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Devices of Responsibility: Over a Decade of Responsible Research and Innovation Initiatives for Nanotechnologies

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Abstract Responsible research and innovation (RRI) has come to represent a change in the relationship between science, technology and society. With origins in the democratisation of science, and the inclusion of ethical and societal aspects in research and development activities, RRI offers a means of integrating society and the research and innovation communities. In this article, we frame RRI activities through the lens of layers of science and technology governance as a means of characterising the context in which the RRI activity is positioned and the goal of those actors promoting the RRI activities in shaping overall governance patterns. RRI began to emerge during a time of considerable deliberation about the societal and governance challenges around nanotechnology, in which stakeholders were looking for new ways of integrating notions of responsibility in nanotechnology research and development. For this reason, this article focuses on nanotechnology as the site for exploring the evolution and growth of RRI.

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Introduction

More than a decade has passed since the United Kingdom's (UK) Royal Society and Royal Academy of Engineering (RS-RAE) published its seminal report *Nanoscience and nanotechnologies: opportunities and uncertainties* (RS-RAE 2004). This report sought to address questions regarding human and environmental health and safety, ethical, legal and societal implications and/or uncertainties arising from the use of nanotechnologies. The authors of the report anticipated that its findings and recommendations would contribute to the 'responsible development' of nanoscience and nanotechnology (N&N) within, and beyond, the jurisdictional boundaries of the UK (RS-RAE 2004, xii). The report, which was widely accepted by key stakeholders including the UK Government, has provided the foundation for a plethora of activities across the globe aimed at the 'responsible development' of nanoscience and nanotechnologies. These activities ranged from soft law mechanisms such as the development of codes of conduct, to dialogue initiatives and research focused explicitly at unpacking the Ethical, Legal and Social Implications or Aspects (ELSI/ELSA) of the technology.[1]

The use of the term 'responsible development' by the RS-RAE in 2004 was not the first time that stakeholders had employed such a concept within the conversation around emerging technologies. As noted by Rip (2014), the expression had been used sparingly up until, and including, the mid-2000s and primarily by actors within the European Union (EU).

Against this backdrop of activity, the term 'responsible development' became increasingly appropriated within the policy and academic discourse by the cognate term 'responsible research and innovation' (RRI). The term, first coined–at least formally–in 2008 (Tancoigne et al. 2016) has continued to gain traction and visibility as a concept in research and innovation (R&I) policy at the EU level (von Schomberg 2011). Now, 9 years after the first formal use of RRI, the term can be considered to be ubiquitous within the EU's discourse around the governance of emerging technologies, cutting across, for example, sub-programmes within the European Commission's (EC) Horizon 2020 research funding programme. More recently we have seen the term being used outside of the EU (see, for example, Guston et al. 2014; Valdivia and Guston 2015; Fisher 2016).

It is therefore not surprising, given the timing of the development and commercialisation of nanotechnology, and the liberal adoption of RRI within the policy discourse, that nanotechnology is viewed by key stakeholders as the leading field of scientific endeavour for activities and discussions about RRI (Rip 2014; Grunwald 2014). This is evident in the variety of RRI approaches or 'devices of responsibility' that have been proposed in order to orient nano research and innovation more effectively. 'Effectively' in this context is said to include and

[1] ELSA and ELSI programmes emerged prior to the advent of nanotechnology, most notably as part of the emergence of biotechnology (Wolfe 2000).

encompass both societal needs and ethical concerns. Yet, we would argue, that little attention has been paid to understanding the effects of RRI initiatives on R&I activities, policy development and/or governance initiatives.

Twelve years after the release of the RS-RAE report, we believe that the time is ripe to take stock of the numerous and varied activities and initiatives aimed at facilitating the responsible development of nanoscience and nanotechnology (collectively referred to in this article as nanotechnologies) across R&I programmes and practices.[2] We *position* these activities within the context of governance in which the RRI activities are embedded, and *operationalise* a model of layers of governance to move beyond the listing of activities and to analyse the nature of these RRI activities and their differences. Such positioning and characterising via layers of governance provides a lens into the motivations of those conducting these RRI activities as well as the 'change aims' of those conducting and/or facilitating RRI activities.[3]

This article proceeds as follows. First, we describe the RRI 'movement' in the field of nanotechnologies, focusing in on the RRI concept itself as it has emerged in policy and academic discourse. Second, we develop a typology of proposed devices and tools of responsibility for nanotechnologies' RRI activities; a particular emphasis is placed on the principles of RRI which are claimed to underlie the proposed approach (es). Third, we map and categorise RRI activities at different levels (or layers) of governance with details of the various groups of actors involved in such activities. Fourth, we consolidate insights gained in the previous sections to reflect on the *de facto* situation regarding the responsible development/RRI of nanotechnologies and, on that basis, propose further avenues of RRI research, RRI development and RRI application.

The RRI 'Movement' in the Field of Nanotechnology

Prehistorical RRI in Nanotechnology

The emergence of new technologies, and the products that they give rise to, have not traditionally been accompanied by a parallel debate on the broader societal issues, including the ethics and governance, of the technology. Such discussions have, in contrast, occurred as a consequence of documented harm being done to humans and/ or the environment, and/or the widespread rejection of the technology and its products by the market. Cases-in-point include, for example, nuclear power within

[2] In 2011, Grunwald carried out a similar study in which he described and assessed the outcome and impacts of 10 years of research on nanotechnology and society, the objective of which was to offer reflections on the opportunities and constraints of further research at the interface between nanotechnology and society. Grunwald concludes that while fields such as Science and Technology Studies (STS), Technology Assessment (TA) and studies of Ethical, Legal and Social Implications (ELSI) likely played a role in the 'normalisation' of nanotechnology, the objective of shaping nanotechnology directly in terms of its development paths and specific application fields was not achieved.

[3] We use the term 'change aims' since often, desired measurable impacts of RRI activities are not made explicit in many of the RRI activities, whereas a global notion of change is often mentioned.

jurisdictions such as Australia and New Zealand (Falk et al. 2006; Clements 2015) and the deployment of genetically modified organisms (GMOs) within the EU's agri-food sector (Burton et al. 2001; Bredahl 2001). There are, of course, exceptions to this statement including, for example, the creation of scientific guidelines for research on recombinant DNA technologies following the 1975 Asilomar Conference on Recombinant DNA technologies (Berg et al. 1975), and the oversight given to the development of in vitro fertilization and other reproductive technologies within Victoria (and Australia more generally in the 1980s) (Committee to Consider the Social Ethical and Legal Issues Arising from In Vitro Fertilization 1983). These activities laid the foundation for fruitful policy and ethical discussions around the technologies, and opened up the scientific advances beyond the privileged few.

