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Capabilities to support responsible research & innovation in European biotechnology

Funding Cultures Lab Working Paper

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Robert D.J. Smith, Michael J. Bernstein, Cian O'Donovan & Filippo Cuttica

ERA CoBioTech

UK Centre for Mammalian Synthetic Biology

FUNDING CULTURES LAB.

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Overview

Emerging biotechnologies from fields such as synthetic biology and industrial biotechnology raise challenges for governance. In response, public funders have developed new approaches to govern these technologies before decisions are locked in and products emerge onto the market. Over a decade of experience with these nascent forms of governance, such as Responsible Research and Innovation (RRI), shows their value but also the limitations, particularly when implemented without consideration of day-to-day working conditions, sector specific distinctions and institutional structures shaping research in the biological sciences.

Drawing on three workshops with members of the ERA CoBioTech funding programme, we show how a new approach, grounded in the idea of human capabilities, can help to integrate the skills, knowledge and institutional conditions needed to enact upstream governance in the design of future funding programmes. We identify the goals researchers associated with RRI in the life sciences, outline five sets of capabilities that enable researchers, managers and administrators to practise responsible research and innovation, and unearth a corresponding set of resources that these capabilities depend upon. Funders that learn to design programmes to maximise and expand the five capability sets are likely to enable more substantive forms of upstream governance than before.

Connecting RRI policies to research and funding cultures

Emerging biotechnologies from synthetic biology, systems biology and industrial biotechnology hold great promise in facilitating transitions toward more sustainable economies. They also raise a range of ethical, political, and social questions about the use of genetically modified organisms, data management and use, the most appropriate forms of ownership to incentivise innovation, the models of sustainability being pursued, and their alignment with public values (see box 1). As the synthetic biology community has long recognised, these issues cannot be addressed through downstream regulation alone; they require 'upstream' forms of governance that shape the trajectories of synthetic biology research and innovation.

One prominent approach to upstream governance that has emerged in this domain is Responsible Research and Innovation (RRI). This concept provides a framework for researchers, investors, developers, funders and regulators to systematically study the potential consequences of their work, to expose the assumptions on which it rests, and to open up decision making to a broad range of experts and public groups (Macnaghten, 2020). Building on decades of experience from genomics programmes, public funders have been quick to recognise the value of RRI and cognate concepts (Hilgartner et al., 2016). We therefore now have multiple examples of what upstream governance can look like in synthetic biology practice within an RRI frame. Examples range from fostering collaborations between artists, natural scientists and social scientists, to anthropological studies of food culture, through patent analyses and new modes of sustainability assessment, to the creation of open intellectual property legal instruments (Casadó-Marín and Anzil, 2022; Kahl et al., 2018; Ribeiro and Shapira, 2019; Shapira et al., 2022; Szymanski et al., 2020). Each example engages with the political, social, ethical or environmental dimensions of making life easier to engineer in context-sensitive ways.

The trend of 'bringing the social in' to laboratories and policy rooms is continuing. While the European Commission has recently removed reference to RRI as a distinct programme of work, many of the issues it covered are being touched on through widespread reference to Open Science, Co-Creation, inclusion of Social Science and Humanities (SSH) research, Mission-Oriented Research and the Do No Significant Harm Principle (European Commission, 2021). Additionally, a patchwork of multilateral 'partnerships' are adopting their own approaches to RRI (Smith et al., 2021a). Outside the European Commission, the OECD is making efforts to translate RRI into the private neurotechnology sector (Pfotenhauer et al., 2021) and the World Economic Forum Global Future Council on Synthetic Biology is currently examining how values can drive ethical and equitable outcomes from the field (World Economic Forum, 2021).

While upstream governance such as RRI is proliferating in the life sciences, two gaps exist in practice. First, funding calls claiming to prioritise RRI and related governance approaches often do so without clear articulations of how these terms should be operationalised (Fisher and Maricle, 2015; Smith et al., 2021a). A mixed-method study of RRI implementation across Horizon 2020 found, "RRI overall has largely been referred to either without proper understanding of its definition, or as empty signifier" (Novitzky et al., 2020). Further, even when declared in

R&I funding institutions there is often an absence of consideration of RRI in evaluation criteria (Novitzky et al., 2020). In these situations, researchers, evaluators and funders are left to either speculate and continuously reimagine what RRI might mean or could be – producing an uneven and often narrowly bounded field – or pay lip-service to the concept knowing it will carry little weight when the time comes to allocate funding.

Second, RRI policies rarely attend to the conditions that shape scientific cultures, even though we know these cultures are vital in shaping the potential for scientists to work in socially responsible ways (Felt, 2017). Because pressures to publish and generate external funding are so significant, postdoctoral life scientists draw from a narrower set of values when performing research than their doctoral colleagues (Fochler et al., 2016). When asked to discuss risk in synthetic biology, young researchers talk primarily about precarity and the risk to their careers (McLeod et al., 2018). Radically interdisciplinary teams include power differentials between the natural and social scientists, which can stymie the wider cultural change and innovation that interdisciplinary research might offer (Barry et al., 2008). When it comes to changing social practices and ways of thinking about research, scientific communities need time and support to build and operationalise novel capacities – new ideas need to be given meaning through new language, new routines and new institutional arrangements (Rothstein, 2013; Smith et al., 2021c).

Proliferating RRI policies that do not attend to the role of research cultures in shaping outcomes may legitimise technology development but are unlikely to achieve the more substantive goal of analysing the social, ethical or environmental dimensions of the life sciences and reconfiguring them in ways that are socially responsible. Here, therefore, we argue that an integrative approach to researcher and funder capacities, in addition to modified research and innovation (R&I) institutions, is vital to supporting the aspirations of policies designed to align biotechnology research and innovation with societal aspirations of responsibility and sustainability. A capabilities approach offers a way to scaffold this integrative attention. Adopting a capabilities approach means funders and researchers can work together with social scientists to build capacities and change institutional structures in ways reflective of the lived realities of scientific research and innovation policy.

