Intervening in emerging nanotechnologies

Nederlandse Geografische Studies / Netherlands Geographical Studies

ISSN 0169-4839

Netherlands Geographical Studies 367

Intervening in emerging nanotechnologies

A CTA of Lab-on-a-chip technology

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Utrecht 2007

Koninklijk Nederlands Aardrijkskundig Genootschap
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ISBN 978-90-6809-409-1

Graphic design, cartography and figures:
GeoMedia (Faculty of Geosciences, Utrecht University)

Printed in the Netherlands by Labor Grafimedia b.v. – Utrecht

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Preface

This PhD project is part of the NanoNed programme in the Netherlands. NanoNed consists of eight leading Dutch R&D institutes that have formed a consortium to coordinate their activities and combine their strengths in the techno-scientific area of nanotechnology. This cooperation ensures the continuation and strengthening of scientific excellence and also secures strong cooperation with industry. The goals of NanoNed are threefold: to build an infrastructure of experimental equipment (NanoLab NL), to strengthen Dutch nanotechnology research, and to disseminate economic relevant knowledge and expertise to start-ups and NanoNed's industrial partners (e.g., Philips). Technology Assessment (TA) is an integral part of the programme, studying the societal and economic aspects of nanotechnology developments. This PhD project is situated in this part of NanoNed.

A specific type of Technology Assessment (TA) is developed in this thesis. Given that the term 'TA' is used in many different environments it can be confusing. It is therefore helpful to make it quite clear at this point what is meant by TA. Here, the focus is on "*TA in the public sector specifically related to knowledge-based innovation on the one hand, and social implications on the other. This view necessarily excludes aspects of TA in the private sector, foresight, and other TA-like activities in the public sector, such as environmental impact assessment.*" (Smits *et al.*, forthcoming 2008)

1 Introduction: setting the scene

This thesis deals with technology, early-stage technology. When new science and technology emerge, societal questions regarding how to deal with the new advances and opportunities also begin to emerge. There are many possible technology options for new science and technology that can benefit society, but not all are equally feasible (in terms of technology and economics) or desirable. In addition, past examples of societal struggles around the introduction of nuclear energy and genetically modified organisms (GMOs) indicate that the embedment of new science and technology in society is not always flawless. One of the main assumptions in the work presented here is that when interaction between the different actors were to take place in a constructive and broader manner at an earlier stage of the development process of new science and technology, the eventual societal embedment can be increased. One of the reasons that such improvements are possible is that considerations other than technological ones can be taken into account at an early stage, and this can alter the decisions taken in the development of new science and technology and during innovation processes.

To facilitate interaction between various actors in the early stages, an intervention will be designed, applied, and evaluated. When designing an intervention a thorough insight is required into exactly what it is you wish to intervene in. One of the key perceptions regarding intervention in early-stage (or emerging) technologies is that the Collingridge dilemma (Collingridge, 1980) makes it difficult to intervene constructively. In other words: in the early stages, opportunities to develop and apply new science and technology seem limitless, yet no one knows which technology options will eventually become successful. While the outcomes can be estimated at a later stage changes are difficult to make due to earlier decisions and investments.

In this thesis there are two central research topics: 1) understanding the dynamics of emerging (nano)technologies and 2) constructive intervention in emerging (nano)technologies. The first chapter will elaborate on these research topics and will conclude with a brief discussion of the implications in terms of research design and the types of results that can be expected.

An outline of the remaining chapters is shown in Figure 1.1. The arrow at the top of Figure 1.1 indicates that in the wider world there are ongoing technological developments and innovation processes. In order to obtain a basic understanding of these technological developments and innovation processes Chapter 2 will focus on the present-day theoretical understanding thereof. For the first research topic Chapter 2 identifies concepts that can be used to obtain an improved understanding of the dynamics of emerging technologies. For the second research topic Chapter 2 provides basic insights for the design of interventions and discusses how the effects of an intervention on ongoing technological developments and innovation processes can be understood.

Chapter 3 develops the research design to study both research topics. Tools that can support the application of the research design are developed in Chapter 4. The empirical data, results, and findings for the first research topic are set out in Chapter 5 where the insights gained into the dynamics of emerging technologies will be discussed. Chapter 6 reports on and discusses

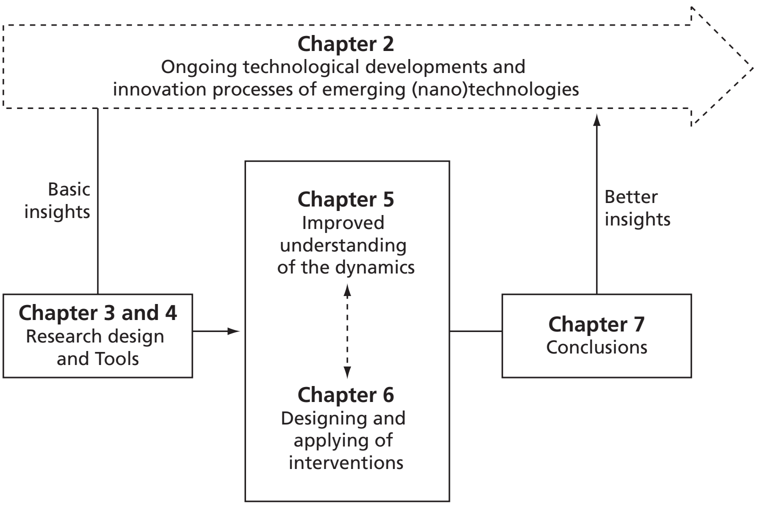


Figure 1.1 Schematic representation of how the chapters in this thesis relate

the application and evaluation of a constructive intervention that uses the so-called 3-step CTA approach. Different designs are tested in order to draw conclusions on how to design such specific interventions. Figure 1.1 also shows that there is interaction between the empirical chapters 5 and 6. However, in this thesis this interaction merely implies that there is a certain amount of overlap in data gathering. Chapter 7 contains conclusions and further discussion.

1.1 Background and relevance

This PhD project is part of the NanoNed programme, or more specifically the Technology Assessment (TA) part of NanoNed. In NanoNed, nanotechnology is the technical topic.[1] The TA part of NanoNed devotes attention to the social and economic aspects of nanotechnology developments. What can be seen is that funds for both private and public investments in nanotechnology research are increasing all around the world (Roco, 2003; RNCOS, 2006). As nanotechnology R&D progresses numerous ideas for technology options that might benefit society are articulated, yet how society will deal with these options remains – for the greater part – to be seen. Some contours are visible though; examples being public engagement activities (Nature editorial, 2007), the formation of ELSA (Ethical Legal Social Aspects) and ethics committees, and regulations to deal with the potential toxic properties of nanomaterials are underway. Another example is the inclusion of a Technology Assessment (TA) programme within NanoNed.