The development and commercialisation of nanotechnologies appears to go beyond previous responsible development practices, with the RS-RAE's (2004) report being an early example of stakeholders raising critical questions and concerns regarding the future of the technology. Eleven years earlier, in 1993, two American Law Professors published a law review article that sought to map out the potential legal, regulatory, policy and political challenges that nanotechnology would give rise to (Fiedler and Reynolds 1993). At the time of publication, the technology was in its infancy, with the only real 'nano' occurring within the realm of the Information Technology (IT) industry. Despite the lack of tangible products on which to draw, Fiedler and Reynolds (1993) spoke of the potential legal, societal and political challenges that the technology is likely to give rise to, and suggested that new, nano-specific legislative measures may be needed to effectively regulate aspects of the technology. The authors did not attempt to sketch out what those frameworks could or should look like, opting instead to suggest that given the ubiquitous potential of the technology, such frameworks would need to be flexible and adaptive.

The framing of nanotechnologies as a key economic driver for developed and developing economies in the twenty-first century (see, for example, National Science and Technology Council 2000, 2003) ensured significant public sector investment in fundamental nanotechnology research and development (R&D). The aggressive funding and policy hype over the technology has been viewed, however, as placing national governments in a difficult position; they act as key proponent of the technology, while also as the overseer of the regulatory agencies charged with protecting human and environmental health from the technology and its products (Macoubrie 2006; Foss Hansen et al. 2008; Hodge et al. 2014). As Fisher and Mahajan (2006a) observe, one way in which the US government attempted to address this conflict of interest–whether real or perceived–was to invest in research activities focused on the societal dimensions of the technology. This was done by incorporating language into the key federal funding instrument–the *21st Century Nanotechnology Research and Development Act* (Public Law 108–153)–that expressly required the funding of a research programme focused on, among other things,

> 'Identify[ing] ethical, legal, environmental, and other appropriate societal concerns related to nanotechnology, and ensuring that the results of such research are widely disseminated' (s.2 (b) (10) (A)).

And that,

> 'insofar as possible, integrating research on societal, ethical, and environmental concerns with nanotechnology research and development, and ensuring that advances in nanotechnology bring about improvements in quality of life for all Americans; and…(s.2(b)(10)(C)).

These provisions, concerned with broader societal concerns, immediately placed a substantial onus on the research community. However, the Act went further. Pursuant to section 2(b) (10) (D), the Act also required the federal coordinating body to, among other functions, convene 'regular and ongoing public discussions, through mechanisms such as citizens' panels, consensus conferences, and educational events, as appropriate;…'

The mandating of broader societal concerns into the *21st Century Nanotechnology Research and Development Act* was, in the opinion of Fisher and Mahajan, without precedent. In their words,

> 'to the best of our knowledge, no federally funded self-critical technological program integrated the considerations of societal issues with the 'nuts and bolts' development of its resulting technological products' (Fisher and Mahajan 2006a, p. 12).

While not employing the terms responsible development or RRI expressly, the intent of the legislature within the *21st Century Nanotechnology Research and Development Act* would appear to have been very much in line with what we now perceive RRI–especially within the European context–to be concerned with. It is to the emergence of RRI within the political discourse in the EU that this article now turns.

A first visible use of the term 'responsible research and innovation' was visible in the European Nanotechnology Network of Excellence FRONTIERS. Financed by the European Commission's 6th Framework Programme, FRONTIERS conducted a series of Constructive Technology Assessment (CTA) exercises (Robinson 2010; Rip and Van Lente 2013) around four different nanotechnology application areas and an additional exercise focused on stimulating reflexivity on the various forms of nanotechnology governance and how this would unfold. Under the banner of RRI, this exercise developed a series of scenarios and created a multi-stakeholder space for reflection on the nature of RRI for nanotechnology both then and in the future (Robinson 2009). This RRI activity was a bottom up affair, what Tancoigne et al. (2016) have labelled as 'little rri'. This is in stark contrast to the more top-down RRI which, as described below, has became the dominant form of RRI in the EU.

The Advent of an RRI Work Programme Within the EU Context

RRI has become an increasingly important policy discourse at the EU level, where it underpins high-level European policy strategies, such as the EU2020 strategy to create smart growth, and cuts across the Horizon 2020 work programme. The policy component of RRI has grown out of discourse around socio-technical integration within, and beyond, the European Commission's (EC) Science in Society programme (Owen et al. 2012). The concept has roots in different traditions, including technology assessment, anticipatory governance, and ELSA/ELSI. These activities have collectively provided the foundation on which the broad RRI agenda is built.

But what exactly is RRI? von Schomberg offers the following definition, which is widely referenced by the community that it has been developed for:

> 'a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on 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, p. 9).

This definition has a broad and ambiguous framing, which allows much room for interpretation whilst at the same time, it provides little practical guidance regarding how to operationalise the RRI concept. What can be drawn from this definition is that RRI aims to bring societal actors–researchers, citizens, policy makers, business, third sector organisations, etc.–together during the R&I processes. The purpose of this early stage engagement is to make explicit the implicit norms and values around a new technology and its potential embedding in society and to better align those processes with the most desirable values for society (EC 2016).

At the EU level RRI is framed as a means of tackling grand *societal* challenges.[4] These challenges include human health, demographic change and wellbeing, food security and sustainable agriculture, clean energy and secure societies. Addressing these challenges is seen as being key to the realisation of future economic growth.

The EC's RRI framework is underpinned by five policy agenda keys or priorities which require action on societal engagement, gender equality, science education, ethics and open access (European Commission 2016). Two expert groups working for the EC have reflected on means and possibilities for the implementation of RRI. One expert group identified policy options for strengthening RRI, including enhanced coordination among EU and national actors in their response to the need for improved alignment of R&I with societal challenges (van den Hoven et al. 2013). The group also recommended policy options that would offer opportunities to enhance the application of RRI criteria in R&D processes. A second expert group has worked on advancing the implementation of RRI by identifying and proposing

[4] The notion of grand societal challenges as a driver for research and innovation policy is itself an emerging trend and it is not clear how it will unfold. Will RRI become part of the 'mission' of mission-oriented public agencies (Mazzucato and Robinson 2016) that incorporate grand societal challenges in their strategic agendas?

indicators with which to monitor, assess and evaluate the performance of RRI initiatives (Strand 2015).

RRI has also gained traction in academic discourse, with the establishment of, for example, the *Journal of Responsible Innovation* (JRI). Such initiatives reflect the increasing engagement of a variety of scholars–including social scientists, humanists, legal scholars, policy scientists and natural scientists and engineers–in the further development and critique of RRI. Somewhat paradoxically, the founding editor of JRI and his successor are both US scholars, based in US institutions.

