring relationships is discussed and a role-based framework for analyzing networked caring relationships is proposed. Section 5.4. then identifies six dimensions to describe the caring capacity of relationships drawing from the EoC literature. The applicability of these dimensions is tested in an empirical case study: the use of nanoparticles for land remediation (Section 5.5). This chapter concludes with a discussion of the usefulness of this framework for analyzing innovation practices.

5.1. Introduction

Several authors have suggested rethinking the notion of responsibility as a form of care in Responsible Research and Innovation (RRI) (Pellé 2015; Pavie 2014; Groves 2009; Adam & Groves 2011; Owen et al. 2013). This paper explores the meaning of caring relationships in RRI, with the goal of developing a framework to assess networked caring relationships in innovation practices.

The popularity of care in discussions of RRI can be seen as a response to the problem of uncertainty in the governance of new technologies. With the increasing complexity of our societies and the introduction of radical and disruptive technologies, it has become harder to predict the negative and positive impacts that technological innovations may have. This leads, in practice, to dilemmas of control: if one wants to regulate such technologies in the early stages of innovation it is unclear what risks and issues may emerge, and once they do emerge, the use of the technologies is often so entrenched that it becomes harder to manage them (Collingridge 1981). Consequently, several authors have argued for more flexible and adaptive approaches to the risk associated with new technologies. These include Adaptive Governance (Klinke & Renn 2011), Resilience-based approaches (Doorn 2015) and Responsible Experimentation (Van de Poel 2015), all of which require a sensitive and receptive approach to the identification of and response to undesirable threats if and once they emerge (Nielsen 2016).

In the wake of this discussion, the notion of care has been introduced as a term to describe the responsibility of innovation practices. Care in RRI is mostly associated with an iterative practice of attentiveness and responsiveness to needs. For example, Owen and colleagues (2013) argued that RRI should be a caring and responsive process. They hold that uncertainty requires a forward-looking understanding of responsibility based on attentiveness and responsiveness, which is inclusive and deliberative and thus more adaptive to societal needs. Pellé (2015) suggests that we should apply Tronto and Fisher's (1990) elements of care – attentiveness, responsibility, competency and responsiveness – as criteria to assess the responsibility of innovation practices. Preston and Wickson (2016), apply care to the case of agricultural biotechnology and show its potential as a way to make more context-sensitive assessments of the social impacts of emerging technologies

Others have focused more on care as a personal characteristic of the innovator. For example, Pavie (2014) developed a list of virtues that an innovator should have to be an "innovator-carer." Nihlén Fahlquist (2015) argued that care, considered as an emotional engagement with someone or something, is an important motivator for taking moral responsibility in light of the complexities of contemporary innovation contexts. Caring can also be seen as a way for innovators to create attachments to the future and to unknown people. Adam and Groves (2011) argued that in caring for the future, we would have to acknowledge the intricate ways in which our own lives and those of other people (and organisms) are entangled. Caring for a common fate then, urges one to take responsibility for the way one is continuously creating one's own and other people's futures.

In Science and Technology studies, care theorists have drawn attention to the relational nature of research and innovation practices. For instance, Atkinson-Graham and colleagues (2015) argue, in line with Davies and Horst (2015) that care is about "exploring what practices strengthen or erode sustainable ways of living together in our research contexts, as well as our own conditions of living and working"(Atkinson-Graham et al. 2015, p.745). In medical practices we see how care in cancer treatments manifests itself as a form of exchange and response between doctor and patient, care in this context thus entails interaction and engagement that goes far beyond mere biomedical treatment. The work of Viseu (2015) shows how care work may also reify existing power asymmetries, and that one should be careful with excepting caring responsibilities if one is one the dependent side of the power relation. Additionally, building caring relationships with one may lead to the exclusion of others, an important 'Dark side' of care that Martin (2015) reminds us of. Caring relationships thus require moral evaluation.

Given that innovation processes are collaborative and networked (Nordmann 2007; Spruit, Hoople & Rolfe 2016), a care perspective can provide valuable insights into how innovators should relate to each other to ensure that they innovate responsibly and 'do RRI'. – Indeed, responsibility itself is a relational notion, as it implies one is willing to account for one's behavior to other people or a collective one belongs to (Kenney 2015). – The notion of care as a relational feature has been debated amongst feminist thinkers for quite some time under the banner of the Ethics of Care (EoC). EoC scholars have reflected on the features and qualities of relationships that would make them caring to a lesser or greater extent. From this perspective, ethical analysis should be about 'how we ought to live together' rather than 'what we owe to each other' (Scanlon 1998). The EoC's notion of caring relationships thus offers a way to describe and normatively assess relationships people have with each other.

However, a fine-grained understanding of what kind of relationships and interactions contribute to RRI is lacking. Therefore, this paper explores the usefulness of the notion of caring relationships as a way to understand forward-looking responsibility in RRI. More specifically, it aims to develop a framework to describe morally relevant features of networks and relationships in nanoparticle development. It does so by bringing in literature about care and caring relationships from ethics, and the EoC in particular, into the RRI debate. In the following, the paper will discuss the role of relationships in moral theory, with a view to deepening our understanding of the moral significance of relationships. It will then introduce the notion of caring relationships and develop a conception of such relationships based on networks of care. Next, it develops a way to describe particular relationships using six characteristics derived from the EoC literature that are important for identifying whether relationships can be considered caring. The usefulness of the framework will be explored in the context of an actual case: the use of nanoparticles for land remediation, while three conceptual challenges to the framework will also be discussed.

5.2. The moral significance of relationships

The understanding of EoC in this paper takes as its point of departure the position that relationships are morally relevant and should be subject to moral evaluation (as well as change in the case of negative evaluation). This section discusses several ways in which relationships can be considered morally relevant. Before we can do this, we must first clarify what we mean when we talk about relationships.

5.2.1. What are relationships?

Relationships are studied in a range of fields and as a result the term is used to signify various things. The term may denote direct interpersonal relationships between two individuals; for example, in the case of psychological studies on loving relationships. Relationships can also be formally established. For example, contractual agreements in law and business constitute a relationship. From that moment on, two or more parties formally agree to be in a business relationship, by means of a market transaction or signing a contract, for example. More generalized conceptions of relationships are also used, such as social relationships between groups of people from different classes, which are well studied in sociology. In EoC, and in this paper, the emphasis is on relationships between specific people rather than groups of people.

Relationships can be distinguished from mere contact between people in that they are not one-off interactions, but involve sustained interaction. Relationships develop over time, and often become stronger because of this sustained interaction. This does not mean that the relationships have to be intimate and personal (although they will always be between people), as we also develop and maintain relationships in professional settings. We may, however, have different normative expectations about the relationships in different settings; for example, in professional relationships values such as loyalty may be more important than emotional affection.

Relationships may be characterized by both similarities and dissimilarities between people. For example, sharing experiences like rites of passage, sharing a language or cultural background, or being part of the same community, such as living in a certain neighborhood, or being a member of a club might be the basis of a relationship. While such similarities in relationships can help create a sense of common identity, it seems to be asymmetries in relationships that are of particular interest in EoC. For example, the recognition that human beings often rely on each other for access to resources and fulfilling daily needs results in key asymmetries in terms of power and dependency. While later I will develop a framework for characterizing relationships (both in terms of symmetries and asymmetries), here we will first explore how relationships matter morally.

5.2.2. The role of relationships in normative ethics

The recognition that relationships are morally relevant is not exclusive to EoC. This section will discuss several ways in which relationships play a role in normative ethical theory.

Relationships give rise to obligations

The relationships we have with other people can be morally relevant because they may give rise to special duties or obligations. Many normative ethical theories hold that moral obligations are universal: they hold for all human beings and are not dependent on the way we relate to those people. For example, a duty for justice counts for everyone equally. Whether I should treat my spouse fairly, for example, by equally distributing responsibilities in taking care of the children, does not depend on this person being my spouse, but rather on the fact that as a person my spouse deserves fair treatment. In other words, the duty for justice is agent-neutral in the sense that it provides reasons for action independent of the particularities of that agent (Ridge 2011).

However, the relationship with my spouse itself, rather than universal moral principles, can also provide reasons for special obligations. For example, if two people run the risk of drowning, one of whom was your spouse while the other was someone you had no special connection to, you would have a moral duty to save your spouse first, because you have a special bond with them. While there may be a general duty to not let people drown, your relationship to your spouse would provide moral reasons to prioritize your spouse over the other person. Such reasons are agent-relative and would justify treating someone with whom you have a particular relationship in a different way. Much discussion between opponents and proponents of EoC has revolved around this question of whether duties stemming from particular relationships can override general duties to humanity.

The obligations that are of special interest in EoC are obligations that arise out of dependency relationships. Collins (2015) has proposed the 'dependency principle' as the normative basis of EoC. This principle states that, if there are people in a dependent position and you have the capacity to help them, you should care for them. Such asymmetry gives rise to a dependency relationship between those in a vulnerable position and those in a powerful position. This asymmetrical relationship then justifies the protection of and responsibility towards the dependent party in the relationship. Daniel Engster argues that the vulnerability of particular people invokes a general obligation to care (Engster 2007). Such obligations are universal as they apply to everyone who is in the same vulnerable situation.

Both these approaches identify vulnerability and dependency as morally relevant features of relationships. For these authors, dependencies give rise to moral obligations; they provide a reason to justify such obligations. In relation to the argument of this thesis, I am interested in making dependency relationships themselves the object of moral reflection (rather than the obligations to which they give rise). Therefore, the fourth section of this paper ('Relationships and their caring characteristics) will, in part, explore how we can characterize dependency so as to distinguish between different types of dependency relationships.

Relationships help achieve what is morally good

A second way in which relationships are morally relevant is that they may be instrumentally useful for achieving some overarching moral good. As a normative ethical theory, utilitarianism is concerned with the maximization of the good, which is often interpreted as human well-being. As a theory, it gives clear guidance about which ends matter: one must promote the greatest good (i.e., well-being) for the greatest number of people. It is, however, less clear how this should be achieved. For example, some have argued that well-being can best be maximized through having a society of virtuous people (Jamieson 2007), while others argue that utility is maximized by establishing a system of rules that parallels deontological theories (Hooker 1990).

One way in which relationships could be seen as helping to realize the moral good is through enabling coordinated action. Elsewhere I have argued that in some cases the building of relationships is needed to respond adequately to hazards in innovation processes (Spruit 2015). Relationships are then preconditions for moral action, and can be shaped and built in such a way as to foster responsible behavior. In such cases, relationships are instrumentally valuable in achieving the moral good.