Looking back in time, historical cases such as the implementation of civil nuclear energy and the GMO (Genetically Modified Foods) impasse indicate that societal embedment of new science and technology cannot be taken for granted. Deuten *et al.* (1997:131) define societal embedment as: “the integration in relevant industries and markets, the admissibility with regard to regulation and standards, and the acceptance by the public." This definition emphasises that different aspects (industrial, regulatory, and the public) are part of how new science and technology are or become embedded in society. In the GMO impasse, society stood up against the developments, but lessons were also learned; societal aspects should be taken seriously and anticipated, partly in order to be able to reap the economic benefits from innovations. For GMOs the interaction with society came too late, while for nanotechnology there is still time. For some actors this interaction (simply) implies improving the communication of scientific facts to the public, while for others the actual relation between science, technology, and society is in need of improvement. This thesis builds on the latter.

This thesis is part of an intellectual stream of what can be called 'managing technology in society' (Rip *et al.*, 1995). In this stream the emphasis is on increasing the societal embedment of (new) science and technology. General knowledge is available about the dynamics of technological developments and improving societal embedment by interventions (Schot and Rip, 1997). Although for nanotechnology, or for emerging technologies more in general, there are special demands on how to set up or arrange processes – in whatever form – that potentially contribute to improving societal embedment. Most notable is the Collingridge dilemma (Collingridge, 1980) (see Section 1.0), which increases the complexity of understanding the dynamics of and intervention in emerging technologies. At the same time, however, there is a challenge to do work on these issues, which is taken up in this thesis.

The remainder of this chapter comprises four sections. Firstly, the relation between new science and technology and society will be discussed. Also, how technology and innovation is viewed in this thesis will be explained. Secondly, the first research topic is introduced by giving emphasis to the fact that emerging technologies have special dynamics. Thirdly, Section 1.5 focuses on what is understood by constructive intervention in this thesis. Lastly, a glance at the research design is presented and an indication of the types of research results that can be expected throughout this thesis will be given.

1.2 New science and technology, society, and innovation

Technology and society mutually influence each other (Bijker *et al.*, 1987). This means that the one cannot be understood without considering the other.[2] Even if the technology mainly exists in laboratories, socio-technical connections have already been formed. In the early stages of technology development, expectations and visions in particular play a major part in shaping the socio-technical connections (Brown *et al.*, 2005; Van Merkerk and Van Lente, 2005). Different parties hold different expectations and visions about what the new technology can and should look like, where it should be used, and what societal needs it can fulfil. Expectations and visions play an important role in the context in which the technology develops and turns into soft requirements for future developments. Nonetheless, the expectations and visions that help technologies to develop do not guarantee success later on.

Technology can be seen as a combination of 'what is made' (the artefact) and 'how it is made' (the knowledge) (Van Lente, 1993 based on Charles Singer). Addressing technology and its development in this way focuses on the artefact and the knowledge on how to make it, which is a rather narrow view. Broader views also exist where technology is also considered to comprise social components such as the actors that develop or introduce the technology and the expectations embedded within it (Van Lente, 1993). When studying technology developments and their dynamics it is useful to have such a broader view.

The term 'technological field' is used in this thesis to communicate that technological developments should be studied as a collection of entities, which is much more than the technology under development. Actors (who can be located in networks or communities), research results, expectations, agendas, visions, and applications are also part of the technological field. It is useful to make reference to technology options when a more micro focus is needed, or as Rip and Kemp (1998) would call it 'configurations that work'. The technology options in a micro focus are (potential) applications that make use of the novel technology. Technology options can remain wonderful demonstrations in laboratory situations or grow into widespread and diffused utilities.

Technology options can be taken up commercially and socially in a successful way, and this phenomenon is usually known as innovation. Innovations are novel products, processes, services, or 'ways to organise' that are successfully introduced. Smits (2002) emphases that innovations are not merely the product (or process, service, or 'way to organise'), but also how the product functions in its context in relation to the actors involved: innovations are (viewed from the societal and/or economic point of view) combinations of hardware (the product, process, service, or 'way to organise'), software (the function that it fulfils), and orgware (the embedment in its context).[3] Thus, for technology options to become commercially and socially successful, configurations need to be made where the *product* (in the case of product innovations) is *used* in a *context* where it has a *function*. The case of diabetes self monitoring is exemplary in this respect. The 'innovation' here is not the small measuring device that can measure the concentration of glucose in the blood, the handheld glucose meter. It is equally as much the solution that it provides for patients suffering from diabetes; i.e. providing improved care at home thanks to a better control of glucose levels as well as an improvement in the quality of life. The self monitoring of glucose levels needs a specific care system around it, patients need to be trained, and health care professionals need to interpret the measurements. The innovation is thus a (socio-technical) configuration, which has social as well as technical elements.

The innovation process consists of all activities required to build the (socio-technical) configuration. This process comprises many interactions, adaptations, and tuning between the social and the technical over time. In the case of diabetes self monitoring a new health care model had to be installed in order to give self monitoring a place. Patients and health care professionals needed to accept the new opportunities and had to be comfortable with the model. Innovation thus requires the involvement of various actors in the innovation process, to name a few: developers, regulators, users, and producers. The innovation will manifest itself when an economically feasible and socially acceptable configuration is found and established. Innovation processes are the ways in which these configurations are created.

1.3 Emerging technologies

This thesis focuses on those technological fields that are technically and socially 'in their early stages'. This is the case for nanotechnology because it still circulates mostly in the academic world and very few visible products are in use. Arguably, emerging technologies have specific characteristics in comparison with later stage technologies. Firstly, the early phases of technology developments show a *great deal of fluidity and open ends,* whereas later stages are much clearer. This means that clear-cut directions of where the technology will end are non-existent and that there are still a large number of possibilities of what to do with the technology. These possibilities can be overwhelming for developers, but include many promising directions in which to develop the technology. At the same time, the decisions taken (however insignificant they may seem) can lead to significant future rigidities (in terms of technologies, applications, and stakeholders).

Secondly, actors operating in emerging technologies are subject to *high uncertainty about outcomes (innovations), yields, and strategies to be taken*. In the emerging field, 'best practices' are not available and whether investments will pay off is uncertain. This also means that there are large differences in how actors assess the possible and likely outcomes and yields, and which strategies they find suitable.