Academic discourse has also sought to emphasise the various dimensions that characterise RRI. While a variety of definitions of RRI exist in the academic discourse, consistent threads between them include an emphasis on the dimensions of anticipation, inclusion, reflexivity and responsiveness (Stilgoe et al. 2013). Wickson and Forsberg (2015) have studied the variety of definitions of RRI and drawing on this research, have developed a description of the central characteristics. According to Wickson and Forsberg (2015), within the academic discourse, RRI can be characterised as:

1. A specific focus on addressing significant societal needs and challenges
2. A research and development process that actively engages and responds to a range of stakeholders
3. A concerted effort to anticipate potential problems, identify alternatives, and reflect on underlying values, and
4. A willingness from relevant actors to act and adapt according to 1–3.

Drawing upon this analysis, it is clear that there are two different RRI discourses operating simultaneously. And while the policy discourse and the academic discourse are not mutually exclusive, they do appear to be operating at different levels and with different priorities. This is arguably not surprising, nor unique to RRI (Søraker and Brey 2014). The EC aims to define policy priorities that fall within the domain of RRI, while the academic literature aims to establish the key dimensions of RRI from a conceptual perspective (Søraker and Brey 2014).

A Tableau of RRI Activities Targeted at Nanotechnologies

The work progamme outlined above has been translated into a number of broad principles that can be identified as proposed RRI mechanisms and initiatives. They include anticipation, reflection, deliberation, responsiveness, precaution and vigilance and/or collective co-responsibility. ‘Safety by design’ or ‘benign by design’ constitute principles encompassing the attempt to make ‘safety’ a fundamental property of new nanomaterials (Kelty 2009; Viseu and Maguire 2012). Table 1, below, organises the various mechanisms proposed, along with the justifications and motivations underpinning them, allowing an overview of the RRI landscape for nanotechnologies.

Table 1 Overview of the RRI landscape for nanotechnologies

Principles of RRI	Proposed mechanisms and approaches in nano	Justification for principle and targeted actors
Anticipation: Describing and analysing possible and desirable futures in relation to intended and potentially unintended impacts Prompting 'what if' questions on the part of researchers, research organisations, research funders, regulators and policy makers	• UK research councils: Requirement to anticipate on intended impacts. Focusing innovation on a social or environmental impact • MVI programme (the Netherlands): research programme in the Netherlands Organisation for Scientific Research (NWO) focused on inquiry into the possible ethical and societal consequences of innovation at an early stage, with a particular focus on the top sectors in Dutch industry • Technology Assessment and foresight methods • Socio-technical scenarios (Parandian 2012; Robinson 2009) • Fictive script (den Boer et al. 2009) • Prospective Impact assessments (Robinson and Rip 2013; OECD 2014b) • Ethical assessments (Grunwald 2005) • Upstream public engagement (Rogers-Hayden and Pidgeon 2008)	*Motivations include:* • Attempt to respond to the temporal dilemma in nanoscience and nanotechnology development • Attempt to respond to the social, technical and commercial uncertainties relating to nano development • Define desirable impacts of innovation and research (von Schomberg 2013) • Setting of research priorities and their anticipated impacts (von Schomberg 2013) *Targeted actors:* Researchers, research organisations, policy makers, research funding organisations, regulators
Reflexivity/reflection: Differentiate here between *reflexivity* of actors and institutions, on the one hand, and *reflection* (as regards what it already covered by regulation, what is known about nanomaterials, etc.), on the other (Doubleday 2007)	• Self-reflection initiatives (e.g. codes of conduct for individual scientists) (Dorbeck-Jung and Shelley-Egan 2013) • Constructive Technology Assessment (Robinson 2010; Parandian 2012) • Midstream modulation (Schuurbiers 2011) • Ethical technology assessment (Kaiser et al. 2009)	*Motivations for reflexivity:* By enhancing enactors' reflexivity about broader issues and the possible need to do something about them, actors will be able to make decisions that can contribute to research and networking that better meets society's needs (Stilgoe et al. 2013) *Targeted actors*: Researchers, research organisations, firms

Table 1 continued

Principles of RRI	Proposed mechanisms and approaches in nano	Justification for principle and targeted actors
Reflexivity of actors and institutions: Reflecting on roles, responsibilities, assumptions, motivation, ethical and broader issues, etc. *Reflection:* Reflecting on existing scientific and technical knowledge, what is not known, areas of uncertainty, etc.	• UK's Department of Environment, Food and Rural Affairs (DEFRA) Voluntary Reporting Scheme • Moratorium • Standards (e.g. ISO 26,000 on social responsibility)	*Motivations for reflection:* Responsibilisation aim (moderation and reflection of self-interest, reconfiguring of roles and responsibilities) (Shamir 2008; Dorbeck-Jung and Shelley-Egan 2013) *Targeted actors:* Manufacturers of engineered, nanoscale materials, industry organisations, academic researchers
Deliberation and public participation The inclusion of new voices in the governance of science and innovation; importance of public and other stakeholder voices in 'opening up' particular framings of issues (cf. Stilgoe et al. 2013).	Upstream engagement: • Sciencewise public dialogue projects • BASF Dialogforum nano • NanoPodium project • 2008 EPSRC deliberative process	*Motivations:* • Getting things 'right the first time' • Effort to restore public trust in science and technology • Democratising the governance of innovation • Diversifying inputs to and delivery of governance • Aim to modulate current research activities/contribute to policy agenda and priority setting, e.g. societal input regarding Grand Challenges • Need to convince what was thought to be a skeptical general public not to reject nanotechnology outright *Targeted actors:* Various publics and stakeholders, civil society organisations and representatives
Incorporation of ELSA research into nano research programmes	EU Framework Programme (FP) funded projects: • FP5: NANOFORUM • FP6: FRONTIERS, DEEPEN and NANOCAP • FP7: ObervatoryNANO, NanoCode	*Motivations:* • ELSA as an historical precedent • ELSA research to inform nano research and development *Targeted actors*: various publics, researchers and industry

Table 1 continued

Principles of RRI	Proposed mechanisms and approaches in nano	Justification for principle and targeted actors
Responsiveness: Responding to the temporal dilemma of the regulation/ development of nanotechnologies; adapting to changing circumstances (Sutcliffe 2008); deliberative mechanism to facilitate feedback to policymakers (cf. von Schomberg 2013)	• Standards (Kica and Bowman 2013; Wickson and Forsberg 2015) • Value-sensitive design (van den Hoven et al. 2012) • Moratorium • Stage-gates (Owen and Goldberg 2010) • Risk registers (Owen and Goldberg 2010)	*Motivations:* • RRI as a framework with which to tackle grand challenges • Anticipating regulatory needs • Social license to operate (Rip 2014) • The coupling of anticipation, reflection and deliberation to action (Owen et al. 2012) *Targeted actors*: policy-makers, research funders, research organisations, regulators
Precaution	• Precaution as one of the principles of the EC NanoCode • 'No data, no market' (Article 5, REACH regulation, European Commission 2006)	Precautionary principle adopted by the European Commission in 2000. Nano has inherited this principle *Targeted actors:* Regulators, policy-makers, industry
Ensuring market accountability (von Schomberg 2013)	• Labelling • Standards • Definition of 'nanomaterial'	*Motivations:* • Transparency aims • Enabling innovation *Targeted actors:* Consumers, firms (manufacturers/ producers/users) regulators
Safety by design/Benign by design	• Attempt to make 'safety' a fundamental property of new nanomaterials	*Motivation*: Establishment of ICON (cf. Kelty 2009; McCarthy and Kelty 2010) *Targeted actors:* Researchers, firms