In a consequentialist understanding of EoC, caring relationships are understood in a similar way, that is, as instrumental to well-being (2002). EoC is concerned with the effect of caring activities on the well-being of other people, and having caring relationships is instrumental to achieving this end. While this position has similarities with utilitarian theories of well-being, it is not utilitarian. Unlike hedonistic utilitarian theories that argue for an impartial and agent-neutral approach to the maximization of well-being (Driver 2014), the maximization of overall utility in EoC may never be at the expense of particular individuals or groups. In some utilitarian perspectives, these may be sacrificed for the greater good.

Relationships can also directly contribute to individual well-being. For example, the work of Ryff and Keyes (1995) in the field of psychology demonstrated that having relationships is a key element in what it means to live a happy and satisfactory life. In such cases, relationships are constitutively important for well-being. This brings us to the topic of the constitutive value of relationships, discussed in the following section.

Relationships are constitutively important
Our relationships with our parents, siblings and extended family significantly shape our moral identities. Caring relationships between child and parent are the first relationships most human beings experience. Furthermore, our societies are formed by networks of human interactions and our group identities influence conceptions of responsibility and ethical conduct (May 1996). Relationships are thus very important for moral education, and examples set in family settings influence the moral capacities of children (Smetana 1999). Innovation practice is no exception to this. Knowledge sharing, collaboration and coordination all require some sort of essential relationship for this practice to occur. In this respect, professional associations in science and engineering amount to communities – networks of relationships – that set ethical codes and guidelines of good practice (Mitcham 2003).

The fact that relationships are constitutive of our moral lives, does not mean that all relationships are equally valuable. For example, many feminist scholars have been critical of communitarian theorists for defending traditional forms of community ties, such as those that may forfeit individual freedoms and rights by enforcing a heteronormative view of family relationships (Friedman 1993; Kittay 2001). Given that not all relationships are equally valuable, it is important to be able to distinguish between those that are and those that are not. The following section will discuss a proposal based on EoC to make such distinctions through the notion of caring relationships.

5.3. From caring relationships to networked caring relationships

In general terms, to care means to be committed and positively contribute to the well-being of another person, organism or any other object of care (e.g., the environment or society). In EoC, to care for someone in a morally relevant sense entails more than having the right kind of emotional response to someone ("to care about something"); it requires an actual commitment to the well-being of somebody else expressed through the performance of caring activities. *Typical examples of caring activities are* parenting, teaching or caring for the ill.

For many care ethicists, caring is an inherently relational activity. Caring activities are often constituted by a relationship between the care-giver and care-receiver. For example, a teacher may care for a student by supporting him or her when they are going through a rough time at home. A teacher is only able to do this if they know the student well and have already built a relationship. At the same time, caring activities contribute to the formation of more durable relationships; for example, when the student recognizes and responds to the efforts of the teacher.

Caring often takes place in the context of dependency relationships. In modern societies, we all rely to some extent on other people. Firstly, this is because everybody will at some point in time (e.g., childhood or old age) and in some way or another depend on other human beings. Secondly, human societies heavily rely on shared resources such as water, clean air and sources of nourishment, which have to be managed together. This means that we all live in dependency relationships with other people; we rely on other people to meet our daily needs of nourishment and shelter to some extent. However, caring typically aims at helping those in particularly vulnerable positions: not just any one who relies on other people. In this regard, Bubeck (according to Butler 2012) makes an important distinction between care and service work: while service is the execution of work on behalf of someone else who could have done this him or herself, care is the execution of work on behalf of someone who would not be capable of doing this him or herself.

In the EoC literature, caring relationships are proposed as a way to deal with such vulnerabilities. Caring relationships are typically portrayed as asymmetrical dyadic relationships between a care-giver and the person he or she cares for. There are two entangled ways in which this term is used in the literature. On the one hand, a more descriptive use of the term signifies existing relationships between care-givers and care-receivers, such as those between parents and children. Such relationships are said to constitute forms of "natural caring" (Noddings 2002). On the other hand, there is a prescriptive use of the term "caring relationships" that suggests that the relationships we have with particular people should be more caring. For example, Noddings argues that relationships in realms that are not associated with natural caring can be modeled to mimic quintessential caring relationships such as that between a parent and a child. These two uses are related: from descriptions of "naturally occurring" caring relationships one can learn about which features of relationships are caring and which are not.

For the purpose of this paper, I am interested in adapting this normative notion of caring relationships to conceptualize responsibility in RRI in a new way. While accepting that the question as to whether the stereotypical imaginary of family ties should be the template of moral relationships is open to debate, I argue that normative approaches to relationships provide an interesting new way to asses our moral lives. EoC "should be able to give moral guidance concerning actual relations that are trusting, considerate, and caring and concerning those that are not" (Held 2006, p. 12). Before moving on to discuss how the notion of caring relationships can inform RRI, one more step is required.

From dyads to networks

The view depicted in the previous section is simplistic in its assumptions about the nature of caring relationships. For the sake of analytical clarity, caring relationships are often presented as dyadic in EoC literature (i.e., a relationship between one care-giver and one care-receiver). However, in practice, care work is often not carried out by one person; even typical caring relationships between doctors and patients are in reality complex encounters between doctors, patients, nurses, family and administrators. The simplification above thus served analytical purposes, but we know that the reality of innovation is much more complex. Therefore, we need to develop a more complex understanding of caring relationships.

The EoC literature offers us three ways to proceed. The first is to follow the line of Tronto (2013) and explore the role of institutions in care. Caring is an activity that takes place in a specific social and political context. To ensure good care, this context has to create optimal circumstances in which the care-giver can actually care; for example, institutions can give such support by providing resources such as money and technology or supporting care-givers in some other respect. Tronto calls this "caring with." This is not only a matter of support, as Noddings (2002) states, there should be no policies or rules in place that prevent care-givers from responding to those they have to care for.

A second, and related, option is to focus more on groups and their role in caring. For example, Collins is concerned with the possibility of group actors bearing duties to perform caring activities (Collins 2015). She argues that when a group of people has a decision-making procedure – which may be as minimal as some of the members of the group instructing the other members to act – they can act together. Such groups have a potential capacity to care that individuals do not have; for example, because the caring work requires collaboration and many hands, as well as because groups may have more combined resources and expertise. If such a group were in the best position to help somebody meet a vital interest, they would have a duty to act upon this and provide care.

Both of these options provide promising ways to take the discussion on caring relationships one step further and move up a level of complexity. However, I want to resist talking about caring at the level of collectives and structures because it may risk losing sight of the role of individual actors. In RRI, much work has been done on responsibilities at the level of collectives; however, I think that what the relational lens of care ethics brings to the RRI table is the possibility of looking at individual action, as well as its mediation by other actors.

A third option that I want to explore in this paper analyzes caring practices in light of the different roles that people can assume. Kittay (1999) describes how, in addition to the roles of care-receiver and care-giver (respectively called "charge" and "dependency worker" in Kittay's terminology), care is also supported by "providers," those who have economic resources with which to support caring activities and the care-giver. Kittay uses the example of the head of the household, who brings their income into the family to support family life. However, in the following I will interpret this more broadly because, in relation to care, while financial resources are necessary, skills, material and knowledge may also be important.

Butler (2012), drawing on the work of Kittay, describes a four-person model of caring practice. In addition to the care-receiver, care-giver and provider, Butler talks about "claimants": those who can make claims about the allocation of resources for caring. An example of a claimant might be government, which, on behalf of the care-receiver, can make claims on resources to be allocated to provide care. Butler writes that, ideally, a care-receiver would make such claims him or herself, but if this is not possible, other parties should do this on their behalf. Kittay describes an additional fifth role: that of the "doulia." Care-giving can give rise to dependencies, and care-givers can become secondarily dependent because they are subsumed by their caring duties. Care-giving is often characterized by such nested dependencies. The doulia, a term derived from the Greek word for "service," assists the care-giver in care-giving. This both serves to protect care-givers from self-sacrificing behavior, and can also be seen as a way in which wider society takes social responsibility for the care provided.

In combination, these five roles allow an analysis of networks of caring relationships that, on the one hand, transcends the binary of dyadic relationships, but on the other, does not lose sight of individual responsibilities and duties of care.

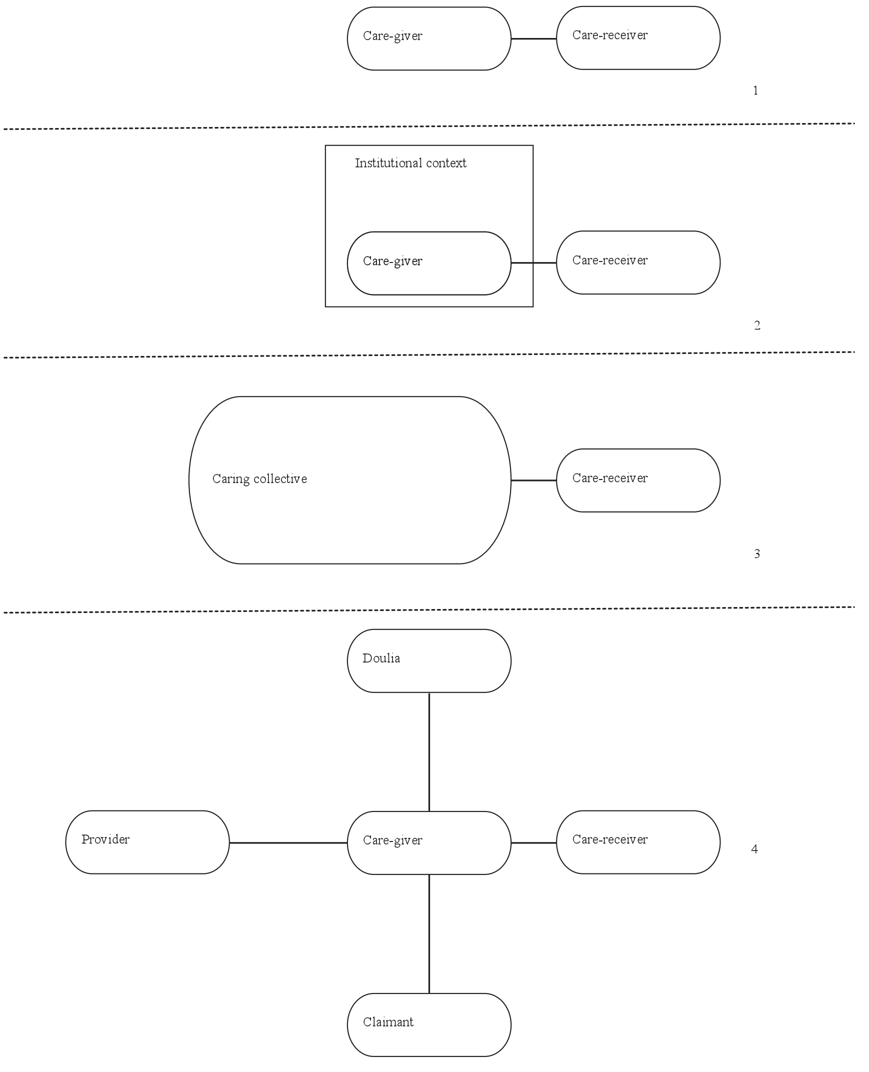

Figure 5.1: A schematic depiction of the different ways to accommodate complexity in caring relationships: (1) the dyadic view on caring relationships, (2) Tronto's institutional approach, (3) Collins' collective approach, and (4) the network approach that will be elaborated in this paper.