Methods and theory

The concept of capabilities emerged from Development Studies, and in particular the Indian economist Amaryta Sen (1999), as a way of evaluating the individual and collective practices that lead to flourishing lives and jobs. To bridge the gap between expectation and programmatic reality of RRI, we developed an 'evaluative space' that mapped the capabilities necessary to pursue RRI and asked how these intersect with people's professional capabilities. In these terms, a capability is the real (i.e. actual, available to us right now) ability to do or be what a person values in their professional roles, or to achieve goals they think are important for RRI.

Whether a capability is realised, however, depends on a combination of internal and contextual factors (Robeyns, 2005), which we collectively refer to as dependencies. Non-exclusively, internal factors include personal endowments, skills, experiences, tacit knowledge,

Box 1: Social, ethical, environmental and political concerns associated with biotechnology in Europe.

An analysis of ERA CoBioTech's funding portfolio identified nine clusters of issues that researchers associated with Responsible Research and Innovation in synthetic biology, systems biology and industrial biotechnology (Smith et al., 2021d). Each is represented with a set of questions. Engaging with these issues is one goal of RRI in European biotechnology.

- **Alignment**. How do scientific values and priorities align with public values and priorities? Is this alignment represented in the political environment and policy landscape?
- **Data**. Where do biological samples, data and resources come from? How are they used and managed? Are adequate consent, benefit sharing and protection processes established?
- **Diversity**. In what ways are research teams diverse (e.g. in terms of gender, career stage and European constituency)? How is funding and capital being concentrated in specific teams, universities or regions? Does the portfolio offer a diversity of potential technological trajectories?
- **GMOs**. How does the community manage the use of genetically modified organisms, both in terms of safety, security and regulation? Do new technologies challenge these processes?
- **Inclusivity**. Do citizens and stakeholders play a role in research and decision making about funding priorities? Can this role be broadened?
- **Openness**. How accessible are data and findings? How does the field manage tensions between intellectual property protections and sharing?
- **Reflexivity**. Are there adequate opportunities to reflect on purposes, motivations and potential consequences of making biology easier to engineer? What assumptions does the research rest on that could be unpacked? Are there unintended, but foreseeable, consequences?
- **Relevance**. How is biotechnology contributing to meaningful social, economic and environmental problems? Are researchers, funders and companies working with an adequate understanding of these problems?
- **Sustainability**. How do we know that synthetic biology, industrial biotechnology and systems biology will leave the world in a better place than it is now? What processes are in place to ensure this? What forms of sustainability are being prioritised (e.g. economic, environmental, social) and researchers pursuing a 'thin' or 'thick' version of sustainability (Karabin et al., 2021)?

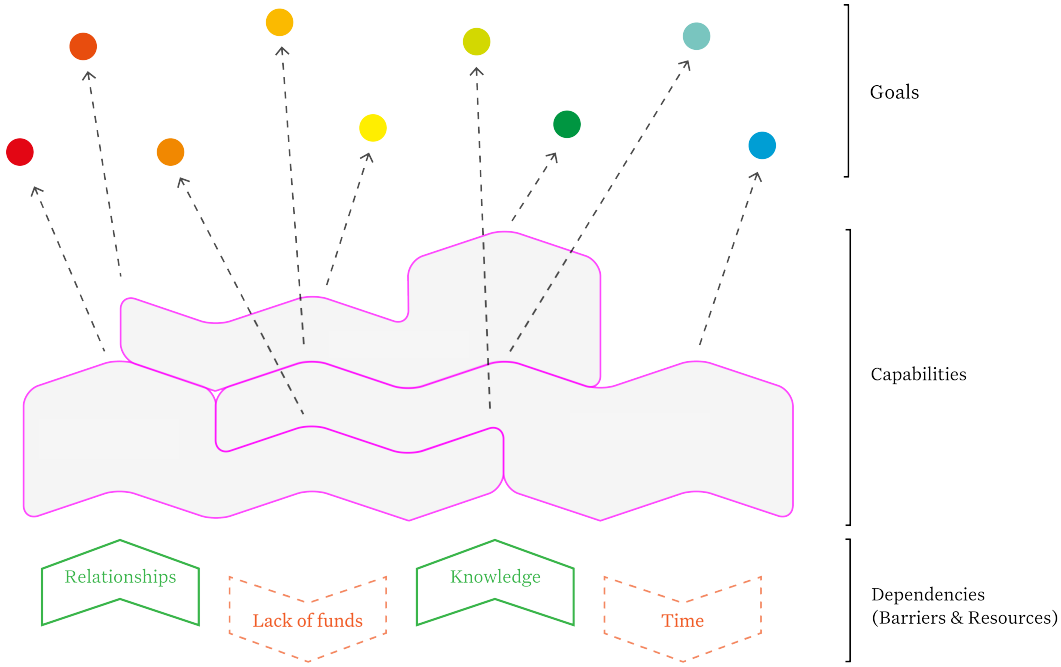

Figure 1: Goals offer a direction for people to work towards. These goals might be the 'RRI issues' identified in our introduction but also include other scientific, personal and professional priorities. Capabilities are the means to realise these goals. To maximise capabilities, people draw on a patchwork of 'dependencies', such as money, time, relationships or social norms. These dependencies can also act as barriers, for instance if a resource is absent or if a policy actively prevents people developing their capabilities.

relationships or formal knowledge. Similarly contextual factors could include access to finance, the job-market, availability of labour (e.g. in the form of PhD students), public attitudes or a favourable policy landscape. Contextual factors may also be social institutions (e.g., norms, rules, ethical frameworks) or material resources (instruments, tools, physical environments). Within our evaluative framework, we identified these 'dependencies' by repeatedly asking people to trace the resources, barriers and ideal situations that would enable them to achieve their desired RRI capabilities.

