‘CTA-Lite’ for Exploring Possible Innovation Pathways of a Nanomedicine-Related Platform–Embedded Responsible Research and Innovation in Practice

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Abstract. Notions of Responsible Research and Innovation (RRI) have received great interest by policy makers and scholars. The application of RRI to research and innovation practices ‘on the labfloor’ however remains a big challenge. In this chapter we present an example of the practical implementation of RRI in the form of a technology assessment (TA) exercise in the context of the Dutch nanotechnology research program NanoNextNL. Specifically, a technical PhD student, supported by a TA facilitator, organised a workshop to explore additional application fields, innovation pathways and commercialisation opportunities, potential bottlenecks and societal benefits of the nanomedicine platform she developed in her PhD project. We describe an approach that we label ‘CTA-lite’ which involves a multi-actor workshop and focuses on the development of an innovation path map. We reflect on the potential for wider uptake of this approach and its possible limitations. Additionally, we consider the benefits for natural scientists of doing such an exercise, and finish with suggestions for future implementation. We conclude that this case provides an example for integrating socio-technical dimensions and reflexive learning into research practices at the labfloor, and that it can serve as an inspiration for other researchers, and in this way supports a move towards mainstreaming of RRI.

Keywords. CTA-Lite, Innovation Path Map, Responsible Research and Innovation, Constructive Technology Assessment, Labfloor Integration

3.1. Introduction

The integration of societal and ethical aspects in research and innovation practices has been an important trend in research and innovation programs. It has been stimulated by European Union (EU) policy makers in various framework programs from early on (Rodríguez *et al.*, 2013), and has been an important element of the United States (US)

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national nanotechnology initiative (Roco, 2011). More recently, Responsible Research and Innovation (RRI) has been playing an important role in the European Commission's Horizon 2020 and former FP7 Program, both as focused projects and as a cross-cutting ambition. RRI is defined as:

> 'an approach that anticipates and assesses potential implications and societal expectations with regard to research and innovation, with the aim to foster the design of inclusive and sustainable research and innovation […] in order to better align both the process and its outcomes with the values, needs and expectations of society' (European Commission, 2015).

Next to its integration in the Horizon 2020 Program, inquiring into the conditions and concrete approaches for RRI has become an important topic for numerous research projects, conferences, special issues, edited volumes and journals, and has managed to mobilise a variety of actors to explore and experiment with RRI ideas (Rip, 2014). Specific directions for RRI can range from anticipating and assessing potential implications and societal expectations, engaging with publics, ethical considerations, to the promotion of gender equality in research and innovation, open access of scientific results, and science education. Additionally, macro-level activities are suggested for implementing RRI by building capacity, reviewing and adapting metrics and narratives for research and innovation, and for fostering RRI by institutional changes (Stilgoe *et al.*, 2013).

Efforts to implement RRI specifically in the field of nanotechnology were already visible prior to the EC's interest. For example, in the Constructive Technology Assessment (CTA) activities in the Netherlands in the mid-2000s, a dedicated project on research and responsible innovation in nanotechnology governance was conducted, supported by the Dutch national nanotechnology research program NanoNed, and led to the first publication using the RRI acronym (Robinson, 2009). The ambition to foster RRI is also an important element of the current Dutch nanotechnology research program NanoNextNL, a consortium including more than 100 firms, universities, knowledge institutes and university medical centres, with a total funding of 250 million Euro.[2] Next to fundamental and application-driven research themes, NanoNextNL includes a research theme on Risk Analysis and Technology Assessment (RATA), which focuses on potential risks of nanotechnologies, technology assessment and governance of nanotechnologies. In addition, technical PhD students are required to dedicate part of their research time to inquire into aspects of risk analysis or technology assessment related to their project. For these PhD students, educational and supportive RATA activities have been organised in the form of an introductory course on general aspects of risk analysis and technology assessment, and a coaching is offered where social science researchers support PhD students on how to integrate RA or TA in their thesis (Walhout, 2015).

In this chapter, we focus on micro-level activities of RRI, namely its practical implementation in research and innovation practices at the labfloor. Specifically, we describe one technology assessment (TA) activity within NanoNextNL as an example to show how PhD students could anticipate and reflect on the societal relevance of their work. We discuss our experiences gained as technical researchers practicing RRI and as social science scholars to supervise such an activity as well as its broader

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[2] For addition details on the program, please see: www.nanonext.nl

applicability. In our case, a technical PhD student (Verena C. Schulze Greiving), with the support of a TA facilitator (Douglas K.R. Robinson), organised a workshop with multiple actors from various fields of expertise to explore potential applications for the microfluidic lipid bilayer platform she developed in her project, as described in Box 3.1 and elsewhere (Stimberg, 2014).