RRI Routes into the Multi-layered Governance Arrangements for Nano Research and Markets

The policy discourse of RRI–visible at the EU level–has, it can be argued, a largely symbolic function in that it demonstrates a willingness on the part of the state to 'do better' in handling, and integrating, emerging science and technology in society (Fisher and Rip 2013). RRI has also been taken up by funding agencies and, perhaps because of requirements to obtain these funds, has also been adopted by some research consortia and companies. As Fisher and Rip (2013) note, this situation gives rise to multi-level dynamics. RRI, as described in section 2 (above), emerged with the motivation of shifting research innovation choices and decision-making mechanisms to include broader concerns than the techno-economic. Thus, in order to investigate how RRI is influencing, and shaping, the emerging field of

Table 2 Demonstrating the layers of governance of research fields and emerging markets

	Public research governance	Market governance
Macro (orientation)	National policies	Regulation
Meso (programming)	Intermediary organisations such as research councils and funding agencies (National Science Foundation), other coordinating agencies (European Space Agency)	Soft law, codes of conduct, roadmaps, standards. New financiers such as foundations also play a role here
Micro (performing)	Research organisations such as public laboratories, maker spaces and fablabs	Firms and private research centres

Adapted from Robinson et al. (2017)

nanotechnologies, it is necessary to conceptualise the kinds of *governance processes* that shape ongoing nano-activities.

It is widely recognised in studies of research policy that an intermediate layer between macro-level national research policies and actual micro-level governance approaches, at the individual organisation level, has emerged. Barré et al. (2013) label this the 'programming layer' where research programmes are created and coordinated by research councils, which define programmes, create selection procedures and funnel national funding to individual projects and activities.

Larédo et al. (2015) and Robinson et al. (2017) have taken this framework further so as to include not only research but also markets. Similarly, instead of national policies guiding the 'macro' layer, one sees market infrastructures (such as standards and regulations) governing technology development and societal embedment. One can also identify a layer of governance and coordination activities between the macro layer of standards and regulations. Thus, research and innovation systems 'governance' can be described in a three-layered framework summarised in Table 2 below.[5]

For the remainder of the section, we employ this multi-layered lens to characterise a range of RRI activities that form part of the governance landscape for nanotechnology R&D activities.

A Multi-layered Approach to Research and Innovation Governance

The Macro-level: RRI Through National Policies and Other Activities

As Table 2 suggests, there are a myriad RRI activities that fall under the macro framing. Some of these have been designed and implemented specifically as part of the RRI agenda, while others have been created in a more organic fashion in response to the emergence of nanotechnologies more generally. In this section we introduce, albeit in a cursory manner, several of the more well-known initiatives.

[5] The development of a robust multi-layered framework is not the motivation of this article. For further details on this discourse, see Larédo et al. (2015) and Robinson et al. (2017).

Arguably one of the most high profile, and also contentious, is the EC's *Code of Conduct for Responsible Nanosciences and Nanotechnologies Research* (EC 2009). The Code–or NanoCode–was implemented in the EU in 2008 following a period of public consultation and debate. The overarching aim of the Code is to, among other things, promote safe and beneficial innovation in the field of nanotechnologies by Member States, relevant research funding bodies (public and private), research organisations, the academic research community and standardisation bodies (EC 2009). It is not, as noted by the Commission 'an end in itself but rather a beginning of a process itself, at European level but also beyond its borders' (EC 2008).

Reports from European projects including the NanoCode and FramingNano projects[6] offer empirical insights into the response to the Code. Dorbeck-Jung and Shelley-Egan (2013) offer an overview of the analyses with respect to awareness of responsibilities, perspectives regarding the content of the Code itself and oversight and enforcement mechanisms–we reproduce this overview here. Only about half of the 304 NanoCode survey participants stated that they were aware of the existence of the Code. This lack of visibility of the Code was also reported in a study carried out by Kjølberg and Strand (2011). Many FramingNano stakeholders felt that the promotion of the Code by the European Commission and Member States was not satisfactory. The content of the code was viewed as being unclear with respect to details such as who is targeted by the Code, what the code is about, and the benefits of adopting the Code, among other items. Many NanoCode stakeholders–the specific number is not provided–felt that the Code should be associated with disincentives (with respect to non-compliance). However, on the whole, a large number of NanoCode survey participants were satisfied with the specific principles underpinning the Code. Notwithstanding this, this satisfaction did not translate to implementation, with only 21% of participants–again, the number is not provided—responding that their organisations had implemented the Code. 'Difficult practicability' was offered as a reason for this. A lack of pressure–specifically enforcement mechanisms–was also offered as a key reason for a lack of uptake.

While we can get an impression of the reception of the Code by some stakeholders, there is still limited transparency around its uptake and impact. It is unclear as to the degree to which the Code has been taken up and implemented by various parties, and the degree to which the Code has impacted on the behaviour of individuals and entities to whom it should apply (even voluntarily). This lack of transparency has the potential to undermine its credibility and potential impact.

Looking beyond the state, we have also seen a number of initiatives emerge within the non-governmental organisation (NGO) community. The catalyst for action, according to Miller and Scrinis (2010, p. 409) can, at least in part, be attributed to a desire to,

[6] The NanoCode project -funded by the EC's Framework Programme 7 (FP7)—aimed to develop a strategic framework with which to guide the further development and implementation of the Code, along with the development of a practical implementation tool to assist stakeholders in evaluating their performance in complying with the Code. The FramingNano project–another FP7 project–aimed to define a governance framework to support responsible development of nanoscience and nanotechnology through international multi-stakeholder dialogue.

> 'move beyond a narrow discussion of 'benefits versus risks' to consider the broader social, economic and political dimensions of nanotechnology, to implement precautionary management of nanotechnology's health and environment hazards, and to involve the public in decision-making'.

This motivation, at least as conveyed by Miller and Scrinis (2010), would suggest that many of the NGO activities that could now be considered as falling under the broad remit of RRI do so organically rather than by design.