Thirdly, *expectations and visions* play an important role in how actors shape their actions and interactions. Decisions about research directions and investments are made on the basis of anticipated outcomes and yields, which is understandable because expectations and visions are the main available source of information (Brown *et al.*, 2005). Expectations can be inflated, which can make technology options 'hopeful monstrosities' (Geels and Kemp, 2000 based on Mokyr, 1990). Hopeful, as the promises accompanying the technology option are high, but also a monstrosity since the eventual functionality and realisation are still highly uncertain. Looking outside the laboratory, there is only a limited number of hard facts and successful innovations.

Despite this (seemingly) chaotic situation of emerging technologies, the analyst can find patterns and gain insights into the development and evolution of emerging technologies. Insightful is that, over time and under a variety of different influences, some technology options become less visible and probable, while others gain more support and strength (Callon, 1995). During the early stages, new science and technology generate considerable interest and activities from scientists, businesses, policy makers, and the investment community. The result is that (although not necessarily) technological paths emerge, or better, since technological developments are socio-technical by nature, socio-technical paths. In the early stages socio-technical paths can be born which (in short) are called emerging paths. Out of seemingly unorganised activities patterns will emerge out of which a path can initiate and grow. Finding these patterns provides a better understanding of the emerging phase. In this search, *expectations and visions* are a prime source of information (Van Lente, 1993).

A deeper understanding of the dynamics that contribute to the emergence and early stabilisation of technological fields is called for (Callon, 1995). Further advances in the theoretical understanding of emerging technologies and methods for analysing emerging technological fields are needed. Thus, from a technology dynamics and innovation studies perspective there is theoretical understanding to be gained from studying emerging technologies. This involves the first research topic as taken up in this thesis, which is organised around the following question.

RQ 1: How to understand the dynamics of emerging technologies?

1.4 Constructive intervention

One horn of Collingridge's dilemma (1980) is that it is hard to foresee the social impacts of technology in the early stages of development. At the same time, changes in the course of the developments can still be made relatively easily. At later stages, in contrast, the impacts are less uncertain, but the possibility to 'steer' or 'control' developments has decreased proportionally. In attempting to control the eventual outcomes and to avoid negative social impacts Collingridge suggests to keep ongoing developments flexible, so that the course of development can be altered and other directions can be explored. This, however, is a troublesome solution: with ongoing entrenchment the mere possibility of persistent flexibility is unlikely, too.

Are there any other routes that can be taken to circumvent the Collingridge dilemma and to aim at improved societal embedment? It has been argued that, when decisions about new science and technology can be made more socially robust in an early stage, the eventual outcomes can be more socially robust as well (Van Boxsel, 1994; Rip *et al.*, 1995). The idea is that the eventual societal embedment of (new) technologies depends on how innovation processes take place. Through innovation processes, innovations form and stabilize, and, in principle, many actors and aspects are placed together in successful configurations (see Section 1.2). Thus, when technological developments and innovation processes are broad and encompassing, already at the early stages, better outcomes can be expected. However, there are some clear examples that this, as a rule, does not happen.

- Neither society as a whole nor individual societal parties were involved in the GMO impasse and the implementation of civil nuclear energy. Society did, however, object to these developments at a later date.
- Research programmes funded or directed by STW (a Dutch governmental technology foundation) include user committees to bridge the gap – to some extent – between the academic and the corporate world. Whereas these user committees consist of scientists and companies the potential end-users are not asked about their opinions.
- Scientists and businesses often use argumentation such as: "If the product is good, it will sell itself". Whether this is true or not, such argumentation rules out the need to consult stakeholders outside the own organisation.

These examples show that dealing with new science and technology in society is not easy, can be unsuccessful, or is done too late. The fact that NanoNed took up this challenge for nanotechnology and included a Technology Assessment component in the programme indicates that there are changes to be seen in the way these societal questions are addressed at an early stage.[4]

The quality of innovation processes is seen here as related to societal embedment and can be specified as 1) broadening the actors' perspectives and 2) enriching the understanding of the dynamics of innovation processes. Broadening implies that the actors involved obtain a more complete overview of (all) the actors and aspects involved in innovation processes, for example, how end-users see or can use potential applications. Imagine, for example, how different the societal acceptance and societal and economic benefits of GMOs could have been had the developers consulted society more actively at an earlier stage. Enriching means that the actors involved will better understand innovation processes and its dynamics. Examples are that actors better understand the role played by the financial parties in supporting companies, or how scientific developments can be related to business needs.

Stimulating broadening and enriching can be done in many different ways. Smits and Den Hertog (2007), for instance, discuss the value of including end-users in innovation processes. They give five reasons for doing so: more effective articulation of social needs, increased competitive strength of private enterprises, a higher level of acceptance and better social embedment of knowledge and technology, an improved learning capacity of society as a whole and enhanced democracy. Von Hippel (1976) argues that although in special situations the end-users can be important sources for innovations, they are, of course, only one of the potential actors to involve in innovation processes at an early stage. Others are venture capitalists, businesses (both small and large) and governmental agencies. The main point here is that the different actors all have their own relevant insights for widening the considerations and to broaden the decision-making in innovation processes. No single actor in a new technological field possesses a complete overview. An external actor can add useful insights for and establish valuable interaction between the different actors. In addition, when various parties are involved in technological development, the creative potential of these parties can already be utilised in the early development stages (Smits *et al.*, 1995). Intervening in technological developments and innovation processes by bringing various actors together is therefore a sensible and feasible way to stimulate broadening and enriching.

Both broadening and enriching will benefit from interaction between different actors. In interaction, actors can, among other things, exchange views and opinions, explore potential uses of the new technology, or inquire about the state of the art. Thus, facilitating interaction between different actors can potentially broaden perspectives and enrich the understanding of the dynamics of innovation processes. When actors gain a more complete overview of the emerging technological field, including the feasibility and potential of different technology options, they are enabled to make well-considered decisions in their work.

To sum up the argument so far, this thesis concentrates on interventions that improve innovation processes by broadening and enriching them at an early stage of technological development. In doing so, it explores an alternative attempt to circumvent the Collingridge dilemma. Intervention, of course, is a broad concept that comprises different types of action and events, such as policy instruments, funding, and events where actors meet. Interventions also differ a great deal in terms of temporality. Here, intervention is used to bring different actors together for a relatively short period of time, which can be considered as a 'soft' type of intervention – soft, compared with, for example, enforcing policy instruments from the government. Soft intervention in the emerging stage can potentially have significant effects (Rip *et al.*, 1995:5), while intervention at later stages might be less feasible since many choices have already been made, significant entrenchment has set in, and certain directions have been taken while others were blocked. The fluidity of emerging stages implies that relatively easy changes can be made in the direction of technological developments and innovation processes.