During the workshop, a multi-path mapping approach (innovation path map) was elaborated to structure the discussion and to facilitate the information gathering. Such multi-stakeholder workshops and multi-path mapping approaches are established tools and have been described previously by social scientists (van Lente and van Til, 2007; Robinson and Propp, 2008; Huang *et al*., 2012; te Kulve, 2014), while this combination seems to be less common in science and engineering. The innovation path map facilitates the specification and checking of general or vague expectations and promises on the application potential of a research project, up to suggesting new and possibly more promising research directions. The workshop typically brought together a variety of actors who would normally not interact in this constellation and therefore creates a promising setting for a PhD student to explore applications for his/her technology and research.

It should be made clear though that this is only one example on how RRI could be practically implemented, and the workshop and the innovation path map utilised here are only two tools that can be chosen out of a pool of available tools from the field of TA or beyond. In any case, the chosen tools should be compatible with the requirements and constraints for integration in daily lab routines, as explained in more detail later. In our example, the PhD student started with the TA exercise in the last year of her project (September 2013) when only limited time was left, which called for an activity with relatively small preparatory effort.

Additionally, the PhD student with a background in chemistry and nanotechnology had only followed one course during her masters on societal embedding of nanotechnology, and the introductory RATA course offered by NanoNextNL, which left her with limited knowledge on TA. Against this backdrop, this chapter aims at: (i) demonstrating the productive integration of such a TA activity in a PhD project supported by a TA facilitator, (ii) testing the approach to use a multi-actor workshop format as a ‘pre-screening’ tool in combination with an innovation path map to structure the discussion and to gather information, and (iii) providing an example for other technical researchers and engineers to follow in the future.

In this chapter, we first frame the context of integrating RRI at the labfloor; we describe the workshop preparation and outcomes; and finally reflect on the general feasibility and limitations of such an approach, the benefits for natural scientists of doing such an exercise and the role social scientists could play. At the same time, this example has the ambition to stimulate researchers to use such approaches more widely for considering social or ethical implications of their research, and eventually could serve as a first step towards the mainstreaming of RRI.

3.2. Framing conditions for RRI at the labfloor

It is not uncommon that scientists perceive themselves as having a moral obligation to work towards scientific and technical progress while others should be concerned with social, ethical and political issues (Rip and Shelley-Egan, 2010). This observation is in line with the historically established separation and 'division of labour' of actors and organisations responsible for the promotion of technology and those responsible for its control at an institutional level (Rip *et al.*, 1995). However, this 'division of labour' is increasingly challenged, for instance by changes in the mentality and directions of the funding agencies and an increasing emphasis on anticipating potential impacts of research and innovation in general. Furthermore, in the context of application-oriented research this division has never been as clear-cut. The concept of RRI encourages researchers to take social and ethical considerations into account in collaborative actions with other societal stakeholders, to anticipate on them, and natural scientists are increasingly made feel responsible for the effects and the impact of their research with the aim to align research with societal values.

Still, integration of RRI in daily practices of researchers and engineers remains a challenge, given current skills and institutional structures. Junior researchers have often followed a purely technical education without background in social sciences language and grammar, literature and methodology which can be something of a hurdle when peering over the wall into the wondrous world of Science and Technology Studies. Additionally, researchers experience a pressure to focus on publishing their research and they are evaluated on this output which demotivates them to spend time on non-core activities, as integrating a societal dimension in their research–there are high opportunity costs: why spending time on unevaluated societal engagement, when your supervisor pushes you to publish or patent?

Apart from that, looking at societal impact and embedding can be positioned as useful for innovation and important for those who will evaluate researchers on their propensity for innovation. Often, research in the lab is detached from envisaged application domains which are seen somewhere 'on the horizon' as mid to long-term goals or as an element to legitimate researchers' work to obtain funding (Bos, 2016). Even if applications are envisioned, they are often not well articulated or detached from the broader context of societal embedding or ethical concerns. RRI activities that aim to be implemented at the labfloor should take these constraining conditions into account, at both the institutional level of research organisations and the micro-level of research practices.

3.2.1. CTA: One possible approach for embedded RRI

Various approaches to broaden the societal and ethical aspects in scientific and engineering research and innovation have been proposed, implemented and discussed (Boenink, 2013; Fisher *et al.*, 2015). One particular approach targeted at researchers at the labfloor, the socio-technical integration research (STIR) method developed by Erik Fisher, has been widely tested and supports researchers to become aware of their decisions, reveal alternative options and make them conscious of potential social consequences of their decisions (Fisher, 2007). In the STIR approach, a social scientist is embedded in a technical research laboratory over a period of 12 weeks where he/she participates in the lab routines and has regular conversations with the technical researcher facilitated by a so-called decision protocol (Fisher and Schuurbiers, 2013). This setup lends itself well for the integration in daily practices, takes the concerns of the scientists as a starting point for reflection, and can be applied also to fundamental research projects where applications are not yet formulated. It requires, however, substantial time investment from a social scientist. It does not immediately provide input from the perspectives of different stakeholders, and the breadth of applicability comes at the expense of providing direction for more specific inquiries, once particular issues are identified, which deserve further scrutiny.