5.4. Relationships and their caring characteristics

This section will investigate which characteristics of relationships are relevant from an EoC perspective and, next, will discuss – based on these features – how they can inform an evaluation of caring relationships. These characteristics will be used in the next section to characterise relationships in the context of an innovation network.

5.4.1. Morally relevant features of relationships

Based on the literature, this section identifies six features of relationships that can be used to determining whether they are caring. This list has been constructed on the basis of work by several EoC scholars (primarily Nell Noddings, Joan Tronto, Virginia Held and Eva Feder Kittay). While other moral theories may list other features, they are beyond the scope of this paper.

Dependence

There are different ways in which people can be dependent. According to Kittay (2011, 2001), having to depend on other people is a fact of life. Children depend upon their parents and other adults to provide them with nurture, access to education and personal safety. Most patients are physically dependent, in the sense that they have to rely on medical professionals for medical treatment and care. Others are politically dependent, particularly when they are part of a minority that is democratically poorly represented. In reality, to a great extent we all depend on the people around us to ensure our safety, fulfill our daily nutritional needs, and to live a happy life.

Most EoC scholars hold that relationships which are characterized by dependency are not *prima facie* problematic.[32] Dependency can become morally pressing when it manifests itself in vulnerable individuals or populations. A vulnerable person is someone who is dependent on someone else for some important value or basic need, such as nourishment and shelter. In such cases, vulnerability can warrant additional protection (Collins 2015) and care. However, as we will see later in this section, one should be careful in assuming that one knows best how to tend to the needs of the person cared for.

Power

Another feature of relationships – which is related to dependency – is power. The power one person can exert is a feature of a relationship in the sense that to be able to exert power there needs to be someone who is being controlled. This can be done in various way, such as controlling the previously mentioned

32 Dependency is a moral problem in liberal theories. In such theories, individual freedom, more specifically, the liberal notion of being free from interference by other people, is a goal in itself. It is here that EoC and many feminist theories depart from such strongly individualized notions of freedom and autonomy, when they accept that our individual lives are socially shaped (Mackenzie & Stoljar 2000).

resources that make individuals dependent, or by directly controlling other people through expressions of violence (oppression) or authority. In such cases, power relationships may lead to the exploitation of one person in the relationship. At the same time, as Dominelli and colleagues have shown, power relationships are often dynamic and open to continuous negotiation (Dominelli & Gollins 1997).

Furthermore, not every expression of control or influence in relationships is negative. The quality of care is often dependent on the competencies of the care-giver (Tronto 1993). If one party in a relationship is more competent to perform a specific task, one may want to give that person the opportunity to take control (e.g., relationships with a medical professional may be of this kind). In such cases, a sense of independence is achieved if people keep decisional control rather than executional control over the care provided (Glendinning 2008).

Attention

Caring relationships are characterized by attention to the other party in the relationship. In EoC, good care is adapted to the particularities of specific people, as a one-size-fits-all approach does not always work. This means that care-givers have to get to know and attune their activities to the needs of the person being cared for. To be able to do this, the care-giver and care-receiver need to pay attention to each other. For Tronto (1993, 2013), attentiveness is a key dimension of caring practices. Attentiveness can be expressed through practices such as active listening and spending time with care-receivers to get to know them. Failing to be attentive to, or even ignoring, particular people you are in a relationship with can be considered a moral failing. Noddings argues along similar lines when she says good caring relationships require "receptivity" if they are to be open to the other person's voice, and "engrossment," which directs complete attention to the other (Noddings 2002).

In some cases, to be attentive requires a great deal of effort by the care-giver. For example, this might be the case if one is in a caring relationship with a person who has reduced capacity to communicate because of their physical state, or because they are not used to expressing their needs. In such a situation, a care-giver should try to find ways to communicate to ensure the voice of the person cared for is heard.[33]

Responsiveness

Closely related to the notion of attentiveness is responsiveness: the ability of the care-receiver, or the person who is dependent in a relationship, to respond to the care provided. The notion of responsiveness is essential to moving beyond a paternalistic view of care in which a person cared for is seen as vulnerable and a care-giver is seen as responsible for all the care work. By being responsive, a care-receiver can confirm whether the care-giver is doing a good job, as well as show appreciation, which is key to sustaining healthy caring relationships. In this way, relationships should provide a safe space in which the care-receiver has both room for reflection (Spruit 2015) and an opportunity to speak up and provide feedback.

In a way, responsiveness does not equate the vulnerability of the person cared for with passivity, but acknowledges that the latter has his or her own perspective and ability to respond. Through responsiveness, the difference between the self and the other in the relationship becomes clear: "one is engaged by the standpoint of the other, but not simply by presuming that the other is exactly like the self" (Tronto 1993, p. 136). However, the ability of certain individuals to be responsive in a clearly articulate way may be limited, such as people with severe physical or mental disabilities.

Emotional engagement

An account of caring relationships can hardly be complete without recognizing the emotional attachments that underlie caring. To be able to build human relationships one strongly relies on one's capacities to emotionally engage with other human beings. Apathy towards the other, not being affected by vulnerability or pain, cannot be a feature of caring relationships. Love, or at least some sort of affectionate capacity and sympathy, is required for good care. Furthermore, in caring relationships it may even be the case that the well-being of the person with whom you are having a relationship also contributes to your well-

33 The notion of attentiveness and inquiry into other human beings resonates with duties to respect other people and recognize their humanity. Such duties, however, are often mainly based on the value of cognitive ability (being rational), rather than one's needs as a fellow human being.

being. For Held, in caring relationships the "… carer and cared-for share an interest in their mutual well-being" (2006, pp. 34–35).

However, being overly emotionally invested in the other person may also be problematic. It may lead to the smothering of the other in the relationship, or self-sacrificing behavior. The appropriate emotional response to the situation of another human being or their vulnerability may be hard to determine, but the complete absence of affects would seem to challenge our understanding of what defines caring relationships.[34]

Availability

Drawing on the work of Gabriel Marcel, Noddings (2002) argued that in caring relationships people should be "disposable," which means that they should be available and ready to help out when the other party in the relationship needs them. This can, for example, be expressed through loyalty and solidarity, or, as Atkinson-Graham and colleagues (2015) show, just by paying attention and listening. Activities that also contribute to the formation and the maintenance of caring relationships. In the following, I choose to use the term "available" rather than "disposable" because the latter term has the connotation of being used and then discarded.

This brings up a negative side of this feature of care-giving as it opens up the possibility that care-givers themselves become dependent as a result of their caring duties. This is known as derivative dependence. The extent to which individuals should sacrifice themselves to care for other human beings has been extensively discussed in EoC and feminist literature. Most EoC scholars underline that the giving of care should not be at the expense of the care-giver's health and well-being. The introduction of the doulia as a role in caring configuration by Kittay can be seen as a response to the issue of derivative dependence.

34 The variety of emotional responses that may be constitutive of good care is broad. Care is usually associated with positive emotional responses to other people: to love, feel sympathy, compassion and attachment to others. However, care does not solely rest on positive feelings. More negatively valenced emotions, such as worry, discomfort and unease or feeling unsettled, may be equally important parts of the affective response we call caring.

5.4.2. From characteristics to caring relationships

The previous section presented several characteristics of relationships that are morally relevant. However, the question of what combination of characteristics amounts to a caring relationship remains. Therefore, this section will very briefly discuss interlinkages and connections between these characteristics.

Before we start, it should be noted that developing an overly idealized notion of a caring relationship may invoke criticism similar to that directed by EoC theory to depersonalized and impartial ethical principles (Friedman 1993) – that idealizations disregard the context and the diversity of people. This is true to a certain extent as any normative ethical theory will have to pre-select morally relevant features of a situation and thereby run the risk of overgeneralization or overlooking certain aspects. However, the list of characteristics provided here is not meant as a dogmatic list of principles. It might function as a way of distinguishing between relationships, but what is considered a caring relationship will depend on the particularities of the situation and the needs of those involved in the relationship.

Having said this, this paper does build on the assumption that some generalizations can be made about the characteristics that would make a relationship caring to a greater or lesser extent. For example, it is not controversial to argue that abusive relationships are not very caring and that loving relationships probably are. These are evaluations of relationships, and any normative use of caring relationships would have to be able to pass some sort of judgment on such relationships.

The attentive reader will have noted that there was some thematic overlap between some of the characteristics presented. Given my aim to provide a framework for characterizing relationships, I decided to provide a more detailed characterization of relationships rather than collapsing all of these terms under more general headings. Interdependence and power are primary examples of such overlapping themes. Both are connected to the possibility of having influence or control over the other person in the relationship. Relationships in which there is too much dependency (i.e., a vulnerability that is not taken care of) cannot be considered caring. Similarly, power relations that are exploitative cannot be considered to be caring.

The characteristics of power and dependency can be interpreted as setting thresholds for how little (in the case of vulnerability) or how much (in the case of exploitation) control of the other may be permitted in a caring relationship. In fact, neither dependency nor power dynamics are required for relationships to be considered caring. Indeed, it seems odd to require relationships to have a certain level of dependency and power. However, in practice, caring relationships without some asymmetries in dependency and power are rare. In such cases, both of these characteristics (and particularly when one is under a certain threshold) can give rise to obligations, such as the dependency principle postulated by Collins.

The last four characteristics (attention, responsiveness, emotional engagement and availability) are at least minimally necessary for caring relationships, but in two different ways. Attention and responsiveness are both characteristics of interaction and, in particular, communication between care-giver and care-receiver. They are more instrumentally important for care, as by facilitating exchange, they contribute directly to the quality of the care provided and will reinforce and sustain a caring relationship.

Emotional engagement and availability are more constitutively important for caring relationships. Being emotionally attached and available to the other person constitutes an important part of what it means to have a caring relationship. These characteristics seem to have more to do with stability in the relationship than direct interaction. Attachment and availability both directly contribute to continuity of the relationship, thereby securing future care and trust. Relationships in which one knows there is someone available who will help when needed, and who does so from the heart, provide an environment to build upon.

5.5. Caring relationships in the context of nanoremediation

This section explores whether the relational dimensions identified above offer interesting insights in relation to responsibility in innovation processes. This is done by focusing on a particular case, the use of nanoparticles for soil and water remediation. This section starts by providing some background information on nanoremediation, in light of the European NanoRem project that has set out to bring this technology to the market. Following this, the network of actors that are involved will be mapped, with the goal of assigning different caring roles. Three relationships within this network will then be examined in more detail with a view to exploring how useful the six features of caring relationships are for recognizing their caring capacities.