Approaching research capacities requires an assessment of both the aforementioned institutions, and the integrative knowledge, skills or competences of the individuals and research groups operating within the boundaries of an R&I system (O'Donovan et al., 2022). By focusing on the means of achieving goals, rather than the goals themselves, one may map which capabilities matter to whom, in what way, and in which contexts. For instance, looking back at issues like the introduction of genetically modified organisms to food markets, a range of capabilities were required for scientists and funders to contribute to public debate, including knowing about biological pathways, being able to talk about research to diverse groups of communities, as well as being thoughtful and careful with research. Institutional support is frequently vital to the realisation of capabilities. For instance with the facilitation of the *GM Nation?* exercise in 2003 and related public dialogues on science, depended on the creation of new organisations, norms and rules that would create space for discussion of publicly-salient issues and train practitioners able to create such discussion (Pallett, 2018; Smith et al., 2021c). Thus, the language of capabil-

ities and dependencies gives funders, researchers and other actors in an R&I system the structured information needed to build socially responsible research and innovation policies, programmes and projects.

The capability sets and dependencies detailed below result from three workshops held in 2022 with life scientists, engineers, environmental scientists, social scientists and science administrators. The workshops aimed to distil lessons from a four-year collaboration with a European Research Area Co-fund on biotechnology (ERA CoBioTech), which also developed a policy framework for RRI (Smith et al., 2019). Each workshop convened approximately 30 people from across the ERA CoBioTech network and discussed capabilities needed to successfully enact RRI in synthetic biology, systems biology and industrial biotechnology, along with relevant goals, barriers and resources. A systematic mapping process produced five discrete 'capability sets' – clusters of knowledge, skills, actions and attitudes – needed to build capacity for responsible research and innovation. We followed a similar mapping/clustering process with the dependencies identified by participants as critical in the production of valued capabilities. Details of the analytic procedures, choices and decisions are outlined in the supplemental data.

Five capabilities to enhance RRI in European biotechnology

The capability sets we present below, and summarised in table 1, are intended to speak to the opportunities, barriers and resources necessary to deliver socially responsible science in the fields of synthetic biology, industrial biotechnology and systems biology. The language of capabilities helps to situate terms such as RRI in the lives of academics, funders, evaluators in their places of work – universities, research institutes, funding councils for instance. By allowing us to examine how cultures, values and practices intersect, capabilities provide a vocabulary to begin to shift from governing the outputs of science to governing the funding and research cultures that produce them. Policies aiming to encourage and build such cultures must focus on the conditions needed to deliver the necessary institutional change, i.e. governance needs to explicitly foreground the people in their environments that can produce social responsibility in synthetic biology and other biological sciences.

1. Criticality and creativity

The capabilities needed to practise RRI and to do good scientific research or to be a good scientist are remarkably similar, which challenges the conventional understanding of RRI as distinct from the scientific process. Porosity between RRI and scientific practice is captured by the capability set criticality and creativity, characterised as ways of being in the world needed to engage with ambiguous, provisional and complex states of knowledge.

Our participants explained that at the level of a project, this would mean being open to different interpretations of what RRI is or could be. For funders, these capabilities might manifest as being able to distinguish between meaningful scientific trends and hype, or through an ability to creatively navigate scientific and political priorities to produce call texts. Social scientists saw critique and critical reflection as central to their work. And while critique is a key aspect of re-

viewing proposals, evaluators emphasised the importance of the ability to critique constructively and engage with diverse perspectives in the peer review process. Finally, while creativity, curiosity and critical thinking are often thought of as intrinsic features of 'a scientific life', scientists in emphasised the importance of creatively responding to external barriers beyond their own control – a pandemic, or delays in the release of funding, for instance.

Our participants felt these capabilities would be made possible through methods to enable collective or individual anticipation and reflection that could enhance decision making about research design, public responses, or a project's goals. They would depend on a rounded education, a critical perspective, perhaps developed through formal education, and even having the 'guts' to debate issues. And they would require institutionally sanctioned opportunities to step outside of 'project time' to reflect on the wider social context and implications of research. The creativity and critical thinking skills reflected in this capability set are regularly viewed as critical to scientific research and education (Agar, 2017; NASEM, 2021), revealing the potential for greater integration of RRI in scientific processes in a symbiotic relationship.

2. Opening and exchange

A norm of today's science is the expectation that researchers will work to break down the barriers with those external to the research process. Scientists are now expected to produce communication and dissemination plans, and there is consistent rhetoric from august organisations about the need to 'maintain trust' between science and its publics, particularly in the life sciences (Smith et al., 2021c). The opening and exchange capability set captures the skills, knowledge and resources necessary to mobilise publics, stakeholders, users or even scientists who may be external to a scientific project or programme's immediate community, yet have a vested interest in how it progresses or could contribute knowledge to its development.

Researchers in projects would use venues to exchange with colleagues, collaborators and interested parties. One social scientist referred to a workshop designed to bring members of the public into the project to reflect on ideas of the bioeconomy and respond to the project's work. Funders saw the ERA CoBioTech programme as producing a diversity of forums for "a range of stakeholders (policy, funder, academics, industry) to engage and ensure that this RRI work has the greatest potential impact." In contrast, others felt the absence of RRI methodologies such as life cycle analysis meant the goals, assumptions and boundaries of a project were ambiguous, making communication with external audiences challenging.

Enacting these capabilities depends on building coalitions of people from different localities to work collectively on shared projects; sustaining professional and personal networks, particularly beyond the lifetime of these shared projects; and establishing common languages. They require methodologies to identify relevant individuals, groups or forms of knowledge and to facilitate conversations with those people. They also require venues and institutional norms that enable people to talk freely about their work — as well as its uncertainties and ambivalences — in public settings.