The approach chosen in the example presented in this chapter, draws on the tradition of CTA, an approach which aims at feeding anticipations on possible future social and technical developments as well as perspectives and assessments of different stakeholders into innovation processes while they are still unfolding. Typical target groups are therefore innovation actors, rather than policy makers who are addressed by many other forms of technology assessment. Many CTA projects have been applied to technologies that are at an early stage of development, as in the case of nanotechnologies or advanced microfluidics, when there is still quite some room for possible reshaping of those technologies, even if this implies that the envisioned uses are often still uncertain and so are the possible social or environmental impacts (Rip and Robinson, 2013). In contrast, at a later stage when the technology is already widely used and embedded in the society there tends to be little room for intervention (Collingridge, 1980).

CTA considers that actors involved in the technology development process have different perspectives and positions and therefore also evaluate the possibilities of a technology in a different way while not always taking into account the view of other actors. Different actor groups may have diverging perspectives for various reasons. A key distinction, which informs the set-up of CTA processes, is made between the so-called enactors and selectors, in line with the earlier mentioned separation between promotion and control of technology. Enactors refers to those who develop and work on a new technology and support it, and selectors to those who may be interested in the technology, but for whom it may only be one option among others (Rip, 2006). CTA projects create interactive events, often in the form of workshops, in order to bridge the gap between different stakeholders, to make them aware of other’s perspectives and assessments, and to discuss possible further developments and their strategic implications, related to technical options just as to possible uses, the integration into value chains or regulatory questions. The discussions and interactions in the workshop are often supported by socio-technical scenarios exploring in an open-ended manner possible developments that may occur within an innovation field. These scenarios are built on prior analysis of ongoing dynamics in the field and conceptual knowledge about typical patterns how socio-technical developments unfold (Rip and te Kulve, 2008; Robinson, 2009).

In this way, CTA aims at increasing the participants’ reflexivity, that is, the consideration for the broader implications of their work and, more generally, the interrelations between science, technology and society. The aim is to enhance the reflexivity of technical researchers which matches the ambitions of ‘embedded’ RRI. In addition, CTA activities can be characterised as exploratory and open-ended and are therefore suitable as RRI activities for new and emerging technologies and project-level activities where the innovation pathways and outcomes are not yet fixed (te Kulve and Rip, 2011).

The CTA-lite approach we present here takes up a number of elements of CTA, but it had been adjusted to the particular conditions and constraints of doing this as part of an ongoing technology-focused research project. It reduces the scope of the interactive workshop and the preparatory efforts. In line with this, the ambition is not so much a soft intervention into a network of actors at the level of an innovation field, but rather a much more focused intervention into a research project of limited scope. This concept of CTA-lite directly compares to software or applications such as SQL Manager where one can get SQL-lite with less functionality but more user-friendliness. Rather than investing large resources into exploring societal and ethical issues comprehensively from the beginning, CTA-lite can be both a training tool and a pre-screening tool to identify cases which might require a more elaborate CTA.

Therefore, the ambition of such a TA exercise should not be to deliver outcomes compared to well-prepared and time-intensive social science practices, but to be a first step to consider aspects that are often delegated to outside the laboratory, for example technology transfer and commercialisation issues (relatively close to the world of lab research), societal embedding or ethical and governance concerns (often perceived to be very distant from the world of lab research). Obviously, various tools and exercises can be linked up to extend the depth and breadth by, e.g., further desktop research, interviews with relevant stakeholders or organising a more comprehensive workshop.

The CTA-lite workshop resembles a number of characteristics of a CTA workshop where the discussion can be stimulated by using pre-engagement tools such as multi-path maps or scenarios, and where various stakeholders are present (Robinson and Propp, 2008; te Kulve and Rip, 2011; Parandian and Rip, 2013).

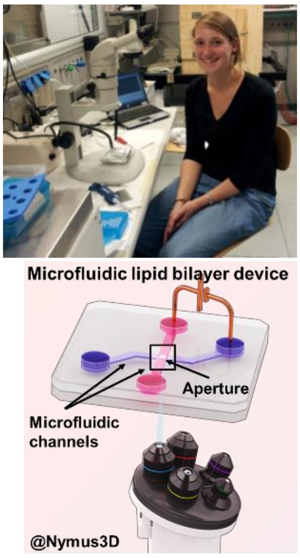
In our case, the preparation time of the workshop was reduced due to time constraints, which also limited the depth of the discussion and the outcomes–but such an activity can make key issues and challenges explicit and sensitises stakeholders to these issues. It is with this motivation that the CTA-lite workshop was set up. Here, the workshop was not seen as a bridging event but as a ‘pre-screening’ tool to explore potential applications of the nanomedicine-related technology developed by the PhD student benefiting from the diverse backgrounds of the participants. This CTA-lite setting favours the interaction with various actors in contrast to a STIR approach.