The information that is presented about this case is based on publicly available information and comes from document research on the NanoRem website (www.nanorem.eu) and observations at the AquaConSoil 2015 Conference in Copenhagen. This section will not provide an exhaustive analysis of the case, but merely serves as a proof of concept and at times will resort to a more ideal-typical discussion of the case. This will, however, allows us to assess the practical usefulness of the framework developed, rather than to continue the theoretical discussion.

5.5.1. Nanoremediation

The rise in activity in the field of nanoscience and nanotechnology has been accompanied by promises of sustainable and green applications that nanotechnology may bring (Smidt 2007). The application of nanoparticles in remediation, and specifically the use of nano-iron, is heralded as one of these promises of green nanotechnology (Salamanca-Buentello et al. 2005). Due to its potential to remediate polluted soils and safeguard valuable water resources, several nanoparticles have become candidates for use in remediation technology. These include nano zeolites, bimetallic nanoparticles and titanium dioxide (Karn et al. 2009).

The benefits of using these particles lie in their low cost and easy applicability. Nanoparticles are generally cheaper to use in bulk form because of a higher reactivity due to a high surface-to-volume ratio. Furthermore, most nanoparticles can be injected into soils as slurry and this requires less drastic management of the sites in which they are used. Above all, the technology is promising for *in situ* remediation in polluted areas that hard to reach. Nanoparticles can be injected into areas under the built environment and remediate land without requiring drastic measures such as soil replacement.

In light of these developments, the European NanoRem project began in February 2013 and will run until the beginning of 2017. This project aims to scale up nanoremediation from the lab to end-user applications. This project is funded by the European Union's 7th Framework Programme and includes 28 parties from 13 countries, consisting of universities, research institutions and private companies. The 11 work packages in the project range from the design and production of nanoparticles, measuring the behavior and performance of nanoparticles in soils, to the dissemination of this technology and information to potential users and decision-makers. Several nanoparticles are being investigated and pilot tested (e.g., Fe-Zeolites, Fe-Oxide, Bionanomagnetite, Carbo Iron and nano-scale Zero Valent Iron Particles, a popular nanoparticle for nanoremediation).

5.5.2. Caring networks in nanoremediation

In this section, we map the network of actors involved in nanoremediation practice, with the aim of assigning different caring roles to these actors. This is not an easy task, as the NanoRem project, and the wider community of scientists, engineers, regulators and professionals working on nanoremediation, constitute a complex web of relationships. Therefore, I proposed a four-step approach to mapping the caring networks: (1) identify whose vital interests may be at risk (the care-receiver); (2) trace who those agents rely on to meet those vital interests (the care-givers); (3) map who controls the resources, competencies and other aspects that may influence meeting those needs (the provider); and (4) if applicable, identify who may make a claim to care on behalf of other people (the claimant).

The first step in identifying a caring relationship is to identify whose vital interests may be at risk. There is wide-ranging debate about what a person's vital interest might be. For example, Maslow's popular values pyramid has served as one way to make a hierarchical distinction between needs (Maslow 1943). Other ways to make such distinctions include reference to widely held notion of human rights, as well as the capabilities approach, which emphasizes the importance of realizing valuable human capacities, such as bodily integrity and practical reason, as a measurement of human development (Sen 2005).

This discussion will limit the focus and only explore vulnerabilities related to health and safety.[35] There are several people who can be considered to be dependent in the nanoremediation project with respect to health and safety. The first group consists of those who work with nanoparticles (i.e., who produce and handle the nanoparticles): for the sake of simplicity, we will call them nanoparti-

[35] I do not want to suggest that caring relationships are only held with other human beings. Indeed, some of the interesting work on care in nanoremediation has involved care for ecosystems and the environment. Puig de La Bellacasa (2015) argues that many human activities see soils as a resource, rather than a habitat for all kinds of human and non-human organisms. Remediation practices are often aimed at making the land available as a resource, rather than as a living environment. Caring for soil would thus entail not exploiting it, and restoring ecosystems.

cle users. These users are vulnerable to occupational health and safety risks related to their use; for example, iron nanoparticles are said to ignite easily, similarly to the way that many dust clouds might (Wu et al. 2009). Furthermore, in general, there is a concern with the potential risks involved in being exposed to nanoparticles in the workplace (Spruit 2015). These nanoparticle users may work as end-users of this technology, such as remediation contractors, as well as in companies producing and developing nanoparticles.

A second group whose health and safety we might care about consists of the local communities that live downstream from polluted areas. These communities are vulnerable to the toxic legacy of the area they inhabit, as well as potential health and safety risks associated with the remediation treatment itself. For example, there are concerns about the commonly used nZVI particles which transport metals bound to their surface over large distances (Karn et al. 2009); although, it should be noted in this respect that the NanoRem project has reported no significant ecotoxic effects after initial tests of five different nanoparticles (Bardos 2015). In the following, I will limit my analysis to nanoparticle users, and in particular nanoparticle end-users (i.e., remediation workers and contractors who use nanoparticles in actual remediation practices, rather than researchers who use them in experiments or are involved in production).

Let us now consider the people that these nanoparticle end-users depend upon. In many countries there is some sort of legal protection of workers against occupational health and safety (OHS) risks, giving their employers a duty of care. These laws make employers at least partially responsible for providing their employees with safe working conditions (Spruit 2015). As regulators of these conditions, governments thus play the role of claimants. In addition, labor unions may also be claimants, by demanding guidelines and regulations on safe work practices. This has at least been the case with respect to the OHS risk associated with nanoparticles in the Netherlands (Spruit 2015).

In doing the caring work, the employers may be assisted by specialists who have expertise in safe work practices. These can be seen as what Kittay calls “the doulias” – the actors that assist the care-giver. However, in practice, OHS specialists take multiple roles. They assist the care-giving employers by developing standards and reducing the burden of determining the best OHS work practices. At the same time, OHS specialists who work in advisory companies can also be seen as providers; they provide knowledge about the OHS measures that can be applied and allocated as a good. Producers of OHS measures (e.g., protective gear, ventilation systems) are subsumed under this provider role as well. We will not go into detail here on the differences and interactions between all of these OHS specialists. For a more detailed discussion see (Spruit 2015).

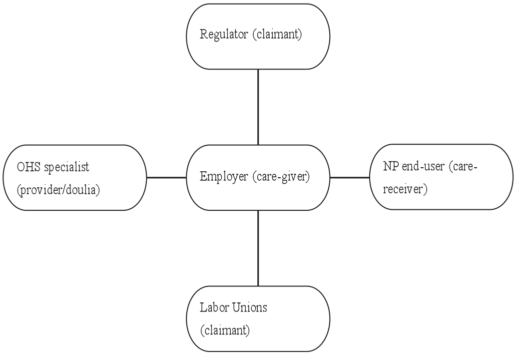

Figure 5.2: Schematic representation of the network involved in caring for OHS risks of nanoparticles for soil and land remediation.

However, this is still a simplified picture, as many people who may influence the nanoparticle end-user's vital interest to stay healthy and safe while working with the nanoparticles have been omitted. For example, contractors with specific remediation expertise (e.g., nanoremediation) are often contracted through remediation consultants. These consultants will have a say in if, how and where the nanoparticles will be used, and also control the financial resources for the caring work. Furthermore, the producers of the nanoparticles play a role as well; for example, the way these particles are stored and transported will influence whether they can form dust clouds. Producers also have to provide safety data sheets on the product they sell.

Furthermore, this discussion has hardly touched on the role of innovators, in other words, the scientists and developers of this new technology. The scientists involved in NanoRem first develop the knowledge that can subsequently be used to develop the technology, predicting the behavior of the nanoparticles in soils (thereby allowing for the optimization of the remediation processes and assessment of the potential risks). The knowledge they produce may also be of interest to the care-receiver; although it must be noted that the toxicity tests in the project have been focused more on ecotoxicity than human toxicity. There are also researchers and remediation specialists involved in the project who do dissemination work; they inform potential users about the technology (consultants and contractors). Finally, by funding research into the toxic effects, governments are not only claimants (i.e., by regulating work practices) but also become providers, albeit indirectly. Taking all of this into account, the following diagram presents an overview of the roles and actors which are relevant to caring in relation to the health and safety risks of nanoparticle end-users.

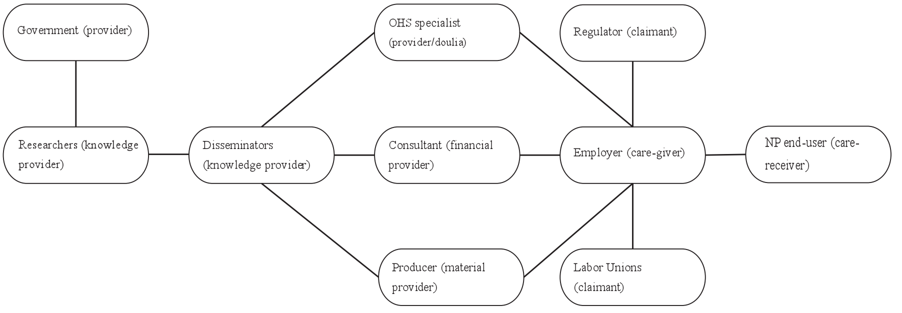

Figure 5.3: More elaborate schematic representation of the network involved in caring for OHS risks of nanoparticles for soil and land remediation. In addition to the actors mentioned in the text, the owners of polluted lands may also play a role; for example, they may allocate, or be required to allocate, additional resources to ensure the health and safety of nanoparticle end-users. In such a case, they take the role of providers.

5.5.3. Characterizing caring relationships in the nanoremediation network

In this section I will apply the characteristics of caring relationships from the previous section (dependence, power, attention, responsiveness, emotional engagement and availability) to three relationships taken from the nanoremediation network. Certain characteristics of these three relationships will be discussed in more detail: the relationship between the nanoparticle end-user and their employer; the relationship between the disseminating researchers and consultants; and the relationship between the funding agencies and the researchers. These relationships were chosen because they represent connections between different roles in the network. These are, respectively, the relationship between care-receiver and care-giver; between provider and care-giver; and between claimant and provider. The analysis presented here is brief and primarily at the level of ideal-types. Research into how the particular actors experienced their relationships has not been conducted.

Let us first consider the relationship between the nanoparticle end-user and their employer.

(1) *Dependency:* nanoparticle end-users rely on their employers to provide the means to ensure safe work practices (e.g., to provide protective gear to prevent exposure, such as through inhalation) in relation to the nanoparticles, as well as ensure that the storage and equipment for handling nanoparticles do not pose a fire hazard.

(2) *Power:* Employers have power over nanoparticle end-users insofar as the latter is an employee. This power is expressed financially, with the employee depending on the employer for income, and is also apparent in the extent to which employees can influence work practices.