One of the more high profile initiatives that could be categorised as such is the declaration on *Principles for the Oversight of Nanotechnologies and Nanomaterials*, which arose out of collective action by a civil society-labor coalition. The 'foundational principles' of the declaration were developed collaboratively by a diverse set of NGO actors over a six-month period in 2007, under the leadership of the US-based International Centre for Technology Assessment (ICTA).

The declaration articulates eight important principles which the coalition,

> 'believe must provide the foundation for adequate and effective oversight and assessment of the emerging field of nano-technology, including those nanomaterials that are already in widespread commercial use' (ICTA 2008, p. 3).

The eight principles range from those focused specifically on health and safety of the public and workers, through to transparency and the inclusion of broader impacts such as social impact, ethical assessment and justice and individual community preferences in the allocation of public funding for research.[7] Principle II calls for 'a modified or *sui generis*, nano-specific regulatory regime' (p. 5), while Principle III states that 'any regulatory regime designed to protect workers from health effects of nanomaterials requires written comprehensive safety and health programs addressing workplace nanotechnology issues' (p. 6). Principle V calls for the public release of 'safety testing data' (p. 8) as part of a broader push for transparency, while Principle VII states that 'social science analyses of nanotechnology's implications should take place alongside that of the health and environmental sciences' (p. 10). Each is expressly underpinned by the precautionary principle. As of 2012, the ICTA report that approximately 70 NGO groups from around the globe have endorsed the declaration (ICTA 2012).

The declaration in itself is an impressive document; the mere fact that so many different NGOs, representing such a diverse constituency, could develop collectively such a document is testament to their shared level of concern across the entire nanotechnologies landscape. A close read of the eight principles, however, suggests that beyond endorsing the document, and using this as a basis for advocacy, there is little that the NGOs can do to action the items that they call for. It is up to the state, for example, to pass nano-specific amendments to existing legislation or to implement a new regulatory regime for nanotechnologies. The declaration therefore

[7] We locate the principles of oversight here at the macro-level because its intention was to influence research and innovation policy, rather than directly engage with individual firms or research organisations.

can be said to serve an important symbolic function, but its impact beyond this is difficult to determine.

These two initiatives are illustrative of the breadth of approaches that RRI activities can encompass at the macro-level, as well as the actors. There is ample space in which actors from across the spectrum can operate, although the degree of impact that they may have in influencing policy and/or legislation will vary enormously.

The Meso-level (a): RRI Through the Shaping of Funding Programmes

Two distinct activities can be distinguished with regard to RRI at the meso-level: (a) RRI through the shaping of funding programmes and (b) RRI as the soft regulation of industrial practices.

Regarding the *first distinct group of activities,* RRI and funding programmes, *intermediary organisations* such as research councils and funding agencies, particularly in the UK and the Netherlands, have been active in adapting their requirements so as to include RRI, and developing programmes of research concerning RRI and innovation. Such intermediary organisations are third parties that do not develop nanotechnologies themselves but exert leverage on developments through their actions, namely by *mandating* scientists to include broader issues within the funding proposal itself.

In 2008, the UK's Engineering and Physical Sciences Research Council (EPSRC) introduced a new strategy for nanotechnologies, one strand of which involved the funding of large scale integrated research programmes in areas in which the technology could contribute to issues of pressing societal or economic need (Jones 2008). The EPSRC also commissioned the development of a framework for responsible innovation to support research policy development at the EPSRC, while also being generally applicable. Research organisations in receipt of EPSRC funding are required to acknowledge and respect the principles of the *Anticipate, Reflect, Engage and Act* (AREA) framework (Stilgoe et al. 2013), while also encouraging and supporting researchers to develop responsible innovation approaches as a core competence (EPSRC 2016).

The RRI-Tools project has carried out a study of the framework (Miller 2015) and some information as to its uptake can be gleaned from this. In 2013, the EPSRC and BBSRC (Biotechnology and Biological Sciences Research Council) jointly released a call that resulted in the funding of several research centres in the UK. Many of the grant proposals included explicit work packages on responsible innovation and the direct involvement of social scientists with relevant experience. Professor Richard Owen–one of the architects of the framework–was involved in assessing the grant proposals. He reported seeing a flexible, embedded approach in response to the framework, with an emphasis on bringing together multidisciplinary teams to develop processes within the project in an embedded way. The study also reports on a specific nanotechnology call–nanotechnology for the environment–in which applicants were asked to submit a 'risk register' (cf. Owen and Goldberg 2010), describe the responsibility for understanding and addressing these risks, identify any known or likely hazards and consider any other potential societal or ethical concerns of their research.

While the risk register was considered by many researchers to be useful in drawing attention to wider impacts and as an approach to managing known potential impacts and risks, it was considered to be of less value in the identification of unknown impacts further along the innovation process. In order to overcome this limitation, a number of applicants proposed work packages or tasks that drew on wider disciplines outside the engineering and physical sciences to help with the identification of such impacts. Moreover, some applicants also included public engagement and stakeholder engagement approaches to understand perspectives and views regarding the emerging innovation. Feedback from the principal investigators and co-applicants regarding the process was largely positive; the process was supported and viewed as a worthwhile activity. On the whole, the response from researchers to the requirements appears to have been positive and constructive, with real efforts made to be proactive in proposing work packages and collaborations so as to facilitate and enable the requirements.

In 2008, the Netherlands Organization for Scientific Research (NWO) funded the thematic Responsible Innovation research programme (‘MVI’ for *Maatschappelijk Verantwoord Innoveren*). The objective of the programme is to contribute to the appropriate embedding of technological and scientific advances in society through the incorporation of research on ethical and societal issues in innovation projects. Intensive collaboration between researchers in the humanities, sciences and social sciences is one of the main cornerstones of the programme, with a strong emphasis on the valorisation of the research.

To date, more than 50 research projects have been initiated and a new call for proposals was published in the summer of 2016 (NWO-MVI 2006). The projects have led to responsible innovations in a variety of areas ranging from the life sciences and healthcare, to energy transition, agriculture and food. Other outcomes include guidelines and tools for companies, government bodies and other actors, models for innovation design processes and new business models. In the autumn of 2016, the programme was developed into a platform (NWO-MVI 2006). The platform has the following objectives:

1. to develop knowledge through the programming and funding of excellent responsible innovation research;
2. to share knowledge developed and experiences gained; and
3. to expand the network of stakeholders to inspire them to innovate in a responsible manner.

From 2016 onwards, the Responsible Innovation programme has been involved in all of the top sectors in the Netherlands–these are strong economic sectors, ranging from agriculture and food to energy, life sciences, chemicals and water (OECD 2014a). This particular development appears to reflect recognition of the value not only of funding research in RRI but also the relevance and importance of embedding RRI within industrial policy at national level (OECD 2014a).