The goals, design, preparation and outcomes of the workshop are described in the next section, followed by a reflection on the format of the workshop, the general outcomes of this particular RRI activity, and potential future implementations.

3.3. CTA-lite workshop: Preparation and outcomes

The workshop was prepared by the technical PhD student (VS) in the frame of a TA exercise in close collaboration with a social scientist (DR) working on Technology Assessment, here called the ‘TA facilitator’.

Box 3.1. The technology at the centre of the PhD project: a microfluidic lipid bilayer platform.



During her project, the PhD student developed a microfluidic device to form artificial cell membranes, lipid bilayers, with the initial goal to use this platform for drug screening on ion channels–cell membrane proteins that play a key role in various diseases. The microfluidic device consisted of two glass substrates, each with one wet-etched microfluidic channel, which were separated by a 12.5-µm thin Teflon layer with a micrometre-sized aperture located at the channels intersection. Across the aperture lipid bilayers were formed by successively flushing lipid and buffer solution through the microfluidic channels. The lipid bilayers were formed spontaneously and instantaneously with a nearly 100 percent yield. A combination of (high-resolution) optical and electrophysiological measurements was applied to characterise these membranes in terms of thickness and fluidity, and various lipid bilayer compositions were analysed and compared. The performance of the device was further demonstrated by proof-of-concept measurements of the pore-forming peptide gramicidin, which was used as a model ion channel (Stimberg *et al.*, 2013). The combined optical and electrophysiological measurement scheme enables to study the interplay between peptide activity and lipid bilayer properties, which is an important aspect to consider for drug development.

During her project, the PhD student developed a microfluidic device to form artificial cell membranes, so-called lipid bilayers, for measurements on ion channels which are important membrane proteins that often play a key role in various diseases (see Box 3.1). The research project was motivated by the aim to develop a platform for drug screening on these ion channels which is a prominent topic in the literature. In the frame of the RATA requirement, the PhD student chose to focus on technology assessment rather than on risk analysis because the main work focused on developing a new technology and she was interested in assessing the societal value of her microfluidic platform. Already in the beginning of the exercise it became clear that knowledge about the content and methodological support was needed. The supervisor of the PhD student (Séverine Le Gac) knew the TA facilitator from previous TA research activities that he had organised and in which she participated, and she initiated the contact between the PhD student and the TA facilitator for this activity.

During the first meeting, the PhD student introduced her research project to the TA facilitator and her first thoughts on how to implement the TA exercise. Her initial ideas were inspired by the work of another technical PhD student from the predecessor program NanoNed who had anticipated potential uses of his research and carried out interviews to check future uses against current practices (Boer *et al.*, 2009). Together with the TA facilitator and the PhD supervisor it was decided to look at the valorisation of the technology and to identify key issues for technology transfer to be aware of different uses and users. This information should be gained through carrying out interviews with potential customers such as researchers and firms, and a brainstorm session should serve to select potential uses and users for the interviews. In the next meeting, the setup of the brainstorm session was further discussed, and it was chosen to organise a workshop with participants from various backgrounds to gain a lot of information from various areas of valorisation in a relatively short time.

Specifically, the workshop was aimed to serve as a tool to:

- explore alternative applications
- look at potential bottlenecks for technology transfer
- define promising innovation pathways for commercialisation and societal embedding
- test the process to explore key factors that are important to consider for the commercialisation and societal embedding of technologies currently being developed in the laboratory, and
- serve as a template for potential uptake by other PhD researchers in the NanoNextNL program to develop their own RATA activities.

The workshop finally took place approximately two months after the first meeting of the PhD student and the TA facilitator (in January 2014)–a relatively quick turnaround for such an exercise.

For the workshop, participants from the fields of natural and social sciences, CTOs from (start-up) companies, actors possibly interested in the core-technology developed by the PhD student and experts in regulation, politics and intellectual property rights were invited to provide input on a variety of topics (see Box 3.2). From the 19 participants that were contacted, 14 agreed to join the workshop.

The workshop started with a presentation by the PhD student to introduce her research topic and to present a ‘concentric circle-diagram’ to display the process of technology transfer and commercialisation as described by Deuten *et al.* (see Figure 3.1) (Deuten *et al*., 1997).

Box 3.2. CTA-lite workshop to explore innovation pathways: additional workshop information.

Workshop participants (n=17)

- workshop organisers (3)
- scientists involved in the same research project as the PhD student (2)
- scientists with research interests related to membranes and proteins but not involved in the project (2)
- participants with expertise in commercialisation from (start-up) companies (3)
- participants from regulations, public agencies, or knowledgeable about intellectual property (4), and
- social scientists (3).