(3) *Attention:* Employers have to be attentive and monitor how their employees use nanoparticles. On a general level, monitoring is legally enforced, as employers have a duty of care to their employees, but the actual provision of adequate attention to the needs and interests of individual employees is difficult to enforce legally.

(4) *Responsiveness:* Employers rely on their employees, while the latter are obliged to use nanoparticles in a responsible way and to give feedback if this is not possible under current working conditions.

(5) *Emotional engagement:* There will be a high degree of variation in relation to this characteristic, but the safety culture in a department, here understood as a mutual commitment to each other's safety, influences whether it is possible to change an unsafe practice against the employer's wishes.

(6) *Availability:* This relationship is supported by claimants, such as OHS specialists and regulators. Elsewhere, I have explored in more depth how these stakeholders together give shape to the care-giving done by the employer (Spruit 2015).

The second relationship is that between the NanoRem project members who disseminate knowledge about nanoremediation and the consultants who advise on and make choices about the application of this technology.

(1) *Dependency:* Neither disseminators nor consultants are dependent upon each other for their vital interests. Some NanoRem project members have developed expertise in using this technology over a long period of time, and may therefore have a professional interest in increasing the popularity of this technology.

(2) *Power:* Contractors and consultants have the power to make decisions on the application of this technology, and they can be seen as gate-keepers. Their choices between remediation technologies are relatively unconstrained, although confined to the alternatives

available. One way disseminators may exert influence is by spreading information and to trying to convince the field of remediation to adopt the technology.

(3) *Attention:* Within the NanoRem project, there have been several occasions on which members actively sought to find out what the needs and interests of the end-users were. For example, during the AquaConSoil Conference in Copenhagen in 2015 a workshop created a space in which the commercial opportunities for nanoremediation could be discussed, and the participants, who were land-owners, scientists and remediation consultants, were invited to indicate what they would need in terms of information and/or the technical requirements of nanoremediation.

(4) *Responsiveness:* The above-mentioned workshop can also be understood as an opportunity for feedback. Unfortunately, this event was not as well attended as the organizers had intended. Myself excluded, there were an estimated six participants from outside the project. This demonstrates that an invitation to express a voice is not necessarily always taken up.

(5) *Emotional engagement:* It is unclear to what extent this relational characteristic plays a role. The emotional attachment between disseminators and consultants is unclear, although whether actors like each other can influence business choices.

(6) *Availability:* Through the active online presence of NanoRem, the project website www.nanorem.eu provides ample information about the project and the technology, including a section for 'decision-makers' (i.e., future users). Furthermore, their presence at workshops such as AquaConSoil, where researchers, consultants and other organizations in this field were present, can be seen as an indication of good availability of the disseminators to consultants.

The third relationship is that between the EU, as the funding agency, and the researchers in the project.

(1) *Dependency:* This relationship is characterized by mutual dependency. The EU relies on researchers like those in NanoRem to produce relevant knowledge that can, in the long-run, inform policy concerning the use of nanoremediation. However, researchers strongly depend on funders such as the EU to continue their research.

(2) *Power:* The funder is in a powerful position as it controls the allocation of research money. Researchers seem, at least financially, to be completely at their mercy.

(3) *Attention:* It is unclear exactly how this manifests itself. The NanoRem researchers are attentive to the requirements of the funders as regulators. The information they offer on their website serves to inform legislators (as well as potential users).

(4) *Responsiveness:* It is unclear whether funders and researchers are responsive to each other apart from the regular review processes and reports.

(5) *Emotional engagement:* It is unclear exactly how this relational characteristic plays a role. However, a more speculative interpretation might be that researchers who work on politically interesting topics may generate more interest from funders. For example, the use of nanoparticles for environmental remediation has been politicized as a topic due to the 2004 moratorium on its use in the United Kingdom (Soil Association 2009).

(6) *Availability:* Researchers make themselves available by writing research proposals. Funders support researchers in their research efforts by making funds available, but this is not a guaranteed long-term availability.

The application of the relational characteristics to this third relationship seems more difficult. While this may be due to a limitation in the empirical material used in this case, it also seems that the relationship between these two actors is weaker. The contact between researchers and funding agencies is, in a sense, characterized by more of a one-off rather than a continuous interaction.

5.6. Discussion

This paper has developed a framework that can be used to characterize networked caring relationships in innovation practices. The previous section applied this framework to the case of nanoremediation, with a focus on relationships in the NanoRem project. The goal of this application was not to draw unambiguous conclusions concerning the caring qualities in NanoRem. The data and level of detail of the case do not allow for this, as the data was originally gathered for other purposes. While this amounts to practical limitations in the application of this framework here, there are also more conceptual reasons why networked caring relationships may be difficult to characterize, which is the topic of the following discussion. Three conceptual challenges will be discussed in this section: the limitations of the relational characteristics with respect to relationships between people who have roles other than the care-giver and care-receiver; the fact that care is a side-constraint rather than a goal of innovation practices; and issues in determining the scope of caring networks.

The first issue that arises concerns the relational characteristics identified in this paper. These were deduced from literature that mainly explores dyadic caring relationships, but they were then applied to relationships between providers and claimants and providers and care-givers, which are of a different nature. For example, the importance of emotional engagement in these relationships is unclear, at least with respect to how it ultimately amounts to care for the care-receiver. Additionally, attention paid by the provider to the claimant may be important, but does not lead to better care in the same way as attention in direct caring relationships. This requires us to further develop the relational characteristics so that they take into account caring relationships between people who hold different kinds of roles. For example, we might replace emotional engagement and attention within those relationships with requirements for mutual commitments to a shared goal and knowledge exchange.

This leads us to the second issue, which concerns the place of care in innovation practice. The development of the EoC approach has often explored the understanding of care in contexts such as healthcare, education and social policy. These are all settings that to a great extent have care as their goal: we expect doctors, teachers and governments to work together to improve the well-being of the people who are dependent on them. There may also be other factors that play a role, such as status, economic development or power, but it is safe to say that we publicly evaluate professionals in these fields on the basis of whether or not they succeed in positively contributing to the well-being of people in vulnerable situations.

In contrast, caring activities can be seen more as a side-constraint than a goal of innovation practices such as those found in the nanoremediation case. This is supported by the fact that in most analyses, care is associated with maintenance, nurturing and practices that have goals other than the goal of innovation practice itself (Davies & Horst 2015; Mol et al. 2010; Denis & Pontille 2015). The fact that care could be seen as a side-constraint of a practice does not reduce the importance of caring. It does, however, lead to issues in the evaluation of relationships. Whereas relationships in more traditional caring practices will to a certain extent always be evaluated with respect to how they contribute to the shared goal of caring, this is less obvious in the case we studied. What it means that relationships have less caring characteristics in such cases is a topic that needs further exploration.

The third issue concerns setting the scope and complexity of the caring network. The networks and roles described in the nanoremediation case are much more complex than the interlinkages and ideal-typical roles in Kittay and Butler's model. This is because in reality there are always multiple actors that can perform one role (e.g., in our case there were multiple providers), as well as actors that may perform multiple roles (e.g., a government that is both a funding agency and a claimant). How big should the network that is taken into account actually be? This also leads to questions about position: Can we argue that remote actors in a caring network share in the responsibility for the quality of the caring work as well? These questions need to be addressed to be able to further operationalize the proposed framework in the context of other innovation projects.

5.7. Conclusion

This paper serves as a first step in developing a framework for the operationalization of the notion of caring relationships in RRI. It proposed that RRI should not be limited to producing good and socially responsible products, but that we should also ask questions about the type of relationships that are currently found in innovation practices.

A framework for characterizing networked caring relationships was developed that enables us to analyze networks of innovators in terms of the role they play in caring (i.e., the role of care-giver, care-receiver, provider, claimant and doulia). Six relational characteristics (dependence, power, attention, responsiveness, emotional engagement and availability) were identified to analyze the relationships between the different actors.

After applying these to a practical case, three conceptual challenges were identified: the limitations of the relational characteristics with respect to relationships between people who have roles other than the care-giver and care-receiver; the fact that care is a side-constraint rather than a goal of innovation practices; and the scope of caring networks. Despite these challenges, I hope this analysis has shown that a relational view on RRI can provide interesting insights into the types of interlinkages that caring requires and that it also holds promise for developing an evaluative framework for caring relationships in innovation practices.

6 Conclusion

This thesis has explored the alignment of relationships and responsibilities in managing the uncertain risks of nanoparticles. In the following I will present an overview of the main findings of this thesis and draw some general conclusions, after which I will reflect on the implications of my findings for Responsible Research and Innovation (RRI).

A primary objective of the thesis was to identify how relationships matter to the way we deal with uncertain risks. Chapter 2 demonstrated that *relationships can be seen as a context in which risk decisions are made*. Focusing on decisions involving informed consent, this chapter identified several qualities of relationships (see table 2.4, page 28), described as 'relational factors', that are reported to influence an individual's decision concerning their own exposure to risks. This chapter then reinterpreted the notion of informed consent and explored how these relational factors can be used to assess the potential challenges to obtaining informed consent in relationships. These factors can be used to create room for reflection on nanoparticle risks, thereby ensuring the validity of informed consent.

Chapter 3 demonstrated that *relationships can be used as an additional decision-criterion in making risk decisions* under conditions of uncertainty. This chapter started from the legally defined position governing the relationship between employer and employee, which gives rise to a duty of care for the employee's occupational health and safety. It showed that uncertainty regarding nanoparticle risks complicates the choice between several available precautionary approaches, making it difficult for employers to operationalize their duty of care. In response to this problem, it was proposed that the qualities of the relationship between employer and employee can inform decisions about the appropriate precautions.

Subquestion 2 of this thesis asked whether there is an obligation to build relationships in order to take responsibility for uncertain risks. It was found that at least in some cases such an obligation exists. Using UC Berkeley as an example, Chapter 4 argued that in some cases *individual nano-engineers need to build relationships* with each other in order to ensure the necessary coordination and collective action required in response to unexpected hazards. This chapter started off by recognizing that the practice of nanoscience and nanotechnology can be very widely dispersed. In such cases, dealing with the emerging risks of nanotechnology cannot be done by individual engineers alone; it requires collaboration and coordination between engineers (e.g. rapid communication, knowledge-sharing and joint action). Under certain conditions, which have been elaborated on pages 58-59, individual nano-engineers have a duty to collectivize; they should build relationships with each other in order to ensure the coordination and collective action required in response to unexpected hazards. This duty is built on the assumption that if agents were to create such connections and organize themselves, they would be able to act adequately and appropriately.