From the two examples from the UK and the Netherlands, we see the notion of responsible development and RRI being taken seriously in the requirements for funding proposals–they are necessary components to receive funding and projects are assessed on RRI criteria along with nanoscience excellence criteria. Such criteria are visible in the EC Horizon 2020 programme, in which sections on expected impact provide openings for RRI to be included and assessed. Thus, RRI is incentivised through the presence and quality of RRI as evaluated by the proposal assessment experts (EC 2016).

The Meso-level (b): RRI as the Soft Regulation of Industrial Practices

Regarding the *second distinct group of activities*, RRI as soft regulation of industrial practices, industry has seen a plethora of initiatives—largely subsumed under the heading of RRI—that have been overwhelmingly voluntary in nature.[8] These include initiatives created by government to which industry is asked to respond, and those which have been created by industry for industry. In relation to the former we have seen, for example, the development of government-initiated voluntary reporting/call-in schemes for engineered nanoscale materials in the US, the UK and Australia (see, for example, Defra 2006; Environmental Protection Agency 2008; National Industrial Chemical Notification and Assessment Scheme 2007; Bowman 2014). The aim of these voluntary data schemes was to gather information regarding, for example, the types, nature and volume of engineered nanoscale materials that were being manufactured and/or imported into the respective jurisdictions. Such information was to provide the relevant regulatory authorities with baseline data about the types of nanomaterials coming into the market. Where appropriate, the information could also contribute to the making of regulatory and policy decisions for the responsible innovation of nanotechnologies. The performance of all three schemes can only be described as 'underwhelming'; industry participation was poor. Onerous paperwork associated with the programmes, and a lack of understanding about the nature to which the information could be used are just two of the reasons that have been articulated for this (Foss Hansen et al. 2013).

The schemes have also been criticised for their voluntary nature. For example, the Soil Association felt that the Defra programme was not a 'remotely' adequate response to the challenge of obtaining additional data on the potential hazards posed by certain engineered nanoparticles to both humans and the EHS (Smithers 2008). The Soil Association felt that a compulsory reporting scheme would ensure that the negative effects of nanomaterials would be accurately represented.

Industry itself has also been very active in drawing up voluntary initiatives. One such example is the Responsible Nano Code for Business (Nano & Me undated), developed between 2006 and 2009 by a diverse set of actors including, among others, the UK's Royal Society, Insight Investment and Nano Knowledge Transfer

[8] The regulation of industrial practices in nanotechnologies is strongly influenced by Corporate Social Responsibility (CSR) discourse and activities. Indeed, CSR has much to offer RRI with respect to actual devices that can serve to contribute to the RRI ambition, e.g. codes of conduct and various voluntary initiatives, along with various theories and perspectives. However, it is beyond the scope of this paper to address the link between CSR and RRI in any detail.

Network and the Nanotechnology Industries Association. The Code is principle-based, setting out seven principles for the responsible development, use and retail of nanotechnologies for business. Principle Two, for example, calls for organisations to proactively engage with stakeholders; Principle Three calls on organisations to put into place measures that will protect those workers handling nanomaterials; Principle Five states that 'each organization shall consider and contribute to addressing the wider social, environmental, health and ethical implications and impacts of their involvement with nanotechnologies' (Insight Investment, Royal Society, Centre for Process Innovation and Nanotechnology Industries 2008, p. 2).

Importantly, the Responsible NanoCode was not designed for the purposes of giving rise to binding obligations, or for creating standards through which the private sector could then be held accountable (Insight Investment, Royal Society, Centre for Process Innovation and Nanotechnology Industries 2008). Rather, according to its creators, the Nano Code should be viewed as being a document that,

> 'establish(es) a consensus of good practice in the research, production, retail and disposal of products using nanotechnologies and to provide guidance on what organisations can do to demonstrate responsible governance of this dynamic area of technology' (Insight Investment, Royal Society, Centre for Process Innovation and Nanotechnology Industries 2008, 3).

In this vein it is, arguably, not surprising that the document provides few, if any, concrete steps for actualising the seven principles.

While it has been reported that the Responsible Nano Code 'has the support of champions in the US, Asia and Europe' (Nano & Me undated), there is seemingly a lack of information–at least publically–regarding how many businesses have adopted the Nano Code, and the ways in which it has been incorporated into their day-to-day business activities. It does not appear, for example, that there is any formal, public reporting of this type of information.

BASF's 'Nanotechnology code of conduct' is, as Bowman and Hodge (2009) observe, an early example of an enhanced role for industry in the self-regulation of nanomaterials. This in-house initiative, which was published in 2004, aims to ensure 'responsible handling of nanomaterials' and includes a commitment to current employees, customers, suppliers and society but 'also towards future generations' (BASF 2016). The content of the code of conduct is defined by four overarching principles, each of which is supported by mission statements. BASF provide information (on their website) on how they implement each of the principles. For example, with respect to dialogue, implementation measures include stakeholder dialogues, Dialogforum Nano and the publication of BASF Safety Research on Nanomaterials (BASF 2015).

A key feature of the Code is the company's commitment to actively engage in a dialogue with society, in addition to a commitment to transparency to provide information not only about the opportunities of nanotechnology but also about the potential risks. To that end, BASF has initiated Dialog Forum Nano, a continuous stakeholder dialogue. The dialogue involves representatives of research institutes, trade unions, retail, industry, churches, and environmental and consumer organisations who develop–with guest experts–recommendations for increasing information and transparency along the product life cycle of nanomaterials (BASF 2016). Reports stemming out of the Dialog Forum Nano are available on BASF's website, along with additional information regarding communication efforts around nanotechnologies and safety information on nanomaterials (see, for example, BASF 2013a, b, 2016). The degree of transparency associated with the Code, and activities underpinning it, makes it seemingly different from many of the other initiatives discussed within the context of this article. It is also important to note, too, that the Code was initiated by BASF well before RRI gained the type of traction that we see today.

Industry has also engaged in novel interactions in order to address uncertainties. The collaboration between DuPont and the Environmental Defense Fund (EDF) to produce a risk framework is an interesting example (see Krabbenborg 2013). DuPont is a chemical manufacturing company which has been at the forefront of developing new ways of handling risk. EDF is the largest environmental NGO in the US, which is known for forming alliances with corporations in order to 'produce tangible environmental results'. The unique history and culture of the two organisations has made it easier for such normally quite adversarial actors to collaborate in a partnership. In 2005, DuPont and EDF formed a corporate partnership to work together to produce a nano risk framework, aimed at evaluating and addressing potential environmental, health and safety risks of nanomaterials across the entire life cycle of the materials (EDF 2016a). The framework–deemed appropriate by both organisations–was published in June 2007 after extensive consultation with a number of stakeholders. The framework itself is a 100 page document, which–according to the document–

> 'should prove invaluable in guiding the user to make decisions and take actions that ensure the safety of its materials and products, as well as in communicating the bases for those decisions and actions' (EDF and DuPont 2007, p. 22).