Workshop organisation

- workshop preparation time: 2 months, but carried out as a minor task next to daily core research activities
- actual workshop time: 4 hours (including lunch to allow informal discussion)
- workshop location: home-university of the PhD student (University of Twente, The Netherlands)
- workshop costs: costs were covered with the budget of the PhD project, and
- workshop post-processing: less than a week, integrated in the writing process of the PhD thesis.

Photos by Gijs van Ouwerkerk

A risk with this concentric approach is the consideration of societal embedding only at a late stage of technology development, as already mentioned by Deuten. In our case, we rather use this diagram in a pre-development phase as a basis for discussion in our workshop. The linear model for innovation separates stages and ‘innovation labor’ in a way depicted by the concentric model. Although often recognised as an oversimplification, the linear model is still regularly applied in discussions of technology transfer and commercialisation.

Therefore, we chose to address this oversimplification head-on, and to dig into the complexities ‘upstream’ in the early stages of development so as to explore: (a) the different innovation pathways that might emerge, and (b) the challenges and factors to consider if desirable innovation pathways were to be pursued. In our workshop, this translated into looking at difficulties encountered when crossing the different boundaries *between* the layers and the innovation activity *within* the layers. Once the innovation pathways and challenges were better articulated, we then tackled the societal embedding, which is heavily dependent on the type of applications and targeted use of the technology. Thus, societal embedding has been taken into account once innovation pathways have been further specified and when specific applications have been selected.

A round table discussion based on the structure of the circle diagram followed, where important considerations and issues to be expected for the valorisation of the microfluidic platform were mentioned by the participants. Specifically, participants suggested that once an application has been chosen the customer and market needs should be analysed, and intimate knowledge of the daily practice in the targeted area of application should be gathered. Costs and resources required for the various applications should be considered early, similar to the intellectual property (IP) protection of the technology. Additionally, various potential bottlenecks for the drug screening application were envisioned:

1. conventional drug screening platforms being strong competitors, as they are standard tools and already achieve high throughput,
2. regulatory aspects to be taken into account during product development,
3. IP protection probably not being possible due to a lack of technological complexity of the platform, and
4. the replacement of animal models for screening purposes is not straightforward.

Next to possible risks and problems, also alternative applications were defined. Targeting the same customer, the pharmaceutical industry, the platform could eventually be applied for drug testing during preclinical studies, which requires lower throughput, or for studying drug delivery, or transport processes across the membrane. Alternatively, the technology could be commercialised as a research tool for universities where the multi-parametric optical and electrophysiological measurements are an added value. Some of the considerations mentioned during the round table discussion may have been relatively obvious for the participants suggesting them, whereas for the PhD student focusing on research and technological developments or participants with diverging backgrounds, such points were generally not trivial and provided new insights. In this approach, the workshop provided an effective way to gain relevant information for the PhD student.

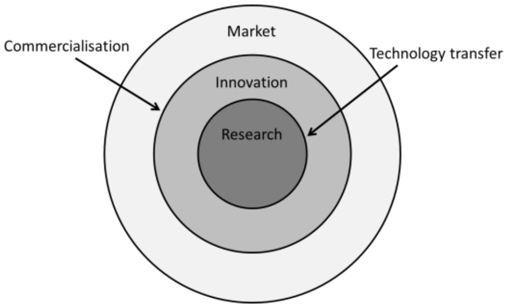


Figure 3.1. Concentric circle diagram.
The concentric circle diagram represents three stages (research, innovation and market) defined for the technology development process and the interface between the different circles (technology transfer and commercialisation).

In a next step, an innovation path map was filled in with all participants to further look at alternative applications and promising innovation pathways, as presented in Figure 3.2. The innovation path map resembles the structure of a multi-path map or a technology roadmap which is often applied in the business community, and which links technologies to products and markets (Kostoff and Schaller, 2001; van Lente and van Til, 2007; Robinson and Propp, 2008).

The different layers are displayed graphically on top of each other, going from technology towards the market in the y-direction. The technologies, products and markets are connected to each other by arrows to display various paths a specific technology could evolve to in time, including alternative products and markets. The x-axis usually displays the time, but here, however, this axis is not aligned in time as many of the routes are still unclear and difficult to predict. Therefore, this map rather resembles a 'visionary' innovation path map than an already well-defined roadmap. During the construction of the map in the workshop, a fourth layer for functionalities was added to the map. The lower layers of the innovation path map, technology and functionality, were filled in rather quickly based on the presentation of the PhD student about her research.

Interestingly, during the completion of the other layers of the map, additional ideas of potential applications, possible issues in terms of technological functionality, as well as concerns about costs and resources of potential products were triggered. The innovation path map provided a useful tool to expand on potential applications for this particular technology and to structure the discussion; it also serves as a visual and concrete outcome of the workshop to put technologies and applications in perspective.