The final subquestion of this thesis focused on the characteristics that relationships should have in order to deal responsibly with the uncertain risks associated with nanoparticles. If individual nano-engineers are to build relationships (as was argued above), this requires an understanding of the types and characteristics of relationships that are relevant to acting responsibly. Throughout this thesis, several characteristics of relationships were identified as relevant in the management of uncertain nanoparticle risks. Focusing on the feasibility of informed consent for nanoparticle risks, Chapter 2 found that *dependency, personal proximity and shared interests* influence whether valid informed consent is obtainable. It was suggested that these relational characteristics can balance each other out; more distant or dependent relationships may be compensated for by shared interest, safeguarding the validity of informed consent decisions.

Chapter 3 argued that the relationship between employer and employee can be assessed and used as a basis when choosing between precautions that are scientifically on a par. In this chapter, three relational criteria were suggested – the existence of a *mutual concern* for employee health and safety, *connectedness and continuity of relationships* between employer and employee, and *the responsiveness* of employers to employee needs – that can inform decisions about risk management strategies. Chapter 5 further developed a framework consisting of six characteristics of relationships that can be used to the extent to which relationships are caring. It is suggested that by evaluating relationships between people in innovation practices on the basis of their *dependency, power* dynamics, *mutual attention* and *responsiveness,* as well as the *emotional commitment* and *availability* between the parties in the relationship can amount to a more responsible practice. This chapter also showed that these characteristics can be used to make qualitative distinctions between relationships in innovation networks.

Listing characteristics that can be used to assess and compare relationships is only half the work. This thesis showed that relationships are relevant when it comes to the way risks are managed. This may be a matter of their capacity to support risk decisions, or in providing a complementary decision-criterion for choosing between risk management strategies, or by their caring characteristics. However, more empirical research is needed to be able to establish whether building and shaping relationships with the above-mentioned characteristics will, in practice, enable the taking of responsibility for the uncertain risks of nanoparticles. Furthermore, the interaction between the characteristics identified and how this interaction affects the taking of responsibility should also be subject to further research. The above-mentioned lists can be seen as a first step in providing an analytical framework to critically examine relationships and inform such inquiry.

This brings us to the main question of this thesis: How should responsibility and relationships be aligned? This was not meant to be a practical question, but rather a normative one: Should relationships function as a mold to shape responsibilities, or should relationships be modelled around a framework of responsibilities? With respect to the first option, this thesis showed that it is possible that responsibilities can be adjusted in order to align them with existing relationships. The notion of relational autonomy that is used in Chapter 2 serves as a way to integrate relational thinking into the formulation of the informed consent principle. By doing so, the notion of informed consent is reinterpreted to accommodate differences in the relationships in which it can be applied. In Chapter 3, the precautionary principle is not reinterpreted but instead complemented with a relational component, because the precautionary principle in its traditional formulation was not specific enough to unambiguously inform decisions between several available precautions. In this respect, the notion of caring relationships was used to develop complementary decision-criteria for the precautionary principle based on the features of relationships.

With respect to the second option above, which suggests that we adjust relationships in order to accommodate responsibilities, Chapter 4 argued that relationships should sometimes be shaped to serve the goal of creating more responsible innovation practices. This approach carves out an important role for relationships in establishing responsible practices. However, it is also an instrumental take on the value of relationships, insofar as they serve the goal of responsibility, which does not fully appreciate the constitutive value of relationships that is established in Chapter 5. Relationships are valuable in themselves, so therefore they should not simply be adjusted for the sake of responsibility. At the same time, the responsibilities that come with using nanoparticles cannot simply be adjusted to the relationships in place; they are morally pressing. This poses a dilemma: aligning relationships and responsibilities seems to require us to be prepared to compromise the value of either one or the other.

Chapter 5 developed a middle ground between these two options. It advanced an understanding of responsibility that is based on a novel characterization of relationships. Rather than seeing relationships as a context in which moral conduct takes place, that is, that relationships in some way either hinder or foster responsible approaches to dealing with uncertain risks, this understanding holds that having 'the right kind of relationships' is part of what it means to take responsibility. The opposite also applies: to take responsibility for someone means to develop (or have) a particular kind of relationship, that is, a caring one. This understanding of responsibility is particularly suitable when it comes to dealing with uncertainty. In situations where it is unclear what exactly should be done – and perhaps it is even unclear what the exact responsibilities are that we want other people to act upon – one still wants to be able to count on the adequate and timely response of other people. This thesis suggests that in such situations one may not be able to assess the desirability of a specific technology, but one can assess the relationships between those who develop and use it.

Trust seems to be an important notion here. Baier describes trust as a three-way predicate: 'A trusts B with valued thing C' (1986, p.263). When a person (A) is not able to do, protect or take care of something valuable (C), one can choose to depend on another person (B) who has control and the capacity to take care of C; B does this on A's behalf. This definition of trust already implies some sense of the sharing of responsibility. C is valued by A (and may be his or her responsibility) and A relies on B to take care of C. It is not a mere transfer of responsibility, because the valuable thing C is still a primary interest of A. Person A is simply reliant on B to be able to take care of C. Trusting others is inevitable if we want to innovate with nanoparticles. Due to uncertainties it is simply impossible and even undesirable to pinpoint exactly what other people might have to respond to or how to mitigate unwanted hazards. In such cases, trusting that other people will take responsibility and take care of what you find valuable and worth protecting is all we have. At the same time, when you trust someone, you run a personal risk that this person does not adequately, or does not want to,[36] respond to those risks. Therefore, trust should not be blind or unconditional.

Trust can function as an indicator of the alignment of responsibilities and relationships. Firstly, when responsibilities and relationships are aligned this means that the latter will not be a reason to excuse someone from the former. Responsibilities will only be allocated in a way that takes into account one's relationships (e.g., will not morally overload individuals who are in exploitative relationships, or when relationships do not allow for the taking of responsibility). This means that when the relationships are aligned, a person can be trusted to act upon their responsibilities. Secondly, qualitatively good relationships provide insights into the motivations, values and interests of other actors. They thereby warrant trust in that person to take responsibility for what is at stake; for example, I am more likely to trust a person in my laboratory with dangerous materials, if I already know I can count on them. Also, if I know someone is responsible it will be easier to build trusting relationships with that person. Trust, responsibility and relationships thus ideally end up in a virtuous cycle that increases the quality of all these three elements.

6.1. Generalizations and limitations

Although this thesis focused on relationships in the context of uncertain risks of a specific technology (nanoparticles), its findings have a bearing on many other technologies that are accompanied by uncertain risks, such as synthetic biology, biotechnology and new energy technologies. All of these fields face issues of governability due to limitations in risk assessment and management methods. Dealing responsibly with such technologies will require some sort of collaboration and coordinated activity, such as monitoring, knowledge-sharing and procedures to ensure adequate action when unwanted risks emerge. This means that these other technological domains could potentially benefit from my analysis, as the qualities of the relationships in those fields also influences the capacity of actors to act upon those responsibilities. Furthermore, the relational

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36 An important distinction is to be made between trust and reliability. Reliability has to do with predictable behavior, or 'dependable habits', in the words of Baier. However, trust has to do with good will; whether you can count on someone else to act in your interest. Someone who is predictably selfish, may be reliable, but not trustworthy.

features identified in this thesis may be developed in the context of nanoparticle risks, but are not specific to the context of nanoparticles.

However, for some fields it may be harder to shape relationships and achieve the sense of connectedness that is behind the idea of caring relationships. For example, more work is needed on determining how to align the responsibilities and relationships of actors in fields where innovation takes place in less institutionalized settings, such as do-it-yourself or hacker communities. Despite the fact that the nanoscience and nanotechnology field is dispersed and unorganized, it does largely take place in 'traditional' venues for innovation, such as university campuses and companies. For example, innovation in information technology can start at home, or take place in the virtual domain through online collaboration. This suggests that different, less institutionalized relationships play a role in these settings. However, it may actually be that for such cases the relational approach developed in this thesis offers new insights into how to align responsibility and relationships, by providing an analytical approach that makes relationships visible outside traditional institutions and recognizes their significance to the management of uncertain risks.

The relationships that are discussed in this thesis – that between employer and employee, consumer and producer, and relationships within innovation practices – are only a subset of the potential relationships that could have been discussed. Business to business relationships, relationships between NGOs and consumers or workers, and relationships between different management layers in organizations have not been mentioned. These relationships are also ethically relevant because they may influence the transfer of information about hazards of nanoparticles, influence the representativeness of NGOs' views, or limit the capacity of some to change work practices. This is a limitation of the research here and a possible interesting avenue for further research.

Another limitation of the research concerns Chapter 4, which established the importance of relationships for collective action on emerging nanotechnology risks solely on the basis of nanoscience and nanotechnology research at UC Berkeley. This, therefore, is limited with regard to the relationships that are considered; for example, it is likely that connections with national or international researchers at conferences also play a role in establishing responsible research practice.

Despite these limitations, the findings in this thesis, and primarily the general framework for characterizing caring relationships that was developed in Chapter 5, can be used to analyze other relationships as well. This is not to say that all these different relationships should uphold similar relational standards. In practice, it will become clear how to balance the different relational dimensions and come to productive relationships, that is, ones that stimulate critical reflection and collaboration to avoid hazards, rather than relationships that are unproductive; for example, because they lead to groupthink or to loyalty to ethically questionable actors.

Another suggestion about the generalizability of the findings in this thesis concerns the nature of the responsibility model in dealing with uncertain risks. This thesis showed that because the risks of nanoparticles are not precisely known, existing mitigation and prevention strategies are either inadequate or their appropriateness is difficult to determine beforehand. Individual actors may perform activities as part of a risk management strategy, but they will need to coordinate and jointly evaluate their activities to assess their effectiveness. In such cases, I argued, they need to build relationships to be able to actively share those responsibilities. I want to generalize this conclusion and hypothesis that uncertain risks require a shared, rather than a distributed, model of responsibility. Responsibilities cannot simply be distributed when it is unclear what needs to be done and when. This thesis proposes one way to conceptualize the sharing of such responsibilities through the development of relationships.

However, this hypothesis may in practice lead to a very demanding conception of responsibility. With respect to some uncertain technologies the nature of the technology prevents making solid risk assessment for longer periods of time. Many chemical pollutants, like the ones mentioned in the introduction as well as nanoparticles, may require decades of research and/or exposure to humans and the environment to establish solid risk information. In such cases expecting individuals to build and maintain relationships to anticipate any unexpected unwanted hazard seems an unfair burden. Therefore, more research is needed on how temporal differences between uncertainties, thus in what time span we expect uncertain risks to be resolved, can inform a relational understanding of responsibility.