A soft intervention that stimulates broadening and enriching can be supportive and productive for the actors involved, which means that actors are be enabled to better play their role in innovation processes (Smits and Leyten, 1991).[5] With constructive intervention various actors are facilitated to deliberate about technology options, their feasibility, and related aspects, but also about the role of different actors in realising the potential of the technology under discussion. In this way, organised joint deliberation about the construction of technology is facilitated, i.e. constructive intervention.

The idea of intervention via actors-in-interaction raises the question: what exactly should count as 'actors'? In this thesis actors are seen as recognisable entities that act and interact to achieve their goals. Depending on the situation, this may be an individual, a small enterprise with one employee, or at a higher aggregated level, the government. Of importance here is that an actor represents himself as an acting and interacting entity, or is recognised as such by others.

To conclude, stimulating broadening and enriching by means of constructive intervention potentially improves the quality of innovation processes. This is the basic challenge of this thesis, which might provide an alternative route to deal with the Collingridge dilemma. The second research topic of this thesis, then, is organised around the following question.

RQ 2: How to design constructive intervention in order to improve the quality of innovation processes in emerging technologies?

1.5 A glance at research design and types of results

For the first research topic a broad exploration of an emerging technology in order to obtain understanding about the dynamics of emerging technologies is needed. Case studies make it possible to give a rich description of an emerging technology. A case study approach is very flexible and it is this flexible character that allows study into somewhat unexplored complex systems such as emerging technologies. Case studies are particularly suitable for 'how' and 'why' questions, where there is no control of behavioural events and the focus is on contemporary events (Yin, 1994; Van der Poel, 1998). By using multiple theoretical concepts to study a single case (methodological triangulation) a broad exploration of the case can be performed (Yin, 1994).

A wide variety of entities, such as actors, expectations, visions and artefacts, over time, make up the dynamics of emerging technologies. These entities influence each other in complex ways. Therefore, while studying different parts of these complex dynamics, (mapping) tools can be helpful, for instance to organise data collection or to support the analysis. A few tools will be developed that support the application of the research design.

For the second research topic the question how to design constructive intervention in emerging technologies is brought to the fore. As will become apparent in the next chapter, a specific Constructive Technology Assessment (CTA) approach will be developed and applied to look at this question. This approach should be able to stimulate broadening and enriching in order to improve the quality of innovation processes and in doing so explores an alternative route to deal with the Collingridge dilemma. Scenarios in general capture the future and make it possible to discuss the future in a more structured manner (Geels, 2002b). Section 1.2 mentioned that technological developments are socio-technical by nature. This thesis will explore how socio-technical scenarios can be used for constructive intervention. This exploration is shaped by designing different intervention set-ups and by evaluating differences in productivity related to these changes in design. In doing so, a research approach is taken that varies the actual set-up rather than the cases to which the intervention is applied.

There is another issue to deal with in the design of constructive intervention that will be taken into account as a variation in the design of the intervention. For whom should the intervention be made available? Will there be observable differences in productivity when the intervention includes different actor compositions? While section 1.2 highlighted that various actors are involved in innovation processes, will constructive intervention for a broad set of actors be more productive than for a narrower set of actors? To answer this question the actor composition will be varied as well. Together with the variation in the 'use of scenarios', four different designs of the CTA approach will be applied. Evaluation of these four designs can provide insights into 'how to design' constructive intervention for emerging technologies. Insights into the feasibility of the approach to stimulate broadening and enriching in the normal working environment of actors, is where the added-value of the second research topic is sought.

The same case (Lab-on-a-chip technology) is used for both research topics. This is an efficient approach in performing the research since some parts of the research allow for data sharing. Furthermore, a general understanding of the case and what might be at stake supports the application of the intervention.

There are three types of results that can be expected from this thesis. Firstly, research on the first topic can provide better insights into the dynamics of emerging technologies. Results on the feasibility and insightfulness of the concepts used to study parts of the dynamics can also be expected. These kinds of results will be presented in Chapter 5. Secondly, in Chapter 4 tools will be developed that can be supportive to the research performed in thesis. Development of these tools and reflection on their usefulness are results. Thirdly, directly related to the intervention as set out in Chapter 6, results will be discussed on how to design constructive intervention in emerging technologies. This can be on the overall as well as relative effects of the intervention.

1.6 Summary

This first chapter started with an outline for this thesis, setting out how the different chapters relate to each other and describing the two research topics: 1) understanding the dynamics of emerging (nano)technologies, and 2) constructive intervention for emerging (nano)technologies.

Then, the background and relevance of this thesis was explained in greater detail. Societal embedment of new science and technology is an issue. 'Managing technology in society' attempts to make a contribution to approaches that can improve societal embedment. For emerging technologies however, the Collingridge dilemma complicates such approaches.

Section 1.2 provided insight into how in this thesis the interaction of new science and technology, society, and innovation is viewed. A distinction was made between technology, technology options, and technological fields. Also the difference between innovation and innovation processes was explained. Innovations are those technology options that are commercially and socially taken up in a successful way.

Section 1.3 elaborated on the first research topic in this thesis: understanding the dynamics of emerging (nano)technologies. The distinctive characteristics of emerging technologies were indicated. Emerging technologies show a great deal of fluidity and open ends. Actors are faced with a high level of uncertainty about the outcomes (innovations), yields, and strategies to be taken. In their actions and interactions, actors operating in emerging technological fields are mainly guided by expectations and visions. The section concluded with the following research question directed at this research topic:

RQ 1: How to understand the dynamics of emerging technologies?

Section 1.4 elaborated on the second research topic: constructive intervention for emerging (nano)technologies. In doing so, it provided argumentation that constructive intervention focusing on stimulating broadening and enriching to improve the quality of innovation processes might be a feasible approach to circumvent the Collingridge dilemma. A further rationale behind improving the quality of innovation processes is that it potentially increases the societal embedment of new science and technology. The research question for this research topic is:

RQ 2: How to design constructive intervention in order to improve the quality of innovation processes in emerging technologies?

Section 1.5 indicated that a single case study is used in the research design. Multiple theoretical concepts will be used to study the case in the first research topic. For the second research topic, multiple intervention designs will be tested and evaluated. Socio-technical scenarios were offered to support constructive intervention.