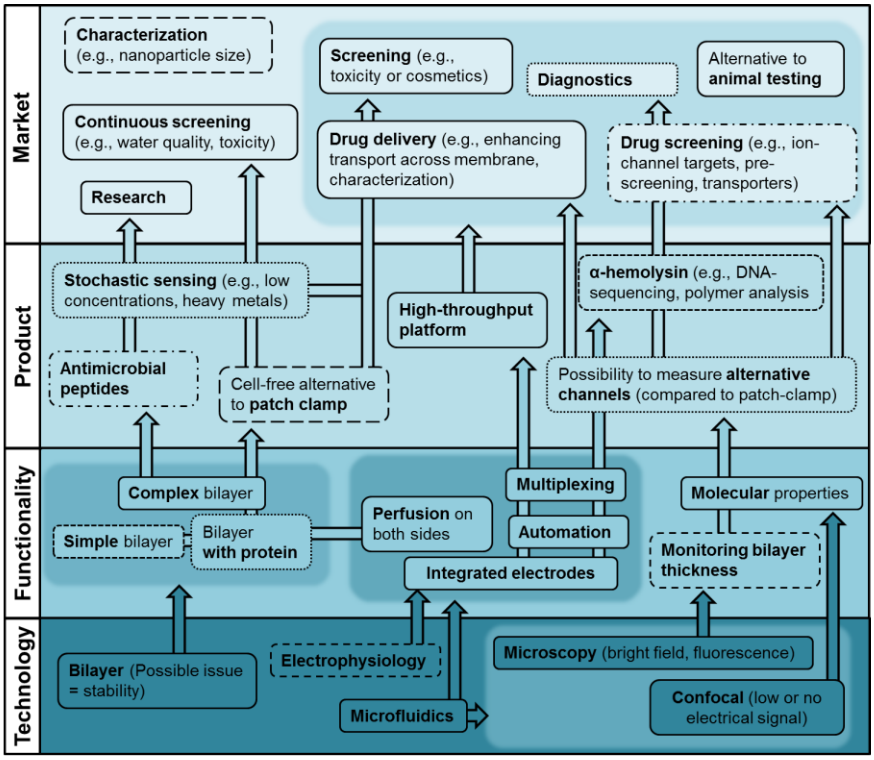


Figure 3.2. Innovation path map. The innovation path map was created during the workshop for a microfluidic lipid bilayer platform.[3]

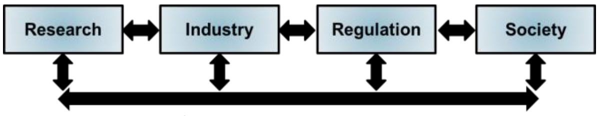


Figure 3.3. Simplified innovation chain model. The various dimensions, research, industry, regulation and society, which are connected in a linear model, can influence each other.

In order to trigger a richer discussion on societal risks and benefits of the new technology, particular innovation pathways should have been selected during the workshop which was not feasible in the given time. To still take these aspects into account, after the workshop four innovation pathways were selected from the innovation path map and analysed based on a simplified innovation chain model in terms of research, industry, regulation, and society (Figure 3.3).

In her thesis, the PhD student was considering and comparing the various aspects for applications of drug screening, screening of nanoparticle toxicity and cosmetics, and for implementation of the platform as a research tool, as shown in Table 3.1

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[3] The map is separated in four different layers of technologies, functionalities, products or markets. Each layer is filled with different boxes that are connected to each other or between the different layers. Colored backgrounds in the different layers indicate clusters of boxes and large arrows show connections to several boxes whereas small arrows connect only to one box.

below. Here for instance, differences became visible between the innovation journeys in terms of uses and demand articulation. Specifically, for drug screening the platform would be implemented in an existing value chain, whereas for nanoparticle toxicity screening and cosmetic testing a new concern or demand, either in the society or in the regulatory landscape, would lead to alternative screening platforms. Since the PhD student did not recognise direct impacts of the platform on society, general aspects of drug development were considered by the PhD student, such as the impact of unsafe drugs explained by the example of thalidomide in the late 1950s which led to new regulations on drug safety (Abbott, 2005).

General concerns and the societal perception of nanotechnology were discussed by the PhD student in her thesis in the context of errors in testing of nanoparticle toxicity. In a next step, these considerations should be discussed with knowledgeable actors in the different sectors, for example by conducting individual interviews, which was however not feasible anymore in the frame of this exercise due to time constraints. Still, the analysis of individual innovation pathways provided useful insights beyond the particular project and put the developed technology in an even broader perspective. This small analysis stimulated the reflexivity of the PhD student on current and alternative research directions and their impacts along the value chain but also helped to increase the awareness of underlying socio-technical dynamics.