This brings me to a final issue which is somewhat underexplored in this thesis: whether having strong relationships may have negative effects. Chapter 2 briefly discussed how strong ties may lead to biases through processes such as groupthink. Other negative effects may include strong emotional attachments that lead to the exclusion of those who cannot build relationships so easily or who are less ‘likeable’ (Chapter 5). Furthermore, if we expect scientists and engineers to organize themselves and build collectives for the sake of responsibility (as was argued in Chapter 4), this may go against other scientific values, such as disinterestedness and organized skepticism, which are important for epistemic reasons (Merton 1973), but seem to be in conflict with relational values that require collaboration and partiality. As a response to this objection, I would say that critical reflection may also be the outcome of deliberation and it remains an open question where the balance lies between relationships that promote objectivity by bringing in new views and those relationships that introduce biases. It is most likely that the relational lens developed in this thesis should be used to complement other ethical approaches in order to avoid these negative effects.

6.2. Implications for RRI

RRI (or RI, Responsible Innovation) is currently one of the dominant concepts in discussions about responsibility in relation to technological development. RRI has been particularly influential in European discourse, as it became a part of the Horizon 2020 funding scheme. In this final section, I would like to reflect on the value of the relational lens developed in this thesis for RRI. As the topic of this thesis has been the alignment of responsibilities and relationships to address the uncertain risks associated with nanoparticles, it therefore presupposes only a limited set of responsibilities – those that focus on dealing with risks – rather than responsible innovation in a broader sense. This does not mean, however, that the findings cannot contribute to the goals of RRI: risk management is part of what it means to innovate responsibly.

The precise meaning of the RRI concept has not fully been defined; nevertheless, there are several ideas that make up the backbone of RRI. First of all, innovation should meet social and environmental needs; or, in a more idealistic formulation, they should enhance societal and environmental value. This means that innovation should have the 'right impacts' (Von Schomberg 2014) and be an expression of 'science for society' rather than 'science in society' (Owen et al. 2012). What exactly the right impacts are, can be established in several ways. Many authors suggest a democratic approach, and on this basis have made an effort to increase stakeholder participation and public engagement with innovation processes (see e.g., the GREAT project[37] and the ResAGorA project[38]).

[37] http://www.great-project.eu/

Others call for greater inquiry into public needs and values and the redirection of innovation according to widely held values (Van den Hoven 2013; Von Schomberg 2013).

This thesis has engaged with the RRI literature on multiple occasions. In Chapter 4, it was shown that RRI not only requires responsible outcomes of innovation processes, but that it sets process requirements determining what research and development practices should look like. This chapter focused on the social structures necessary for RRI,[39] arguing that if we want individuals in the field of nanoscience and technology to innovate responsibly, they should organize themselves into collectives that can do RRI. RRI – in this case, narrowly interpreted as the need to be able to respond to emerging unwanted hazards of nanotechnology – then functioned as an argument in establishing whether individual engineers have a duty to collectivize.

Chapter 5 engaged with the notion of 'care' that has become popular in RRI discourse, and developed a way to operationalize this notion by exploring what caring relationships in the particular case of nanoremediation innovation practices would amount to. The chapter showed how the relational lens can help to analyze innovation processes in terms of relationships and networks. RRI is often depicted as a collaborative project. For example, Von Schomberg (2013) talks about the shared responsibility of innovators and societies to tackle the grand challenges of our times, such as global warming and food security. Owen and colleagues (2013) also assume collaboration and interaction when they state: "Responsible innovation is a collective commitment of care for the future through responsive stewardship of science and innovation in the present" (Owen et al. 2013, p.36). The framework developed in this thesis provides a way of exploring in more detail the nature of these collaborations and interactions.

A third, more tentative, contribution of this thesis to RRI discourse and practice might be the institutionalization of the relational lens developed here. I do not want to argue for an institutionalization of particular types of relationships; for example, to describe how people ought to relate to each other. I also do not want to suggest that we should generalize the relational criteria developed in this thesis and assess relationships between organizations, such as scientific and

38 http://res-agora.eu/news/

39 The four principles of RRI, anticipation, reflectiveness, deliberation and responsiveness, developed by Owen and colleagues (2013), are another example of such process criteria.

governmental institutions, on the basis of these criteria. Rather, institutions can provide opportunities for building relationships that foster responsibility and that ensure risks are dealt with responsibly. This suggestion is in line with Tronto's (2013) perspective on care in democratic societies: she calls for the building of institutions that support those who are doing care work. Similarly, the capacity of individuals to build responsible and caring relationships could be stimulated when setting up research projects, funding schemes, professional organizations and collaborations with industry. The precise details on how this should be done requires further elaboration, but I hope that this thesis provides a first step in creating awareness about the importance of relationships to the RRI approach.

7 Epilogue: Implications for engineering ethics education[40]

Within the Ethics and Philosophy of Technology section at Delft University of Technology, which I have been part of for the past four years, we are intensively involved in teaching ethics to engineering students at Bachelor's, Master's and PhD level. We are not alone in this, with various other departments and colleagues in the Netherlands and worldwide also engaged in this field. This epilogue will briefly reflect on what the findings of this thesis imply for the way we teach engineering ethics, drawing from personal experiences gained during the Global Perspectives program at the University of California, Berkeley (Sunderland et al. 2014).

During the Global Perspectives program, we collected several examples of institutional and social burdens that impede ethical reflection and action in research practice: in particular we considered how PhD students' supervisors and departments play an enabling and/or obstructive role in allowing their PhD students engaging with ethical aspects of their work. The problem was already apparent in the reluctance of PhD candidates to participate in the program, while those who did participate found the implementation of their findings and passing on their experiences from the program very difficult. Many lost their initial enthusiasm after embarking on failed attempts to share their experiences and ideas with their engineering colleagues. Other students mentioned that although they were often aware of the 'right thing to do', funding arrangements did not allow for alterations of research practices to include ethical considerations. One of the participants in this program, for example, recalled a situation in which sustainability considerations failed to convince funders that a different nano-ink should be used for etching. He said that the particular nano-ink being used was useful for research purposes because it was well-defined and easy to

40 This section is to a large extent based on and contains excerpts of Spruit, S. (2014) Responsible innovation through ethics education: educating to change research practice. Journal of Responsible Innovation, 1(2), pp.246–247. Available at: http://dx.doi.org/10.1080/23299460.2014.922344.

handle, but it would not be desirable as a component in consumer products because of its toxic properties.

Despite these institutional barriers to ethical action, ethics education resources rarely discuss how to address such institutional and organizational challenges. Many engineering ethics textbooks focus on ethical reasoning: ethics is defined as the systematic reflection on morality, through which we can determine the right thing to do. While students are not typically asked to analyze a case's broader context, some institutional barriers are well documented. For example, the often used Challenger case demonstrates the role of management structures and power relations in engineering decisions, and discussions of whistleblowing acknowledge all sorts of institutional barriers to doing the right thing. In addition, some institutional barriers have less to do with power hierarchy and more to do with the competitive forces. Within universities tenure structures, for example, present hurdles to ethical inquiries, especially when ethical considerations are relegated to the 'broader impacts' sections of research proposals. Interestingly, most faculty members involved in Berkeley's Minner Fellow program in Engineering Ethics seemed to be well established in their field, supporting the view that those still building their careers have less opportunity for non-scientific ventures.

If we want to fully realize the empowering effects of ethics education and take seriously the social hurdles to ethical action, we should offer opportunities for students to develop skills that might enable them to change existing practices and address social barriers. However, rather than opening a discussion about how to change one's ethically problematic organization, textbooks instead focus on reasoning capacities and the quality of argumentation. If they do take into account how social structures should be addressed, it usually consists of guidelines for gauging when whistleblowing may be permitted. Whistleblowing should be a last resort because of the huge personal and commercial risks that are involved. Instead, future engineers should be equipped to tackle issues within their organization before problems become so embedded in the organizational culture that the only way out is whistleblowing.

This thesis contributes to this goal by taking a step towards aligning responsibility with the social reality of research contexts. Although the framework sketched also has limitations in its application (see Chapter 6), it takes a step forward in making the way that relationships influence the responsibility of engineers more clear. In addition to strong reasoning skills, addressing these broader institutional issues requires knowledge of change management and social change. Such knowledge might be cultivated by social change. Such knowledge might be cultivated by incorporating local ethical organizational research into course design, with the aim of empowering students to become true partners in realizing the responsible innovation project.

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Summary

Technological developments in the field of nanoscience and nanotechnology have led to the development of several newly engineered nanoparticles. These materials are already being applied in a variety of consumer contexts, as well as business products, and are expected to be more widely used in the coming years. Despite all the promises, novel nanoparticles are still accompanied by scientific uncertainty about their hazardous effects. Due to these uncertainties, conventional methods for managing risk are deemed insufficient. In response to this, it has been proposed that the management of uncertain risks requires a forward-looking notion of responsibility, which entails various kinds of anticipatory activities to ensure an adequate and timely response to emerging risks.

The question of who should bear this responsibility often remains implicit in such discussions. However, innovation processes cannot be responsible, nor can they reflect on or account for what they do, or make intentional choices. Ultimately, responsibility should rest with particular individuals. At the same time, it has been recognized that the collaborative nature of innovation processes creates problems for the allocation of responsibility to individual actors such as scientists, engineers and product developers. Activities that lead to the development of nanoparticles and nanoproducts are often complex and distributed; they take place at multiple locations, combine insights from several disciplines and involve many different agents. This suggests that in order to determine a viable allocation of responsibility for uncertain nanoparticle risks, it is necessary to reflect on the way people interact in the field, and how this influences the capacity of individuals to take responsibility for emerging hazards.

This thesis contributes to this discussion by exploring the relationships between people who are involved in various ways in the development and use of nanoparticles, and by exploring how such relationships should be taken into account in the allocation of responsibility. The ultimate aim is to align the responsibilities that people have with the relevant relationships in the field. The goal of the thesis is primarily normative: it develops a framework to ethically assess relationships. However, the normative analysis is strongly empirically informed: it is supported by data from two case studies, one on the use of nanoparticles in a work environment and one on the use of nanoparticles for

land remediation, complemented with literature from the empirical sciences and a collaborative paper with two nano-engineers.

As a first step, this thesis explores *how relationships matter* to the way we deal with the uncertain risks of nanoparticles. Exploring the possibility of informed consent in relation to nanoparticles, Chapter 2 shows that several features of relationships, such as dependency, proximity and the existence of shared interest can influence the quality of decision-making processes about uncertain risks. Following this, Chapter 3 shows that relationships, such as those between employer and employees, can give rise to duties of care for uncertain risks. Chapter 4 argues that the existence of relationships is necessary in order to be able to respond to new and emerging hazards in the field of nanoscience and nanotechnology. On this basis, Chapter 4 argues that in some cases there is *an obligation to establish relationships*. In particular cases, where there is a need for collective action, but no such collective exists, individual engineers involved in innovation processes would have a duty to collectivize: they must organize themselves into a collective that can adequately act upon emerging and unwanted hazards.