To close, there are three types of results that can be expected from this thesis: 1) better insight into and conceptualisation of the dynamics of emerging technologies, 2) tools that are useful in studying emerging technologies, and 3) insight into the effects of constructive intervention in emerging technologies and methodological lessons on designing such interventions.

Notes

1 A variety of terms is used to characterise nanotechnology, among which enabling and generic technology are used as umbrella terms. All of these terms highlight that on the technical level it is difficult to speak of nanotechnology as a whole and that it can also be seen as technologies for different application areas such as 'nano in electronics', 'nano in materials', or 'nano in drug delivery'.

2 Some even go as far as stating that technology and society are inseparable. A seamless web (Hughes, 1986) so to say, which leaves behind the idea that developments can be described by using discrete entities such as "technology and science, content and context, and foreground and background" (page 291), and therefore also science and society.

3 Orgware can also be called socioware.

4 There are also other reasons for the TA component in NanoNed, such as the national interest in increasing the sharing of knowledge between different actors in order to stimulate innovation to reap economic and social benefits from emerging technological fields. The TA component was highly valued by the programme evaluators.

5 The main type of interventions is made by actors in the field when they look for places with direct and productive interaction. Examples are workshops about new and promising technologies, and governments that push for scientists to collaborate with industrial partners.

2 Theory and Conceptualisation

This chapter provides theoretical building blocks for studying and understanding emerging technological fields, and for designing and evaluating constructive intervention in such fields. The chapter starts with general views on technological development and innovation processes. Then theories from science and technology studies (STS) and innovation studies literature are discussed. Together, these theories make up a theoretical framework. Next, the text will concentrate on three particular elements of the dynamics of emerging technologies. For each of these elements, a concept is derived that provides theoretical support to investigate the elements. Relevant literature on these core concepts will be discussed.

Section 2.4 will introduce Technology Assessment (TA) as a form of Strategic Intelligence (SI). Further, it will be argued that the intervention developed in this thesis can best be build upon a particular type of TA, namely Constructive TA. Then, further insights will be provided into how constructive interventions in general can lead to broadening and enriching of thinking, actions, and interactions of actors in their normal working environment. The chapter ends with formulating research questions for both research topics.

2.1 Views on technological development and innovation processes

In 'intervening in emerging technologies' there is a challenge to deal with the Collingridge dilemma. Stimulating broadening and enriching through constructive intervention was suggested in Section 1.4 as a feasible route in taking up this challenge. However, there are further complexities that make it difficult to intervene in and obtain understanding about emerging technologies. These complexities arise from the dynamics of technological developments and innovation. Different kinds of scholars for decennia have been interested in understanding these complexities as well. Dynamics of technological development and innovation have been studied from economic, historical, policy, and sociological angles. It would go too far to provide a complete overview of these different viewpoints, but what is useful at this point is to see what general observations can be found that overlap in the different viewpoints. This is presented below as a condensed summary of views on technological development and innovation processes, which are further specified for emerging technologies.

Technological developments and innovation processes are complex in the sense that many different actors such as businesses, governmental agencies, and financial institutions, contribute to innovation processes. Innovation processes therefore have multi-actor dynamics. Also, different actors operate at different levels of aggregation. For example, scientists work in laboratories, while governmental actors make policies for society at large. This makes that innovation processes have multi-level dynamics. Further, these different levels mutually influence each other. Actors can also be active at more than one level. For example, a scientist is active in his own research group, but can also be active as a spokesperson, which is recognisable in larger parts of society. So, innovation processes have multi-actor and multi-level dynamics (Smits *et al.*, forthcoming 2008), which make these processes complex, and especially in emerging technologies, unpredictable and uncertain endeavours.

At the same time, particular directions in which the technology is developing start to emerge. For emerging technologies, these directions are still nascent and far from concrete. Such emerging (socio-technical) paths are the result of increasing interest and effort, and many interactions between different actors (and often a flavour of serendipity) (David, 1985; Arthur, 1989). Also, over time, some technology options do manage to find their way into innovations (taken up socially and economic in a successful way), while others do not. So, entrenchment has already begun as certain choices, efforts, and investment have been made, which to some extent structures emerging technological fields.

Furthermore, actors operating in emerging technological fields are influenced by various enabling and constraining effects that guide and shape technology developments. Actors act and interact in environments full of patterns, such as how to do research, rules and policies to adhere to or benefit from, and expectations to comply with. Previous actions and interactions between different actors formed these patterns. Emerging technologies start to exist in such worlds. Through (inter)action of the actors operating in the emerging technological field, new and specific patterns develop. These patterns enable and constrain actors in undertaking further actions and interactions. For example, a new journal dealing with the topic of the emerging technological field can give the actors more identity and recognition towards others. Or, the first innovation that makes use of the new technological possibilities draws the interest from previously uninvolved actors. Or, new visions arise or a new impulse is given to existing visions, which gives the technological developments more focus and direction.

For innovations to occur, many interactions between the technical and the social domain are needed. Interactions between the social and the technical domain also get shape in interactions between actors. Exemplary in this respect are expressions from NGOs when they accuse scientists that the technologies they develop are socially unacceptable. Such interactions are visible in nanotechnology as well (ETC Group, 2003). So, interactions between (different) actors are key in understanding innovation processes. For emerging technologies, interactions between different actors have not yet stabilised and are still rather *ad hoc*.

These observations on technological development and innovation processes in general, and emerging technologies in particular, can be summarised as follows:

- Innovation processes have multi-actor multi-level dynamics.
- Due to the existence of enabling and constraining effects actors are not completely free in their actions and interactions.
- For innovations to occur, mutual interaction between the societal and the technical domain is necessary.

In this thesis a particular view is taken on technological development and innovation processes. Interactions between actors and technology and how these interactions shape ongoing developments is seen as important; at least more important than, for example, prices, outputs, and income distributions as is the case in neo-classical economics. It is a (social) constructivist view that matches this prioritisation of the perspective on actors. In the (social) constructivist viewpoint, actors are put central. Together, actors construct the world they live in.

So, in answering the research questions (Section 1.3 and 1.4), the constructivist viewpoint is prioritised over others. To deepen the basic understanding of the dynamics of emerging technologies, theories that deal with technological development from the constructivist viewpoint should be taken up in further conceptualisation. However, as became apparent in the first chapter, this thesis is also interested in how technology options are commercially and socially exploited into innovations. Innovation studies literature is therefore relevant in conceptualising the dynamics of emerging technologies as well.