Table 3.1. Innovation pathways for the microfluidic lipid bilayer platform.

	Technological considerations	**Commercial interest**	**Regulations**	**Societal embedding**
Drug screening	*BLM with proteins* Optical and/or electrophysiological	*Preclinical testing*: Improved efficiency, or reduced costs	Regulatory framework already existing	N.A.
Nanoparticle toxicity	*Variable BLM composition* Optical (confocal) and electrophysiological	*Pre-screening:* Transport of particles across membrane or membrane disruption to predict toxicity	New accreditation needed	Growing concern for nanotoxicity
Cosmetics	*BLM without proteins* Fluorescence and electrophysiological	*Pre-screening:* Membrane permeation, improved testing	Enforced in the EU	Demand for reduced or no animal testing
Research	*All variations on BLM models* High-resolution optical & electrophysiological	*Research:* Platform for universities or research entities	N.A.	N.A.

* Various application areas (drug screening, nanoparticle toxicity, cosmetic testing, and research) are analysed in different dimensions such as technological considerations, commercial interest, regulations and risk management, and societal embedding. (BLM = bilayer lipid membrane, N.A. = not available)

3.4. Reflections and suggestions

In this section, the practical implementation of the workshop is discussed and the format is compared to more comprehensive CTA workshops reported in the literature. Additionally, suggestions for improvement are provided for future activities, overall outcomes and limitations of the chosen approach are discussed, as well as ideas for further implementation.

In the example presented here, the preparation time of the workshops was minimised to facilitate its integration within the PhD activities, also taking into account the challenges of time-scarcity mentioned earlier. One of the key factors for reducing the timeframe of this activity was the organisational and methodological support of the TA facilitator. His methodological knowledge and support also helped to bridge the gap between natural and social sciences, and helped the PhD student to grasp the required main concepts of TA and to take the lead in organising this workshop. Furthermore, in the NanoNextNL program PhD students are required to integrate RATA in their thesis and therefore it is expected, by supervisors, program officers and financial supporter, to spend time and effort on such activities.

In this case, the results of the CTA-lite exercise were presented in a full chapter of the PhD thesis, and a professor of the social sciences was part of the PhD examination committee. Since the PhD student was one of the first students that finished within the NanoNextNL program, the exercise she carried out was presented to other PhD students as an example on how to implement TA. Altogether, the broader framework of the research program stimulated appreciation of this activity, rather untypical for a technical PhD, by supervisors and the NanoNextNL program office.

Following, the workshop format is compared to well-prepared CTA workshops organised by experts in this field. Often as a preparation for CTA workshops, social scientists carry out extensive literature studies and interviews to get acquainted with the topic of research and to understand issues that are at stake in this field (Huang *et al.*, 2012). These preparatory actions have been limited in the CTA-lite approach because of time constraints and since the PhD student was already familiar with the technology she was working on and with the corresponding scientific literature in the particular research field. CTA workshops are also often triggered by a social scientific research question, for instance to identify strategic moves of stakeholders in an innovation field or to anticipate opportunities and challenges of new and emerging technologies (Robinson and Propp, 2008; Parandian and Rip, 2013), which obviously requires more extensive preparation compared to a workshop that aims at exploring potential applications and innovation pathways for a specific technology.

Pre-engagement tools, such as multi-path maps or socio-technical scenarios, can help to improve the quality of the engagement by stimulating productive interactions of the workshop participants (Robinson and Propp, 2008; te Kulve and Rip, 2011). Similar effects were also observed in the workshop when making use of the innovation path map, which triggered the discussion and facilitated the exploration of application areas as well as potential bottlenecks. Generally, pre-engagement tools are based on thorough desk research and interviews with a broad variety of actors and therefore contain more in-depth information on, *e.g.*, relations between actors or problems that are at stake in this particular field. For an embedded TA exercise which is not the core activity of technical PhD students, such an extensive preparation would not be conceivable unless it would be seen as a part of the project in its own right.

Additionally, a dedicated budget in research projects for RRI activities to cover workshop costs such as location, lunch or maybe travel reimbursements for the participants, could help to increase acceptance and motivation of researchers to carry out such an activity. Finally, CTA workshops aim at bringing together a comprehensive set of stakeholders and enhancing their reflexivity (Rip and te Kulve, 2008). In the CTA-lite workshop, actors were invited from various fields which was, especially for the PhD student, a good opportunity to get in contact with different stakeholders. Thereby, she could learn from their expertise and hear about their perspectives, which therefore definitely enhanced the reflexivity of the PhD student and her supervisor. We can only guess to what extent the workshop provided new insights to the participants, since this could not be thoroughly evaluated after the workshop and within the scope of this TA exercise project. However, and in contrast to common CTA workshops, this was not the primary aim of the workshop. Altogether, clear similarities between the CTA-lite approach and a regular CTA process are visible, while both scope and effort were more modest and focused here.