Capability Set	Illustrative capabilities to…	Examples of resources to provide…
Criticality and creativity Engage with ambiguous, provisional and complex states of knowledge.	• Understand a project's goals and assumptions. • Take an expansive approach to what RRI is or could be. • Foresee future impacts. • Look at things from a new perspective. • Have the guts to debate issues.	• Time (to reflect and change course). • A manageable workload. • Knowledge about the plausible trajectories and outcomes of a technology. • Funding to resource the work taken for critical reflection. • People that are creative, open-minded and willing to work to understand each other. • Comprehensive knowledge of the science and of RRI.
Fluency Know what it might mean to practise RRI in a given institutional context or scientific field.	• Understand the variety of roles and institutions associated with RRI. • Incorporate RRI into scientific proposals. • Recognise and appraising different approaches to RRI. • Understanding sustainability impacts of specific technologies. • Choose alternative, more sustainable technologies or materials.	• Opportunities to consistently engage with experts in RRI. • Opportunities to collaborate and exchange experiences with others. • Time (to learn). • Information, case studies and training on RRI at a programme's outset. • Opportunities and permission to engage with broader RRI questions in funding panels. • Project designs that place RRI activities early on so they can shape outcomes. • Incentives to make decisions that incorporate responsibility and sustainability considerations.
Opening and exchange Mobilise external constituencies in a scientific project or programme.	• Systematically include different public groups in your research. • Engage with non-academic groups, stakeholders and industrial partners. • Build interpersonal skills.	• Professional practitioner knowledge about engagement strategies, methods and approaches. • Laws and regulations that enable information sharing. • Coordinated opportunities to engage with hard to reach external audiences (e.g. policy makers, civil society organisations, certain publics). • Consortium members with existing relationships to external groups. • Functional platforms to facilitate the public sharing of information.
Plurality Value difference, negotiating tensions, and accommodating dissent.	• Appreciate the multiple ways a problem can be framed. • Be open to new ways of doing science. • Actively listen to one another. • Collectively balance competing goals, priorities and opinions. • Collaborate across laboratories, countries and disciplines.	• People to explain what RRI is about, and debate the pros and cons of different approaches. • Techniques to align different disciplinary priorities and norms. • Opportunities to talk informally with people who have different experiences to your own. • Clear channels of communication between project partners. • Forums and shared spaces to interact with one another. • Compassionate and responsive leaders to learn from.
Directionality Formulate individual and collective courses of action, then putting them into practice	• Internalise each others' goals in a stable coalition. • Establish a common language. • Identify, developing and choosing compassionate leaders. • Collectively agree on the importance of RRI. • Adapt to changing circumstances. • Monitor progress towards RRI goals. • Be flexible in response to external pressures.	• Incentives to direct resources, time and energy to RRI activities, and to collaborate rather than compete. • A commitment to pursue RRI work from the programme's start to end. • Collaborators whose goals, interests and timelines are aligned. • Appropriate financial support to do the work associated with RRI. • Opportunities to advocate for RRI, to clarify your own thoughts and build shared understanding.

Table 1: Summaries of the five capability sets relevant to Responsible Research and Innovation. Examples of capabilities are provided in the second column. The final column gives examples of the resources required to support these capabilities, which should be the target of future policy interventions.

3. Fluency

Responsible research and innovation practices will be subject to the site-specific features and dynamics they occur in. Research developing a new high-value compound raises similar but distinct issues to research developing gene drive mosquitoes. The norms and resources available to a research-intensive university will be different to those of a start-up. Thus, there can be no single way of enacting RRI; there are certain ways of practising social responsibility in science and these may or may not align with the goals of RRI as defined by a programme. This may make it sound as though 'anything goes', but it is rather a reflection of the sophisticated challenge of taking something generic and wrangling it into doing work in a specific setting. Throughout the three workshops our participants emphasised the need for skills and knowledge to do this tailoring between extant ideas of RRI and the specificities of a particular context.

The fluency capability set captures the skills, knowledge and expertise needed to know what it might mean to practise RRI in such particular contexts. For instance, an evaluator explained that there was initially a lot of confusion about "the why and the how [of RRI], especially when evaluating proposals." Worrying about their role in 'RRI-washing', one evaluator suggested that, "we're still learning how to make RRI meaningful, both at the funding proposals and project activities level" and that conversations in evaluation panels have been central to that process. It was through *doing* RRI that these questions were figured out. Some researchers connected learning about RRI to interdisciplinary research teams, which enhanced their ability to have a broader view of the social impact of their research. And through exposure to conversations about RRI, some funders began to notice the variegated way RRI was practiced by researchers, enabling them to begin to identify substantive and instrumental approaches: "I noticed that RRI was mentioned in many presentations, but not all, and in varying degrees." Thus, our participants emphasised that being asked to incorporate RRI into their working lives built knowledge of what RRI could mean or be in practice.

Capabilities relating to fluency may be substantive – perhaps formalised – knowledge of RRI and the social scientific research that accompanies the concept. They may be about developing a vernacular to discuss RRI collectively. They could engender knowledge of how the goals of RRI relate to a project or programme. They could involve the institutional awareness to translate RRI in a bureaucratic and project-centred funding system. Or they could involve simply being aware of the resources available to you to do research within an RRI framework. They can be built in diverse ways, through 'learning by doing', through exchange with other projects, and through codified documents and formalised training opportunities. One common dependency that our participants identified was having chances to continuously and informally engage with social scientists in the programme.

4. Directionality

Directionality captures the wide range of capabilities related to formulating individual and collective courses of action, then putting them into practice. These capabilities involve generating buy-in amongst different actors, deciding on shared courses of action and then actively steering together. They require leadership and power sharing, and in a scientific context they are likely

to depend on institutional systems – often built by bureaucracies – to sustain and value the time it takes to do them.

This is important because passive forms of governance such as compliance and accountability mechanisms, while critical, often work to close down issues and assumptions. Instead, the RRI literature prioritises active forms of governance that encourage discussion of issues and enable assumptions to be scrutinised (Macnaghten, 2020; Stirling et al., 2018). One participant, for instance suggested they, "would still like to see a European discussion on the role of genetically modified organisms" to understand which problems they might be a publicly acceptable solution to, what alternative solutions are available, and importantly "how money should be allocated" amongst these different solutions. They thus connect the practice of RRI to a programme's ability to engage in debates about valued trajectories about science, technology and society.

An active mode of governing requires a careful balance between 'opening up' spaces for debate and 'closing down' to take decisions and move forwards. This might involve understanding the needs and desires of external stakeholders and end users, translating those needs into the context of a specific research project and then taking decisions to modify existing research trajectories in response. An evaluator suggested that it might involve distributing responsibility at multiple levels. For instance, instead of asking individual researchers to enact RRI, they suggested the evaluation panel could, "have looked more at general impacts of biotechnology such as the competition with food/feed, the possibility of using the new waste streams created by the bioeconomy." and engaged in "discussion about the consequences of funding certain projects over others". For this participant, an evaluation panel's collective capability to engage with broader questions about a programme's trajectory and tailor funding decisions accordingly were thus central to practising RRI. This would involve the panel incorporating broader discussions about sustainability impacts into its processes and then making active attempts to 'steer' innovation in response.