The Framework is supplemented by a number of additional documents including nanomaterial risk assessment summaries and worksheets for single and multi-walled carbon nanotubes light stabilisers for use as a polymer additive.

Information regarding the public impact, coverage and distribution and influence of the Framework is documented, and available, on EDF's website. On endorsements and public impact, EDF report that the Framework has received endorsements from, for example, the American Chemistry Council's Nanotechnology Panel, General Electric, Intel, the US National Nanotechnology Initiative, the European Union and Woodrow Wilson Centre's Project on Emerging Technology (EDF 2016b). According to Project's website, the Framework document has been 'downloaded nearly 5,000 times. [And] Nearly 20,000 people from 120 different countries have visited the Framework's website,…' (EDF 2016b).

Impact is also reported upon. According to EDF 'the information sets for OECD's nanomaterials testing program were informed by the 'base sets' included in the Nano Risk Framework' and,

> 'the U.S. delegation to the ISO's Technical Committee on Nanotechnology Standards submitted the Nano Risk Framework as the basis for an ISO Technical Report on Nanomaterial Risk Evaluation. This process is ongoing,

> but at this stage, it appears that the process will result in an internationally endorsed technical report based on EDF and DuPont's Nano Risk Framework, updated with the current science and reflecting input from across the globe' (EDF 2016c).

These types of statements suggest that the Framework has been influential, and that there is something tangible that can be pointed to in terms of impact.

Yet despite the broad support that EDF and DuPont have received from a number of significant and influential stakeholders across jurisdictions, the Framework is not without its critics. In response to the publication of the Framework, the 'civil-society labor coalition' (mentioned above) issued a public statement condemning the efforts of DuPont and EDF (ETC Group 2007). The coalition urged 'all parties to reject the public relations campaign' aimed at usurping the government oversight of nanotechnology policy (ETC Group 2007). Furthermore, they voiced their concern that voluntary regulation is a strategy to delay required regulation and hinder public involvement. Such condemnation has been countered by others including, for example, Kundahl (2008), who welcomed the partnership between DuPont and Environmental Defense as a 'rare communications partnership' representing a 'forward-looking and transparent approach to communications between traditionally adversarial stakeholders' (p. 188).

The initiatives described above highlight the key role of industry in advancing the RRI cause. In particular, industry initiatives targeted at industry have expanded industry's role to include self-regulation of nanomaterials and novel ways of addressing risk which integrate societal perspectives. While such initiatives may be viewed as an effort on the part of industry to anticipate and circumvent 'harder' regulatory measures, the impacts of such processes may nonetheless be beneficial, for society, the environment and so on.

The Micro-level: RRI via Direct Integration into R&D Practices of Individual Organisations

Social scientists have also played a role in the development of RRI activities in R&D programmes. In this sub-section we focus specifically on two such examples, both of which are direct engagement programmes. They are the Dutch TA NanoNed programme, and the US Socio-Technical Integration Research (STIR) programme.

The Dutch R&D consortium NanoNed (Nanotechnologie Nederland) was a Dutch R&D consortium established informally in 2001 in order to consolidate ongoing efforts to mobilise government funding for nanotechnology research and research infrastructure. NanoNed became fully operational in 2005 and included a Technology Assessment subprogramme, TA NanoNed, which carried out projects in Constructive Technology Assessment (CTA) of the interaction between science, technology and society (Rip 2010). CTA inserts itself into ongoing technological developments through strategy articulation workshops with stakeholders in a particular domain of nanotechnology, such as lab-on-a chip or drug delivery. The TA programme of NanoNed paid close attention to ongoing developments in research and innovation, as opposed to studying ethical, legal and social aspects from an outsider's perspective (Rip and van Lente 2013). A key impact of the TA NanoNed programme was the willingness of nanoscientists to integrate a CTA programme in the subsequent national nanotechnology initiative, recognising its importance through allocating finances to fund research into CTA issues as well as continuing the development of support tools for nanoscientists to engage with societal, ethical and governance issues. This second national initiative, NanoNextNL (2010–2016), included a risk analysis subprogramme, along with the TA subprogramme, entitled 'Risk and Technology Assessment' (RATA). RATA was labelled Theme 1, signifying the importance of studying the potential consequences of new technologies at an early stage (Rip and van Lente 2013).

Continuing with the approach of the earlier TA NanoNed programme, RATA includes risk assessment professionals as well as scholars in risk assessment. A key part of the RATA program is the requirement that natural science PhD students funded in the NanoNextNL programme undergo some training in RATA aspects, with the original idea of the PhDs devoting some time to doing RATA research. Whilst training courses have been popular, doing RATA research as a natural science doctoral scholar is seen to be beset with challenges and constraints, with the effect that only a few enthusiastic PhDs are able to include RATA research in their natural science PhD. Schulze Greiving et al. (2016) have provided an in-depth description of one of the 'successful' PhD projects which included a form of CTA to explore certain elements of RRI in nanomedicine innovation pathways.

Socio-Technical Integration Research (STIR) is a form of collaborative inquiry between natural scientists and engineers, and social scientists and humanities scholars that aims to broaden and enhance R&D decision making processes. The STIR programme was housed at the Center for Nanotechnology in Society at Arizona State University and has been taken up in over 30 public and private laboratories in a dozen nations across North America, Europe and East Asia (Fisher and Rip 2013). An 'embedded' social science and/or humanities scholar conducts a 'laboratory engagement study' which feeds back social scientific observations into the field of study in real time over a period of 12 weeks (Fisher 2007). The results of the interactions are assessed in terms of a framework of 'midstream modulation' (Fisher and Mahajan 2006a, b) that aims to clarify and enhance the 'responsive capacity' of laboratories to the broader societal dimensions of their work. Accordingly to Fisher (undated),

> 'Initial results from STIR project field studies are in some cases strongly suggestive of both the possibility and the utility of conducting hands-on, lab-based socio-technical integration activities between social and natural scientists'.

Broader impacts of the STIR project are said to include the training of doctoral students around the world in responsible innovation research, the development and testing of RRI tools and techniques and the creation of interconnected scholars across disciplines and jurisdictions (Fisher 2012).

Such impacts are difficult to measure due to the presence of confounding factors and the qualitative nature of studies that do not/cannot control for such outside factors. However, with the National Science Foundation having recently funded an extension of the STIR approach–STIR Cities: Engaging Expert Performances of Sociotechnical Imaginaries for the Smart Grid–it is suggestive that those who are engaged in, or evaluating, STIR consider the approach to be valuable.