For the workshop, mainly participants from the researcher’s and TA facilitator's own network were invited, but no actor from the pharmaceutical industry, a stakeholder group that was anticipated as important potential customers, was present. The participation of relevant actors, especially outside of their own network, can be an additional motivation for researchers and the other participants to use the event for networking and as a platform to start new collaborations. Here, 14 of the 19 invited participants agreed to join which shows a general interest of the participants for such activities but might also be explained by the personal relationship to the workshop organisers since reluctance of enactors to participate in CTA workshop was observed previously (Rip and Lente, 2013). Tips and tricks from experienced TA facilitators could be helpful for the invitation of stakeholders outside their own network. The background and expertise of the invited participants also usually strongly influences the outcomes of the workshop, which should be considered during preparation. Having mainly technical participants for instance will result in a more technical discussion with fewer insights into possible application areas, risk and regulation discussions or societal aspects.

In general, the workshop allowed the PhD student to become aware of the bigger picture in which her own research was situated, and of potential applications and possibilities for commercialisation. Specifically, the PhD student got insights into socio-technical relations between the developed technology, its implementation in existing systems and potential impacts of this technology on existing value chains or indirectly on societal embedding. Here, the workshop was organised in the last year of the PhD project, while an earlier integration of such activities would have been more favourable to benefit from its outcomes and feed this back into her research project. If the workshop would have taken place earlier, the PhD student might have focused on other research directions such as testing nanoparticle toxicity rather than drug screening, which turned out to be more challenging to achieve. We would suggest that the integration of such an activity could be most fruitful at the end of the first year or during the second year of a research project, in order to strike a balance between the PhD student already being somewhat familiar with the research topic and the possibility to exploit insights from this exploratory activity.

In the future, such a workshop format could for example be useful for PhD students who have to write a research proposal in the beginning of their own project to define possible research directions and to anticipate challenges and opportunities.

The same holds for senior researchers who are in the phase of setting up a new research line and in the process of writing research proposals. Here, the workshop could provide a good orientation phase to identify promising applications and to adapt the research accordingly. Some of the authors already experienced the latter while supporting a senior researcher in the organisation of a workshop to explore applications and define potential users for novel semiconductor materials. Additionally, the senior researcher wanted to use this workshop to strengthen existing collaborations and to identify actors that are potentially interesting for future collaborations. Here, an innovation path map was prepared in advance by the senior researcher and the map was complemented during the discussion. Alternatively, such a workshop format could be used by senior researchers who want to explore or continue a certain research direction. Mostly already half-way of a PhD project, the supervisor should apply for new funding to pursue a given research line, to create higher impact of the research and to ensure knowledge accumulation.

3.5. Conclusion

Through this activity, both the PhD student and the TA facilitator learned an important lesson: there is room for what we call ‘CTA-lite’. In the frame of the NanoNextNL RATA requirement, the limited format of the workshop takes into account practical considerations such as time-constraints, the gap between technical and social sciences, and the limited reward often given to non-core activities, and is therefore suitable for the implementation in daily research practices. This example shows that the characteristics of the activity but also the general research landscape are important parameters for successfully practicing RRI. Additionally, the TA facilitator played an important role to bridge the gap between technical and social sciences and to reduce the timeframe of the exercise. The CTA-lite approach is thus a good trade-off between ‘limited resources’ and ‘bringing RRI into laboratory life’. Even though it does not have the comparable depths and complexity of an elaborate CTA approach, it can bring up tensions, issues, opportunities and perspectives of the potentially unfolding pathways of a new technology from the laboratory into society. Therefore, it is also useful as a training tool.

The example of the CTA-lite workshop already inspired other PhD students within NanoNextNL to organise such an activity to identify important research questions related to the most promising innovation pathways for follow-up projects. Similarly, this workshop format has been used to support a senior researcher to explore possible applications for his new research line and to find interesting collaborators.

Here, the innovation path map was used as a tool during the workshop to stimulate discussion, but has also already been tested in educational activities as a separate tool in combination with a more detailed analysis of selected innovation pathways. It plays a similar role as a roadmap but is more open ended, similar to multi-path mapping exercises (Robinson *et al.*, 2013). Compared to technology assessment approaches with the help of actor maps or socio-technical configurations, an innovation path map can also be applied to technologies where no application is envisioned yet which is specifically interesting for more fundamental research projects.

In conclusion, following this CTA-lite exercise various other activities emerged that were initiated by researchers, which shows the relevance of practical examples to bring such activities to the labfloor. To further stimulate RRI implementation, more tools should be characterised in terms of practical considerations and demonstrated by practical examples to support technical researcher with the integration of social and ethical dimensions in their research projects. Such a toolbox would be a promising move towards the mainstreaming of RRI.

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