5. Plurality

Our final capability set captures the shared commitments, methodologies, and skills needed to understand and value difference, to negotiate the resulting tensions, and to develop processes that are able to move forwards productively while accommodating dissent. Within this set are values such as intellectual pluralism — the ability and willingness to be open to different ideas or the ability to engage with experiences different from one's own.

For instance, we might think about understanding and appreciating that there are different perspectives to the same scientific, social, political or environmental problem. One funder pointed to a gap between the way that biological and social scientists describe problems and solve them, stating bluntly: "for people who have not dealt with social sciences, the texts, explanations, or conclusions are often too long-winded and thus boring. For social scientists on the other hand bioscientists' texts, explanations or conclusions seem too short-sighted." This funder is pointing to different ways of knowing that occasionally exist between different disciplines, highlighting that responsible innovation depends on finding ways to bridge this gap, to negotiate these differences and move forwards. Capabilities relating to the plurality set involve identifying tensions between different ways of knowing and experiencing the world.

Having the fora and agency to actively listen to these different, sometimes conflicting, viewpoints are central to this capability set. However, several researchers also emphasised the importance of leadership, for instance having a principal investigator able to "listen to and integrate different viewpoints", in creating these environments. A junior researcher pointed to the inter-generational aspects of this capability set, noting that "our project co-ordinator was a very gentle and effective leader. I certainly gained experience in the benefits of compassionate leadership, and expect that others did likewise." Not all conflicting views surfaced may be resolved, but a shared recognition of the generative potential of this tension, and an acknowledgement that different forms of expertise share political legitimacy, is at the heart of this capability set (Scott, 2021).

How to design with capabilities

The capabilities framework connects the many faces of governance by foregrounding (i) specific issues for RRI to engage with, (ii) the capabilities people value when engaging with these issues, and (iii) the internal and external factors these capabilities depend upon. It enables us to systematically unearth individual, collective and institutional dimensions that shape practice, and consider how things could be different; to ask how funding programmes could be reconfigured to better support RRI practices. By drawing attention to instances where capabilities are constrained by systemic factors, it allows groups seeking to build new research and innovation cultures to see the limits of their power, and develop alternative courses of action.

But how can funders embark on this process of programme design? Recalling that capabilities will not emerge in uniform ways but according to peoples' situations and values, our recommendation is to focus first on identifying the goals of and valued capabilities for RRI, then on developing interventions that create the conditions for capabilities to emerge or thrive and, finally, on establishing opportunities for formative evaluation to better tune programmatic interventions, capabilities and goals.

1. Collectively identify goals and capabilities

A particular asset of a capabilities approach is how it makes explicit and internalises the value-judgments animating research and innovation systems (e.g., addressing a societal challenge; delivering economic returns to private individuals), as well as the goals of individuals and research groups (O'Donovan et al., 2022). To put this differently, capabilities are defined by people *aiming to do something in the world* and are therefore inherently normative. In this project, we identified nine issues that researchers associate with RRI and five corresponding capability sets that people value when practising RRI. We thus worked with an assumption that engaging with each issue was the overall goal of practising RRI within our ERA CoBioTech research system. These issues were identified from an analysis of what is a relatively diverse portfolio of agriculturally- and industrially- focused biotechnology research in Europe. Similarly, our five capability sets emerged from discussion between diverse groups of people in the programme. We therefore expect the issues and capability sets to have broad relevance for RRI in the non-medical biological sciences.

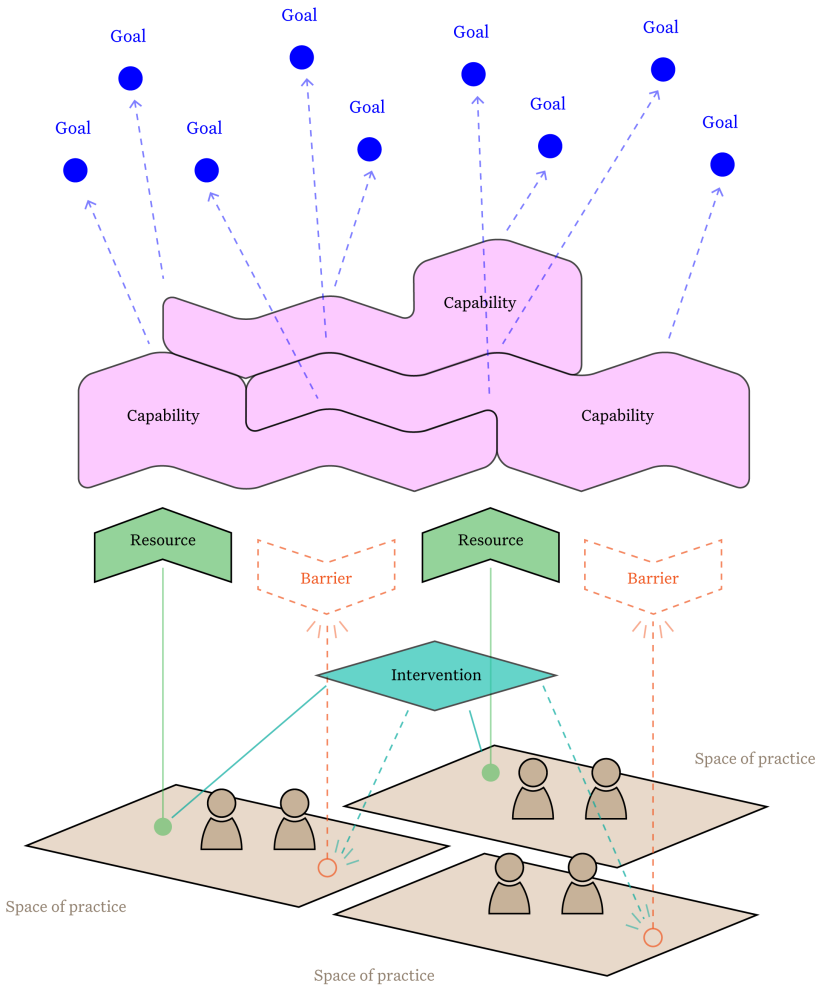

Figure 2: Goals, capabilities, and dependencies as per figure 1. A funding programme is constituted by people's work in various material spaces. Interventions are designed to change the dependency landscape of these spaces, by providing resources and/or removing barriers to achieving capabilities.