Discussion

RRI aims to distribute responsibility across actors, and, arguably sectors. We have shown the importance of intermediaries such as research councils and funding organisations in proposing and encouraging RRI initiatives. Funding organisations may refer to RRI in setting funding requirements which may lead to change in actual research practices. Actors' responses to the pressure to 'action' RRI at the micro-level will not only depend on their position and context, but may also be influenced by (and influence) behavior and interactions at the collective level of institutions and sectors (Shelley-Egan 2011). Indeed, our overview of the wide range of mechanisms and approaches proposed by various actors at different levels attests to Fisher and Rip's (2013, p. 167) observation that it is,

> 'this multi-level constellation of declarations and activities that carries the move in the direction of (…) RRI, more so than any particular type of initiative, which may seem considerably less effective by itself'.

In this article we have shown that for over a decade now there have been considerable activities in nanotechnology R&D that could be considered as 'responsible research and innovation'. We are now in a position to make a diagnosis on the *scope* of the RRI activities (research, development, application) and the *context* of RRI activities and nanotechnology (micro, meso, macro layers).

With respect to the *scope* of RRI activities,[9] what is particularly striking is the limited activity concerned with institutionalising and embedding RRI in research and innovation organisations.[10] It is clear that research into what should constitute RRI and/or the philosophy of RRI, has received substantial attention. This is illustrated by the large number of international projects at the EU-level, in addition to the number of scientific articles published on this theme. There is a rise in the development of practicable tools, and in experimenting with them.

[9] By scope we mean the stage of emergence of the nanotechnology field, whether it is research, a prototype or working in society. Another element of 'scope' is that nanotechnology is often part of a larger technology or system. The 'scope' of the nanotechnology will play a role in the questions and issued raised for implementing RRI.

[10] Outside the nano sphere, this is changing, however, with the recent initiation of two European Horizon 2020 projects–RRI –Practice and Joining Efforts for Responsible Research and Innovation (JERRI). The RRI-Practice project brings together international experts in RRI to understand the barriers and drivers to the successful implementation of RRI both in European and global contexts and in specific organisational structures and cultures in research conducting and research funding organisations. JERRI aims to institutionalise practices and attitudes with respect to RRI within the two largest European Research and Technology Organisations. Moreover, the RRI-Tools project, funded by the EU's Seventh Framework Programme which ended at the close of 2016, has a key implementation objective in its development of a Training and Dissemination Toolkit on RRI for various stakeholders in the research and innovation value chain.

Whilst important, the experiments are, in the main, orchestrated by social scientists and last for a limited time, usually the duration of a research project with little continuous experimentation. Such experiments are rarely explored within the context of specific organisations over a period of time. CTA, as part of the Dutch National Nanotechnology Initiatives NanoNed and NanoNextNL, are exceptions to this with continuous experimentation over a 12-year period between 2004 and 2016 (Rip and Van Lente 2013) with many projects between the Science Technology and Policy Studies department of the University of Twente and various nano research centres in the Netherlands–in particular MESA + (Rip and Van Lente 2013). This is mirrored in the midstream modulation exercises and the current US STIR programme which started in 2006 and runs to the present (Fisher and Mahajan 2006b; Schuurbiers and Fisher 2009).

Regarding the *context,* the majority of RRI activities have occurred largely at the meso-level in terms of inclusion in funding programmes (research) and voluntary codes (markets). It is at the micro-level of research and innovation where RRI is supposed to be embedded, and we see some activities led by social scientists (including the authors of this article). These include, for example, the aforementioned CTA projects in the Netherlands (Schulze Greiving et al. 2016) and the STIR activities in the US (Wiek et al. 2016). However, both of these have limits. The STIR programme has behavioural change as an objective, and has been successful in terms of training and sensitising researchers to be more reflexive. However, what is not clear is how such reflexivity can be institutionalised in research organisations. This can be rephrased into a question, or a call to arms, for RRI scholars: how can RRI be embedded into the normal routines of behaviour of professional researchers? Perhaps, more importantly, how can RRI activities be embedded so that they are valued by the research organisation itself as being part of each individual researcher's core activities and evaluated as such within research institutions, rather than (at best) interesting side projects or (at worst) distractions from the core activity of research. We see this as a key issue, not only with regards to nanotechnology but for RRI research and evaluation more broadly.

As this article has illustrated, the RRI landscape is becoming increasingly populated with devices, each of which has been designed to change the behaviour of individuals and/or entities at one of the three levels. Understanding how they work, and how they have changed behaviours is, however, beyond the scope of this article. It is a limitation of the analysis presented here, and the landscape more generally. Put simply, 'correlation does not imply causation'. Given the nature of these activities it is impossible to control for confounding activities and/or events, any of which could have impacted on observed outcomes. Accordingly, without controlling for confounding variables in this way, we are unable to draw conclusions about the significance of each device in terms of its actual impact.

Towards a New Agenda: The Need for an Evaluation of the Embedding of RRI

The scope and context of RRI in nanotechnology highlights the importance of investigating the actual uptake of RRI by the actors it seeks to reach and then influence. While the field of RRI continues to attract new supporters and proponents within the policy and academic worlds, along with additional economic resources, in addition to new projects and mechanisms geared towards the actual implementation of RRI, *the actual effects on the practices of researchers and innovation actors remain unclear*. Grunwald (2011, p. 48) similarly concludes that ethical and STS reflection did not make a difference at the technical level, in the sense of 'directly influencing the R&D agenda and process of nanotechnology and, therefore, the course of research and technology itself'. Rather, they shaped the technology in the sense of making a considerable impact on the scientific and social environments in which nanotechnology research takes place including, for example, in the expansion of research agendas in areas such as toxicology and the social sciences.

We offer two reasons for our assertion. First, the majority of devices mapped here in this article rest on ideas about being responsible and reflexive–stemming mainly from academic discourse in social sciences and philosophy–rather than as a result of linking up with the actual ongoing practices, mandates, institutional contexts, and so on, that are at play in the R&I systems. Second, the majority of the proposed activities are developed by those outside of research and innovation (for example, by governmental agencies, non-governmental organisations, social scientists and ethicists) and thus at a remove from the processes and structures of research and innovation actors, such as universities and firms. Universities, public research organisations and firms all have their own organisational structures and regimes of action. RRI must either fit or stretch these existing arrangements, which leads us to conclude that longer term explorations of RRI in these organisations, as well as in situ learning, is necessary. As mentioned previously, EU-funded projects focused on the implementation of RRI at the organisational level have just recently begun.

We conclude that RRI activities focusing on discussions on the content of RRI and time-limited and real-world isolated experiments in RRI should perhaps make way for a third element of RRI—long-term embedding of RRI in research and innovation organisations coupled with learning in situ. This third element needs to receive greater attention if RRI is to move from being a primarily academic concept and movement to something that can actually infuse the values of RRI within the institutions that undertake research and innovation.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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