2.2 STS and Innovation Studies literature

In Science and Technology Studies (STS) and Innovation Studies literature, dedicated studies on the constructivist viewpoint in relation with technological change are made. In these studies there is not necessarily explicit interest in the early stages of technological development, as in this thesis, but it is also not absent. Three STS theories and the body of innovation studies literature are discussed below that together provide the theoretical building blocks for this thesis.

The first STS theory to discuss is *quasi-evolutionary theory*. This theory builds upon evolutionary economics. Evolutionary economics takes variation and selection (like in evolutionary biology) as a central mechanism for explaining technological development. Technology is further considered to be endogenous (rather than exogenous) in economic growth processes. The theory stresses the importance of paradigms, which consist of a dominant cluster of search processes that guide variation and selection (Nelson and Winter, 1982; Dosi *et al.*, 1988). Over time, as a resultant of variation and selection processes, paradigms lead to trajectories or paths. Quasi-evolutionary theory goes a step further by highlighting that the variation and selection environments are coupled (Van den Belt and Rip, 1987). One of the possible coupling mechanisms takes the shape of a niche (a protected space): "to expose novel variations to the selection environment, but protect such variations from a too rapid and rigid selection." (Raven, 2005:28) There is anticipation in the coupling of the variation and selection processes. Variation is not blind because it is guided by search heuristics, which are basic rules used by scientists that promise success, but do not guarantee it (Van Lente, 1993). Van Lente further elaborates on the role of expectation dynamics and agenda building processes in these anticipation processes. Expectations and visions are used by actors when they interact and (re-)shape their agendas.

Second, *social construction of technology* or *SCOT* (Bijker *et. al.*, 1987) emphasises the mutual interdependence between technology and society by focusing on the role of relevant social groups in technological development. The different attributions of meaning by the relevant social groups to a technology will produce different descriptions of the same artefact (Bijker, 2001). These differences show the interpretive flexibility of artefacts. Over time, these differences can disappear and closure can be reached. Closure leads to stabilisation around a certain meaning of technology and a corresponding prototype. SCOT is sometimes seen as a limited view due to the lack of attention to wider political and economic configurations. In line with this, Barker *et. al.* (2001) suggest that *societal* construction of technology might be a better approach.

Third, *actor network theory* or *ANT* (Callon *et. al.*, 1992; Callon, 1991; Latour, 1987) assumes that technological development is taking place in networks of heterogeneous elements or actors, which include also material (non-human) objects. When actor-networks evolve by mobilization, enrolment, and translation of (new) elements, a trajectory can unfold and irreversibility is introduced (Callon, 1995). Further, Van Lente (1993:22) mentions: "Actor-network theory is actually a general social science approach, but often applied to technology." In line with actor-network theory, Callon *et al.* (1992) define techno-economic networks to study the relationship between the dynamics of research and of economics. A techno-economic network distinguishes different poles, that is, a scientific, a technical, and a market pole. Intermediaries (texts, technical artefacts, but also skills and money) provide linkages between the poles. Van Est (1999), in his dissertation, splits the market pole into a 'business' and 'consumption' pole and adds a 'political' pole. In doing so, he renames the techno-economic network (with three poles) into an innovation network with five poles, which is better capable of dealing with the broad and diverse set of activities in innovation processes. A network of linkages around a certain technology represents the current state of the technological development (or techno-economic/innovation network).

Innovation studies literature is not always clearly distinct from STS literature, as these scholarly communities are often interested in similar phenomena. Innovation studies literature shows that innovations built on existing patterns in industry, businesses, and society. Innovations destroy and rebuilt or shift existing patterns (Schumpeter, 1942). These patterns can have a very diverse nature and take different shapes and forms. For example, in (and between) businesses, core capabilities enable innovation and give companies a competitive advantage, but on the other hand turn to core rigidities when they become less valuable over time (Leonard-Barton, 1992). The point is that the core capabilities enable as well as constrain innovation processes. Abernathy and Clark (1985) analysed the US auto industry (mainly in the first half of the 20th century) and found that existing patterns sometimes need to be shifted and rebuilt as a result of outside pressures. New technology options is one of such pressures. Thus, innovation is subject to some degree of 'creative destruction' (Schumpeter, 1942), meaning that particular structures are broken down and rebuilt.

Innovation studies have also an interest in stabilisation of technological developments. When technological developments become more stable, dominant designs can emerge (Utterback, 1994; Tushman and Anderson, 1986) or lock-in can occur (Arthur, 1989; Unruh, 2000). Especially lock-in is often seen as an unfavourable outcome or problem that needs to be overcome (Unruh, 2002), because other technology options could have been more favourable or could have lead to more societal embedded outcomes.

Rip and Schot (2002) take the concept of the innovation journey from Van de Ven *et al.* (1999) to understand and map the technology dynamics and its complexities. They operationalize the activities at different poles from Callon *et al.* (1992) to indicate feedback and feed-forward mechanisms. The existence of feedback and feed-forward mechanisms shows that innovation processes are far more complex compared to a linear model in which scientific findings are given to industry and end up in society just like runners in a relay race pass the baton (Godin, 2006). Rip and Schot (2002) further highlight that along the innovation journey certain patterns emerge through linkages, alignment, and networks between actors.

The observation that innovations built upon existing patterns is relevant as emerging technologies do not come into existence out of nothing. New patterns that are formed in emerging technological fields are of particular interest to the first stabilisations in emerging technologies. These first stabilisations have enabling and constraining effects that affect actors active in emerging technological fields and therefore potentially steer technological developments into certain directions. For emerging technologies, a further conceptualisation of these new patterns can lead to a better understanding of the dynamics of emerging technologies. For the early stages, feed-forward mechanisms are mainly articulated in expectations and visions that through anticipation are turned into tentative agendas (Rip and Schot, 2002; Van Lente, 1993).

2.3 Three core concepts for emerging technologies: emerging irreversibilities, positioning, and spaces

From a constructivist point of view, the dynamics of emerging technologies should be understood mainly as actors that mutually interact and interact with technology. Important is that these interactions shape the ongoing developments. Through interaction, actors attempt to achieve their goals. In studying emerging technologies from a constructivist angle, this thesis focuses on three elements of the dynamics of emerging technologies. These elements build upon the STS theories and innovation studies literature described above. Below, for each of these elements a theoretical concept is identified and links with STS theories and innovation studies literature are made.