Finally, in Chapter 5, this thesis explores *the characteristics required of such relationships to foster responsibility* in nanoparticle development. In doing so, I shift from a narrow notion of responsibility focused on dealing with risks to a broader conception of responsibility that not only takes into account risks, but includes the potential benefits of innovation as well. The chapter develops a framework to characterize morally relevant features of relationships based on the Ethics of Care. Several features of relationships are identified that can be used to evaluate whether relationships amongst those developing and using nanoparticles are caring. These include dependency, power, attention, responsiveness, emotional engagement and availability. The usability of this framework is explored by applying it to the context of innovation in relation to nanoparticles used in the context of land and water remediation.

In Chapter 6, the thesis concludes with a reflection on the alignment of relationships and responsibilities, discussing whether relationships should be adjusted to responsibilities or – vice versa – whether the responsibilities we allocate for nanoparticle risks should be adjusted to the relationships at hand. I suggest that there is a middle ground between these two options – an understanding of responsibility that is based on a certain characterization of relationships. This understanding holds that having ‘the right kind of relationships’ is part of what it means to take responsibility. This thesis ends with a discussion of the implications of these findings for the practice of and scholarship in Responsible Research and Innovation.

Samenvatting

Ontwikkelingen in de nanowetenschappen en nanotechnologie hebben er toe geleid dat we in staat zijn nieuwe nanodeeltjes te produceren. Deze nanodeeltjes worden gebruikt voor toepassingen in verscheidene producten voor consumenten alsmede industriële doeleinden, en men verwacht dat dit in de toekomst alleen maar zal toenemen. Buiten grote beloftes gaan deze deeltjes echter ook gepaard met grote onzekerheid over de gevaren die zij met zich meebrengen. Deze onzekerheid maakt dat gangbare methoden voor risicobeoordeling en risicomanagement beperkt toepasbaar zijn op nanodeeltjes. Dit vraagt al tijdens het innovatietraject om een pro-actieve houding wat betreft deze deeltjes om te zorgen dat er adequaat en tijdig wordt gehandeld in het geval gevaren bekend worden.

Het is echter onduidelijk wie precies de verantwoordelijkheid draagt om onzekere risico's te managen. We weten dat samenwerking en genetwerkt handelen, dat ten grondslag ligt aan innovatieprocessen, het toedelen van verantwoordelijkheden aan specifieke personen zoals wetenschappers, ingenieurs en productontwikkelaars veelal bemoeilijkt. Activiteiten die leiden tot de ontwikkeling van nanodeeltjes en nanoproducten vinden plaats op verscheidene locaties, combineren inzichten van verschillende disciplines en tellen vaak veel verschillende betrokkenen. Ondanks deze complexiteit, hebben wetenschappers en beleidsmakers de ambitie om, onder andere in het kader van de risico-ethiek en het debat over maatschappelijk verantwoord innoveren, onzekere risico's te beheersen. Dit suggereert dat we moeten reflecteren op de manier waarop mensen die betrokken zijn bij de ontwikkeling van nanodeeltjes interacteren, en hoe onderlinge relaties de mogelijkheden van individuen beïnvloeden om te reageren op onverwachte en onzekere risico's.

Dit proefschrift draagt bij aan dit vraagstuk door een verkenning van de relaties tussen mensen die betrokken zijn bij de ontwikkeling en het gebruik van nanodeeltjes; en een verkenning van hoe deze relaties in ogenschouw moeten worden genomen bij de toedeling van verantwoordelijkheid. Het uiteindelijke doel is om de verantwoordelijkheden die we toedelen aan mensen in lijn te brengen met de relaties die er zijn in dit veld. Dit doel is normatief: ik ontwikkel een kader om relaties mee te kunnen nemen in ethische discussies over verantwoordelijkheid en om relaties zelf ethisch te kunnen evalueren. Deze normatieve analyse is echter sterk empirisch geïnformeerd en wordt ondersteund door twee cases: een case over het gebruik van nanodeeltjes in werkomgevingen en een case over het gebruik van nanodeeltjes voor bodem- en watersanering. De analyse is daarnaast aangevuld met literatuur uit de maatschappij en gedragswetenschappen en een gezamenlijk onderzoek naar professionele identiteit met twee nanotechnologen.

Ten eerste onderzoekt dit proefschrift de manier waarop relaties een rol spelen in de omgang met onzekere risico's. Hoofdstuk twee verkent of het toepassen van geïnformeerde toestemming (*Informed Consent)*, zoals gangbaar is bij blootstelling aan risico's bij medische behandelingen en bij mensgebonden onderzoek, mogelijk is voor nanodeeltjes. Dit hoofdstuk laat zien dat eigenschappen van relaties (zoals afhankelijkheid, nabijheid en de aanwezigheid van gezamenlijke belangen) tussen iemand die risico's produceert ten opzichte van iemand die risico's loopt de kwaliteit van besluitvormingsprocessen rondom onzekere risico's kan beïnvloeden. Vervolgens laat hoofdstuk drie zien dat afhankelijkheidsrelaties, zoals die tussen werkgever en werknemer, aanleiding kunnen zijn voor een zorgplicht ten aanzien van onzekere risico's. Hoofdstuk vier beargumenteert dat de aanwezigheid van relaties in de nanowetenschappen noodzakelijk kan zijn voor een adequate reactie op nieuwe onzekere risico's van nanotechnologie. In gevallen waar collectieve actie gewenst is om met onzekere risico's om te kunnen gaan maar waar (nog) geen professionele banden bestaan die dit kunnen faciliteren, is er zelfs een plicht voor onderzoekers om zich te organiseren; dat wil zeggen, om relaties te vormen zodat men gezamenlijk deze verantwoordelijkheid kan dragen.

Ten slotte bespreekt hoofdstuk vijf een aantal mogelijke eigenschappen die relaties moeten hebben om een verantwoorde omgang met nanodeeltjes te bevorderen. In dit hoofdstuk bespreek ik naast de nauwe verantwoordelijkheid om de kans op fysieke schade te beperken, ook de verantwoordelijkheid van nano-onderzoekers, productontwikkelaars en eindgebruikers om een positieve bijdrage te leveren aan de samenleving en het milieu. Dit hoofdstuk ontwikkelt daartoe een normatief kader om innovatie-netwerken te beoordelen op basis van de Zorgethiek. Verscheidene dimensies van relaties worden geïdentificeerd, die vervolgens gebruikt kunnen worden om te beoordelen of de relaties tussen hen die nanodeeltjes ontwikkelen en zij die nanodeeltjes gebruiken 'zorgzaam' zijn. Deze dimensies zijn: afhankelijkheid, macht, aandacht, responsiviteit, emotionele betrokkenheid en beschikbaarheid. De bruikbaarheid van dit kader wordt besproken door het toe te passen op het gebruik van nanodeeltjes voor bodem- en watersanering.

In het zesde, concluderende, hoofdstuk reflecteer ik op de afstemming van relaties en verantwoordelijkheden. Ik bediscussieer of relaties moeten worden afgestemd op verantwoordelijkheden, of – vice versa – de verantwoordelijkheden, die we toedelen in de omgang met de onzekere risico's van nanodeeltjes, rekening moeten houden met de bestaande relaties. Ik opper dat er een middenweg is tussen deze twee uitersten, namelijk een formulering van verantwoordelijkheid die zelf relationeel is. Deze formulering houdt in dat het hebben van 'het juiste type relaties' deel uit maakt van wat het betekent om verantwoordelijk te handelen. Dit proefschrift eindigt met een discussie van de implicaties van mijn bevindingen voor zowel de uitvoering van Maatschappelijk Verantwoord Innoveren als het hier aan gerelateerde academische debat.

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About the author

Shannon has a BSc in Biomedical Sciences, and a MSc in Medical anthropology and Sociology, both obtained from the University of Amsterdam. Before she started her PhD research at the Delft University of Technology she was affiliated with the Centre for Society & the Life Sciences at the Radboud University, Nijmegen, where she studied collaboration in the nutritional sciences.

Already during her studies at the University of Amsterdam she was involved as a teaching assistant and course developer in various applied ethics courses. Teaching Bio-ethics courses to Biology, Biomedical Sciences and Psychobiology students with Henriette Bout initially sparked an interest for Philosophy of Science and Technology, and applied ethics in particular. Since then she has been involved in the coordination and teaching of several applied ethics courses, as well as the design of innovative new course designs. For instance, the Impact! Project that explored the role of creative methods for ethical reflection.

Shannon is currently a postdoctoral researcher in the department of Multi Actor Systems at the Faculty of Technology, Policy and Management of Delft University of Technology. Within the context of the RESPONSE project she explores how relationships and interactions between stakeholders influence the emergence of controversies, how formal and informal assessments interact with each other in practice, and the governance of energy technologies more generally.

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Spruit, S.L. 2015. “Impact! Ethical reflection through Art,” Society for New and Emerging Technology Conference, Montreal

Spruit, S.L. 2015. “Nanotechnology as social experiment,” New Technologies as Social Experiments Conference, Delft

Spruit, S.L. 2015. “On care in science and engineering,” Conference of the Society for Philosophy of Technology, Shenyang

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Spruit, S.L. Van de Poel, I.R. Doorn, N. 2013. “A Systematic reflection on the relational aspects of Informed Consent,” Twente University Colloquium, Enschede

Spruit, S.L. 2012. “Nanoparticles as social experiment: Contextualizing the experimental nature of nanotechnology,” Society for New and Emerging Technologies Conference, Enschede

Public talks and panels

Spruit, S.L. 2016. “Technologie zal ons tot slaaf maken,” part of the television show on the 2016 Brainwash Festival, Human, NPO 2

Spruit, S.L. 2015. Member of a panel on the ethical implications of information technology “Technocrazy,” at Vitamine Z Festival, Tolhuistuin, Amsterdam

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Simon Stevin (1548-1620)

'Wonder en is gheen Wonder'

This series in the philosophy and ethics of technology is named after the Dutch / Flemish natural philosopher, scientist and engineer Simon Stevin. He was an extraordinary versatile person. He published, among other things, on arithmetic, accounting, geometry, mechanics, hydrostatics, astronomy, theory of measurement, civil engineering, the theory of music, and civil citizenship. He wrote the very first treatise on logic in Dutch, which he considered to be a superior language for scientific purposes. The relation between theory and practice is a main topic in his work. In addition to his theoretical publications, he held a large number of patents, and was actively involved as an engineer in the building of windmills, harbours, and fortifications for the Dutch prince Maurits. He is famous for having constructed large sailing carriages.

Little is known about his personal life. He was probably born in 1548 in Bruges (Flanders) and went to Leiden in 1581, where he took up his studies at the university two years later. His work was published between 1581 and 1617. He was an early defender of the Copernican worldview, which did not make him popular in religious circles. He died in 1620, but the exact date and the place of his burial are unknown. Philosophically he was a pragmatic rationalist for whom every phenomenon, however mysterious, ultimately had a scientific explanation. Hence his dictum 'Wonder is no Wonder', which he used on the cover of several of his own books.