However, there are many goals one can associate with responsible research and innovation. Some of the concept's developers envisaged it as a way of engendering a new politics of science (Macnaghten, 2020). Others see it as conservative concept that can insulate science from political scrutiny (Hartley et al., 2017; Frahm et al., 2022). While it may be tempting to take our goals and capability sets as easily extractable from one setting to the next, the potential multiplicity means our first recommendation is for programmes to collectively identify goals that make research and innovation socially responsible in a their specific context. This aligns with key the recommendations of capability theorists, such as Sen, who argue that capabilities "depend on purpose and context, and should be a result of public reasoning" (Robeyns, 2006: 356).

Ideally, the goals of RRI and the capabilities important to achieving them would be co-created at the outset of a funding programme with a diversity of people who are affected by said programme. The diversity of goals suggests that it will always be hard to agree to precise objectives, and our own participants' emphasis on the utility of 'interpretative flexibility' means this may not be desirable. Broad directions and principles, however, should be achievable and provide a settled baseline for collective interpretation of RRI. At the level of a funding programme this

might mean agreeing on general principles or priorities, or to delimiting certain concerns as particular foci. As detailed in our examples below, for specific calls such funders could, and arguably should, be more precise in their prioritised goals and capabilities. In all cases, a collective process would serve as an enrolment exercise that grants legitimacy to a programme's RRI policies and actions.

2. Use capabilities and dependencies to guide interventions

To think about how to design with the capabilities framework, it helps to revisit what a capability is and where it comes from (Figure 2). A capability is the possibility to be a particular kind of person, or to act in a particular in a way to achieve a particular goal. For example, you could have the ability to travel, to make money, and participate in a community of cyclists by having a bicycle, as well as the knowledge of how to use and maintain it. These capabilities can be achieved by individuals or collectives and they occur in particular places — laboratories, meetings, conferences, for example. Finally, people depend on skills, knowledge, resources and other external conditions to achieve capabilities. The dependencies identified by our workshop participants include cognitive, relational, organisational, epistemic, informational, institutional, political-economic and infrastructural factors. Paying attention to 'dependencies' is important because it gives the flexibility needed to configure capabilities to the contexts of the individuals or collectives enacting them, and the situations those people find themselves in.

A natural extension of collective processes to identify valued goals, capabilities and the dependencies critical to their realisation, is to design interventions to support RRI. Table 2 provides a summary of the interventions identified by participants using the goals-capabilities-dependencies design framework. To ground these ideas in the specificities of a funding programme, we have mapped interventions to particular locations in a programme's lifecycle, and have also identified cross-cutting themes (e.g. time, valuation). To give an indication of priority, we also asked participants to estimate the extent to which the intervention was pragmatic or transformative, and the extent to which it would be feasible, and whether it was exciting.

When designing interventions, programme participants need to keep the three dimensions — goals, capabilities, dependencies — in view. However, the contextual nature of capabilities make them hard to design for with specificity. A capability of 'fluency' will manifest differently in a microbiology lab compared to an evaluation panel, for example. The way a capability manifests will *always* be always be emergent and specific to the individual or collective achieving it, and the situation they find themselves in.

Therefore, when thinking about programme design, a funder's attention should primarily be on providing the underpinning dependencies for people to achieve capabilities and programme goals. Dependencies are also heterogeneous and multilayered, but they are also specific, identifiable, and can be common to an R&I system. There will, of course, be differences in the delivery of knowledge, skills and conditions needed to achieve 'fluency' in a lab versus in an evaluation committee. But there are also remarkable commonalities in the *kinds* of knowledge and methods about RRI that would be useful, the availability of time to learn about these methods, as well as a set of rules and norms that incentivise people to achieve fluency. Multiple capabilities can also be contingent on similar dependencies. For instance, participants emphasised the importance of

Target activity	Illustrative interventions
Programme management & coordination	• Diversify the people (experiences, perspectives, expertise) who design programmes and evaluate project proposals. • Include government and policy actors in programme activities and call design. • Extend the length of projects to improve staff continuity. • Ensure that all funders can fund RRI components.
Agenda setting & call development	• Use RRI processes to develop funding calls that scientists can then address, i.e. explicitly include RRI in the agenda setting process. • Help researchers to think about RRI in early in the proposal development process; it will be relevant from lab to application. • Ask researchers to explain how RRI was considered in the development of the proposal rather than just what will be done if the project is funded. • Facilitate the co-designing of RRI activities with "experts" from the programme before proposals are submitted.
Project development, management & coordination	• Ensure that the individual leading RRI work within projects is heard and connected to the work of the consortium. • Fund social science staff time. • Use tools such as life cycle analysis to analyse a project's potential feasibility and impact before the substantive research begins. • Create 'mission-oriented RRI' — i.e. prioritise particular RRI activities and approaches for specific calls. • Have flexible project agreements to enable, for instance, personnel changes.
Industry, user & public engagement	• Task a business or end-user partner with leading RRI in each consortium (to create culture change in industry). • Prioritise and simplify industrial participation in research projects. • Create placements and secondments with stakeholder and user organisations (industry, policy etc.) • Ensure project teams engage with public communities to improve the societal relevance of their research.
Collaborative activities & shared learning	• Devote more programmatic resources to allow staff and researchers to interact with one another. Do this from the programme's inception. • Create more awareness about the time constraints and pressures experienced by different partners through discussion. • Actively employ researchers of different career stages to create mentorship and knowledge exchange opportunities.
Training	• Educate all funders, evaluators and researchers about RRI, especially with respect to its implementation and practice. • Produce and provide resources that will help all participants in the programme to put RRI into practice (e.g. ideas, sources, experts).
Time	• Create project timelines that enable funded staff to devote meaningful amounts of time to RRI activities while also fulfilling their technical goals. • Enable researchers to change their projects in response to discussions about Responsible Research and Innovation. • Increase money and time allocations for project meetings to foster in-depth conversations — in turn encouraging the development of shared language, questions and consideration of the social, environmental and ethical issues from the outset of a project. • Extend postdoctoral researchers' contracts to give them more time to develop their skills and provide more opportunities to learn as a cohort.
Valuation	• Create incentives to encourage people to engage with outside experts. • Make it valuable to 'just' talk with one another (e.g. beyond talking to publish or create measurable impacts). • Acknowledge that learning how to do RRI activities well can take considerable amounts of time. • Foster socially valuable research activities as much as economically or academically valuable activities.