Firstly, over time, the previously open-ended future where many technology options are still possible, slowly becomes fixed. In other words, entrenchment sets in. This does not happen over night, although gradual changes at early stages can have significant influences later on. ANT in this respect emphasises that the margins of choice for various heterogeneous actors are high, but slowly decreasing (Callon, 1995). Over time, socio-technical networks can converge when agreement on the network increases, i.e. when it becomes more clear which actors and techniques are part of the network and which technology options prevail over others. This process, where irreversibility is introduced, also occurs at the early stages of technology development. SCOT provides stabilisation of meaning by multiple actors (closure) as a mechanism by which entrenchment sets in. Innovation scholars talk about dominant design and lock-in, which can be considered as the end states of stabilisation. In businesses, core capabilities can turn into core rigidities. Quasi-evolutionary theory emphasises that search processes can becomes stabilised, which results in techno-economic paradigms that guide innovations. Especially in early-stage developments expectations play a major role in shaping the search processes. David (1985) and Arthur (1989) offer the concept of path to capture that technologies develop in certain directions and not in others.

In emerging technologies such paths are not yet visible, but they are emerging. What can be made visible are the first orderings that later might lead to path emergence. Examples are: orderings in how actors interact in networks, look for solutions to recurring problems, or the financial support is organised. These orderings, or patterns, influence the actors operating in emerging technologies. Some options become more and other become less prominent. The concept of *emerging irreversibilities* specifically addresses these first influential patterns in technological development. How irreversibilities emerge and what types of patterns are influential needs to be better understood.

Secondly, different actors relate to each other and to technology in different ways, which influences the interactions between actors. The effects of these interactions partly shape the directions in which technologies develop. It is not the effect of interaction that is of interest here, but more how actors and technology relate to each other and how this influences interactions in the first place. SCOT highlights that different actors interpret technologies differently, but doesn't say much about how actors relate to each other directly, unless the relation is made via the technology. Quasi-evolutionary theory also describes relations via the technology.

Understanding how actors interact and how they see themselves in relation to others is also a subject in psychology theories. Harré and Van Langenhove (1999) emphasise that the *positioning* of actors is important to understand the interactions between them. A position is the role that an actor can take in a certain situation or conversation. In technological developments scientists fulfil different roles than end-users. For emerging technologies it can be argued that, how actors relate to each other and which roles they have or can take is often undetermined and uncertain. Interactions are therefore partly based on existing interaction patterns, but also on the roles that actors expect each other to take on. Whether such expectations about the roles of others and the role that an actor has in mind for himself are in line with each other likely influences interaction as well. Gaining insight into such dynamics can increase the understanding of how actors relate to each other and how this influences interactions. By means of positionings (expressions of position) such dynamics can be studied.

Thirdly, interactions between actors do not just happen, they are usually organised. Interaction can be organised at specific places where actors meet, but can also take place through other media (e.g., through scientific literature). There are many different ways in which interactions can become organised. Quasi-evolutionary theory mentions that interaction can happen in niches or protected spaces, which is a specific way to organise and secure interactions for a certain period around a certain technology. To capture the ways in which interactions become organised more generally, Rip and Joly (2004) introduce the concept of *spaces*. They also mention that: "it (space, ed.) is an analytical concept that should be articulated as such, but also refers to a phenomenon of interest." In this thesis the concept of space is mainly used for the latter purpose. It is used to address that interactions are organised and that there are different ways in which this can occur. Furthermore, the focus will be on what happens within spaces, not what happens between and across spaces.

So, in understanding the dynamics of emerging technologies, this thesis further concentrates on three elements thereof, namely 1) how over time early entrenchment sets in, 2) how actors relate to each other and how this influences interactions, and 3) how interaction between actors is organised. For each of these elements a theoretical concept was identified.

To summarise the relations between the elements and the concepts, emerging irreversibilities are the first signs of entrenchment that occur in the dynamics of emerging technologies, which influences actors in their actions and interactions. In interaction, actors use positioning to emphasis how they relate to each other. Studying positionings can be used to understand how actors relate to each other and how this might affect interactions. Interactions do not simply occur, they are organised. There are many different ways in which interactions can be organised. The concept of space takes the organisation of interaction as a point of departure and can therefore be used in a general manner to describe organised interaction.

A better conceptual understanding of these three elements is necessary to obtain further understanding thereof and to improve insight into the dynamics of emerging technologies. In the remainder of this section, the concepts are further defined and literature that is related to the three concepts is discussed.

2.3.1 Emerging irreversibilities

Even in emerging technological fields, when technology developments are open-ended and fluid, not all actions and interactions are equally easy. A key notion is that emerging irreversibilities denote a decrease of fluidity and openness, and by this enable and constrain the future activities of actors. Such a decrease can be seen as an ordering or pattern; in how actors interact, arrange themselves in networks, search for solutions, take decisions, and the institutions they create. Patterns can also be found in the organisation of financial support, expectations and visions that become shared among various actors, and solutions to certain problems that become standard. Emerging irreversibility results in a certain degree of black boxing. Given that certain decisions, interaction, or solutions become standard, no explanation or justification is needed anymore. Or, when there is convergence in using a particular technique for a particular problem, why try something else? Here, pattern is used as an open concept and there is a large variety in patterns that can be seen as emerging irreversibility. A working definition of emerging irreversibilities can be given as follows:

> *Emerging irreversibilities are patterns that enable certain actions and interactions (make it easier) and constrain others (make it more difficult to do something else).*

Emerging irreversibilities provide a certain degree of structuration that enable and constrain in the sense that actors encounter more or less resistance or support for the different options that they try to explore and develop. Over time, some options become less visible and probable, while others gain more support and strength. In this, emerging irreversibilities exceed a certain pressure on actors that guides them in particular directions (and not others). When actors try to act against irreversibilities, this requires effort. The converse is true when actors attempt to achieve things in line with irreversibilities. Actors can then rely on a certain amount of predictability and support, and therefore improve the success of their strategies. For example, when many different actors agree that promising applications of Lab-on-a-chip technologies are Point-of-care applications (diagnostics at the location where care is provided), it is easy to link up with this trend and apply for finance. Other potential applications might have less recognition of the promise behind them, which makes it more difficult to become successful.

The term irreversibility gives the impression that there is no way back once irreversibility has set in. On this issue, Callon (1991:150), as he discusses the irreversibility of translations, notes that: “It is also a matter that is never finally resolved: all translations, however apparently secure, are in principle reversible.” Further, potentially all social activity is irreversible (Arendt, 1958), but that is not what is meant here. Emerging irreversibilities have a certain strength that represents the effects on actors. When emerging irreversibilities first emerge they still have to gather more strength in order to become more influential.