Table 2: Example interventions proposed by participants in workshop 3 using the goals-capabilities-dependencies framework.

social scientists at multiple points in the programme — from behind the scenes in administrative spaces, to research projects — in providing or building multiple capability sets. Similarly, dedicated opportunities to meet and share knowledge played similar cross-cutting roles.

Five of our participants' interventions were fleshed out in a rapid prototyping session. To demonstrate that it is, in principle, possible to design interventions that would reconfigure systems to allow people to create, build and enhance their capabilities for Responsible Research and Innovation, we close by describing three interventions below. We have chosen the interventions to illustrate the breath of ambition possible when designing with capabilities.

3. Establish opportunities for reflection, learning and 'tuning'

Ultimately, asking members of a research and innovation community to self-consciously reconfigure the spaces in which they operate will be a process that takes time and continued experimentation. There will be failures, uncertainties and the possibility for experiences gained in one setting to be relevant in another. Furthermore, neither the identified capability sets nor dependencies are fixed or exhaustive: we expect that over time, goals change, capability sets evolve and new dependencies become visible.

As a final step, we therefore strongly suggest funders establishing monitoring and learning processes within and across programmes. As identified by our participants, who highlighted the lack of time, money and opportunities to pause and 'step outside' project time, learning processes will likely need to be deliberate, protected and adequately resourced — just like those process suggested in steps one and two, above. Establishing such processes creates spaces in which interventions advancing capabilities and dependences can be better 'tuned' to each other, and to the goals they orient towards. The metaphor of tuning aptly embodies the way in which getting capabilities and dependences aligned, on the one hand requires hearing the input of diverse participants. Simultaneously, it speaks to the need for well-calibrated, precise actions to harmonise the function of instruments in light of their fit, be they programmes, networks, projects, labs or otherwise, in wider R&I systems.

In practice, this means creating periodic opportunities to engage in formative evaluation (Molas-Gallart et al., 2021). It also means engaging in summative reflection to examine the impact of interventions on capabilities (e.g. their creation, enhancement or potentially degradation), and the dependencies provisioned by the programme and broader R&I system (O'Donovan et al., 2022). While indicators and metrics may help to monitor these dimensions, new mixed-method approaches that create shared spaces for reflection are more likely to provide opportunities for learning amongst the community (Smith et al., 2021b). In addition to giving space to tune capabilities and dependencies advanced by interventions, such opportunities can foster reflection on programmatic goals in and of themselves. Leveraging the directionality capability set and the dependence of well-resourced formative evaluation spaces, funders and programme participants can decide on – or to continue the metaphor, 'tune' – the interventions they prioritise to advance goals and capabilities. An effective learning process also includes understanding when certain R&I system structures are beyond the scope of what a programme alone can change—itself revealing further opportunities for funders and academic leaders themselves to take on upstream change with the community by enrolling other actors.

Monitoring as reflection

Point of intervention: Project monitoring & evaluation.

Goals: Alignment • Relevance • Reflexivity

Capability sets enhanced: Fluency • Criticality & creativity • Plurality

Dependencies accessed: Knowledge of RRI • New forms of valuation • Social scientific expertise • External relationships • Case studies of success

This intervention aims to use project monitoring exercises to encourage researchers to develop narratives about the social, environmental and policy impacts of their work recent or forthcoming work. Mirroring policy experiments with narrative CVs, it would centre on a somewhat incremental reformulation of mid-term and final reporting mechanisms to include narrative-driven reflections. Researchers would be asked to tell a story about the people they had interacted with in the project and activities they had developed to address their needs. This could be written collectively. A goal of this narration would be to aim for a coherent discussion of different perspectives and knowledge that could shape the project. Researchers would also be asked to avoid certain tropes, such as underestimating scientific-literacy, and to consider the relationship between important ideas such as acceptance, scientific uncertainty and trust.

The overall goal would be to make a modest change to reporting processes that could be sustained over time and that, over multiple projects, may begin to change scientific cultures. It would enhance capability sets of fluency, plurality and criticality and creativity. Researchers would likely require training to complete the exercise, thus generating knowledge and information resources. Additionally, the group felt that by integrating into monitoring infrastructure, the intervention could support academics to deepen their knowledge and look beyond the lab. The intervention might therefore also drive access to other important resources such as external expertise, networking with other projects as well as time and valuing of non-measurable achievements. They also foresaw possible benefits for the running and planning of future projects because, for instance, discrete scientific goals would have to be situated within a wider context.

Mission-oriented RRI

Point of intervention: Agenda setting • Call design • Proposal development

Goals: Any (according to funder decisions)

Capability sets enhanced: Fluency • Directionality

Dependencies accessed: Information & knowledge of RRI • Shared vocabularies • Collective commitment to RRI • Social science expertise

This prospective intervention uses a funding programme's call definitions to direct RRI towards particular goals. The idea would be to create a series of directed funding calls which would also have specific requirements for RRI and could incorporate consideration of RRI dimensions within their own design. For instance, a call focused on the production of bio-based chemicals could require only certain feedstocks and could mandate engagement with the producers of such feedstocks. A call that focused on GMO's, projects would be primarily directed and evaluated on their engagement with the political aspects of GMOs. Or a call focused on next level building blocks for chemistry might prioritise projects' engagement with sustainability. Pragmatically, it would be funders' responsibility to define the focus for each call, but this could be achieve with in-house expertise, or through broader stakeholder consultation. Direction towards particular RRI goals would be achieved by weighting the evaluation towards relevant criteria.

A targeted and goal-oriented approach to RRI would build capabilities of directionality and fluency, with specific calls focusing on other capabilities, such as openness and exchange. While there are many calls for generic training at the outset of a programme, this approach would narrow the remit of such training, making it tractable. It would encourage people to develop a shared collective language that is specific to the funding call. It might also ensure that the capabilities from social scientists enter projects as a valued member from the outset because scientists would understand they are very clearly required for particular aspects of the research. And it would also help to direct multidisciplinary teams towards a shared goal and demonstrate the value of RRI. The corollary of the intervention would be that funders need to do more work to actively steer research in particular directions, which would also require more knowledge and agreement of goals at the outset of the funding programme.

Giving time to RRI

Point of intervention: Funding call design • Proposal submission • Research projects

Goals: All

Capability sets enhanced: Fluency • Directionality • Plurality • Criticality & creativity

Dependencies accessed: Information & knowledge of RRI • Time • Interdisciplinary communication • Shared vocabularies • Collective commitment to RRI • Social science expertise

Whereas our first two example interventions targeted individual aspects of a funding programme as levers for broader change, this one is more ambitious in its scope. Participants were concerned with the underpinning resource of time, and specifically how to actually give people the time and resources to do RRI well within projects.

They identified four interrelated issues that work to crowd-out RRI from project time. First, time us usually not given to consider how RRI might work before a project proposal is submitted or awarded—and this does require time to work through. Second, project timelines do not usually include time for staff to learn about or even do RRI activities on top of demanding technical milestones. Third, project timelines are such that even when set in advance, there is no time to iterate on approaches to RRI, or the technical work based on insights surfaced by participating in RRI activities (the very language 'timeline' imposes a linearity anathema to iterative loops). Finally, the timeframe of the project form in general, is usually quite short, making time scarce when it comes to conducting longer-term reflective processes, or building sustained relationships with partners vital to include from the perspective of RRI.

This intervention consists of modifications to the way funding calls, proposal submissions and research is conducted within a funding programme. First, pre-call initiatives would identify important challenges and enable teams of scientists/engineers/social scientists to build ideas. The programme would also create collaborative and multidisciplinary sessions between participants from different projects, and would create opportunities to co-design RRI activities with "experts" from the programme before submission. At the submission phase, participants imagined including sections and questions that would ask how RRI was considered in the development of the proposal, rather than only asking for descriptions of what will be done within the project timeline. Research project timelines and financing would need to be reimagined to allow all researchers — PhDs, research fellows, co-investigators and the principal investor — to have a longer work timeframe, facilitating learning and skill development. The programme would also create mechanisms to reward RRI engagement.

The breadth of this intervention — effectively to reimagine a funding programme — would be similar in its breadth of target capabilities. Participants felt the intervention would enhance the training of early career researchers, foster communication between different disciplines, particularly the natural and social sciences, and would build connections between different project partners. In addition to bringing more thought to the design of the project as a whole, one impact could be that RRI becomes something that is shared collectively across the project.

Conclusion

A strategic, evidenced and holistic approach to advancing the capabilities and associated dependencies of synthetic biology researchers and cognate professions represents an investment in long-term culture change in the European biotechnology community. Over a decade of investment into Responsible Research and Innovation has produced new practices in the governance of emerging biotechnologies. This work has been guided by procedural frameworks such as the anticipate, include, reflect and respond approach developed by Owen, Stilgoe and Macnaghten (2013) and by issue-oriented approaches such as the European Commission's (2015) which focuses on education, engagement, ethics, gender, open access, sustainability, justice and governance. When operationalising these ideas, too much attention has been paid to the role of individual researchers at the expense of the role of research and innovation cultures that shape what is possible to achieve under the rubric of RRI (Smith et al., Forthcoming; Felt, 2017). This is, in part, because we do not have appropriate ways of systematically unearthing institutional dimensions, examining how they shape practice and considering how things could be different.

The language of goals, capabilities and dependencies provides a framework to produce funding, research, and innovation cultures that are positioned to respond to the social, ethical, environmental and political concerns associated with biotechnology in Europe. This language offers a way of 'making RRI doable'(Fujimura, 1987) by aligning the different goals, resources and capabilities necessary to practise socially responsible research in the life sciences. As our exemplar interventions show, a particular strength of this approach is its ability to build a latent capacity within the community of biotechnology researchers and funders to not only navigate current issues and concerns, but also shape future programming over time.

The nine goals associated with the social, ethical, political and environmental dimensions of biotechnology in Europe, the five capability sets, the numerous enabling dependencies offer a basis to imagine interventions that would build capacity for socially responsible research in future biotechnology funding programmes — our own workshop participants generated over 50 ideas to this end. These interventions would: value different forms of knowledge and find ways to accommodate and productively channel the conflicts that emerge among them; actively learn and elaborate what responsible, sustainable, ethical synthetic biology research means in practice for its community of researchers, funders, and potentially affected stakeholders; invest in protecting spaces and rewarding time spent to critically reflect on the assumptions and goals of the scientific field and reimagine ways funding and research practices 'could be otherwise'.

We anticipate that investing in initiatives to enable capabilities for RRI would ultimately lead to the expansion of these capabilities to unearth previously unidentified dimensions, in turn enabling further capacity building and culture change. While political circumstances beyond the control of programmes such as ERA CoBioTech produce a frothy mix of governance concepts — ELSA, RRI, SDGs, Co-Creation, Open Science, Circularity, Do No Significant Harm — a community that has identified its core goals, works to give these goals practical, systemic meanings, and makes time to learn from prior experiences will be resilient to the introduction of new buzzwords that articulate longstanding concerns with a new gloss.

Perhaps most importantly, prior experience with governance in the life sciences tells us that it is the act of 'giving meaning' to RRI that is most valuable to a programme's constituents (Doezema et al., 2019; Rothstein, 2013; Soneryd, 2016). Thus, rather than any straightforward attempt at extraction and implantation, our primary recommendation to future administrators would be, at the inception of their programmes, to embark on the collective process of identifying goals, mapping attendant capabilities, tracing underpinning skills, knowledge and conditions, and generating interventions.

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