Furthermore, emerging irreversibilities can be weak or strong, but can also be perceived as weak or strong. A perception of irreversibility (“we cannot achieve this due to …”) could be proved false when an actor has the intention to test the irreversibility, i.e. tries interactions or actions that go against it. These actions can strengthen (confirm) or weaken the irreversibility

Table 2.1 Cases of possible emerging irreversibilities

A growing attention into a certain research topic
Research results becoming a standard solution
Increasing societal discourse that links up with technological advances
Growth in available financial support (in research or businesses)
Broad recognition of a specific set of promising applications
Guiding effect of collective roadmaps

depending on the outcome of the attempt of the actor. The greater the degree of irreversibility, the more difficult it becomes for actors to go against it.

The definition provided above emphasises the enabling and constraining effect that emerging irreversibilities have. This main characteristic of emerging irreversibilities helps to recognise possible emerging irreversibilities. Table 2.1 provides cases of possible emerging irreversibilities.

Before continuing, two of these cases (also discussed in Van Merkerk and Van Lente (2005)) are elaborated. These cases illustrate the enabling and constraining effect that emerging irreversibilities can have on actors. The first case of an emerging irreversibility is 'the growing attention into a certain research subject'. In nanotechnology, the use of nanotubes is exemplary for this kind of emerging irreversibility.[1] Figure 2.1 shows the growing attention in journals for a certain topic and indicates that the term 'nanotubes' was increasingly used in the titles of scientific articles (extracted from the PiCarta database). This growing trend in research on nanotubes illustrates that researchers find it important to explore this new area of research.

In 1999 a new specialised journal, the *Journal of Nanoparticle Research*, was launched.[2] This indicates that there is now enough research going on to compose a journal. This new outlet for publications on a new topic and the early definition of a new audience, indicate a next step in an emerging structure. The new journal makes it easier for (especially) scientists in the field to link

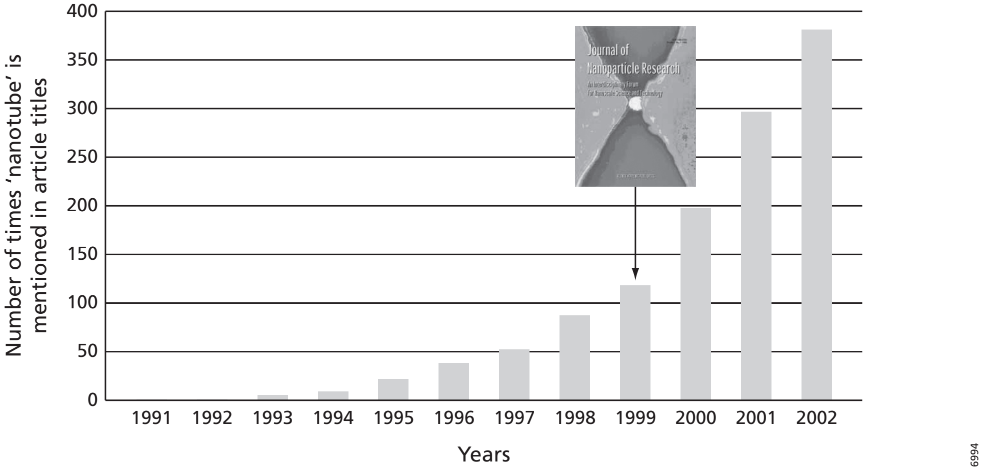


Figure 2.1 Growth of attention in for a particular topic. Data drawn from the PiCarta database

up with the trend of doing research on nanotubes, since they now have a platform to publish their work. While this step is in principle reversible, the more successful and accepted the journal becomes, the harder it will be to undo in practice. The reason for this is that, it has changed the perception and routines of researchers and has shaped expectations of a new audience.

A second case of an emerging irreversibility is 'the guiding (or steering) effect of collective industrial roadmaps'. Industrial roadmaps can be seen as articulated expectations about the direction in which a collective of companies or an industry (as in the case of chip manufacturing) develops for a certain period (say, 10 years). The fact that these roadmaps are made is an indication that actors involved in this process try to achieve shared goals. The development direction – as is written down in the roadmap – is the expression of the shared expectation that the direction is right. The roadmap, thus, functions as a device to keep the actors together and provide them with a certain amount of predictability on which they can base their own strategies. To deviate from it can only be done with increasing costs and effort.

There exists a link with the concept of emerging irreversibility and literature on path dependency, which discusses the effects of technical interrelatedness (David, 1985; Arthur, 1989), increasing returns, and lock-in. However, for studies of emerging technologies (and for managing processes of emergence), the literature on path dependency is less useful as it focuses on sub-optimal routes being taken and lacks the exploration of indicators. Literature on path creation shows a break away from pure path dependency (Garud and Karnøe, 2001), acknowledging agency in 'mindful deviation' and the mobilising of resources by actors leading to the creation of new paths. To date, a certain amount of work has been done on the processes that lead to path creation of early-stage technologies. Take for example the work by Hoogma *et al.* (2002) where they investigate the role of technical niches (that can change to market niches) in path creation. Here, studying early entrenchment with the concept of emerging irreversibilities can sideways provide insights into path creation as well. Emerging irreversibilities provide some direction in the actions and interactions of actors. In due course these directions can become more fixed and can stabilise, i.e. a path is created.

2.3.2 Positioning

In interaction, actors use positioning to express their own role and the roles of others. Artefacts can also be positioned. In emerging technologies it can be argued that, actors are still finding their place, which means that the different roles that actors can or should fulfil are undetermined and uncertain. However, the absence of clear positions does not mean that actors are completely free in the role they want to fulfil. Actors can base their positioning on 'how things always went' (which is not necessarily useful in the new situation) or base their positioning on expected roles, i.e. roles that actors will likely fulfil in the (near) future.

Expected roles of selves and others are of interest in studying the dynamics of emerging technologies. The reason for this is that in emerging technologies actions and interactions are mainly based on expectations and visions (Brown *et al.*, 2005). Further, studies of expectation dynamics made clear that it is sensible to look at prospective structures to obtain understanding about interactions in the present (Van Lente and Rip, 1998). In emerging technological fields, expectations are prominent and the major anchor points for actors in these fields. In the present actors act on what they think will become true and which collective expectations are sound to link up with. In this, also the roles of other actors are expressed. So, in statements about the future (such as expectations or visions) also positions are attributed. Such positioning statements will be called prospective positionings.

The dynamics as just described to some extent overlap with the main theme of positioning theory (Harré and Van Langenhove, 1999).[3] Positioning theory, a dynamic version of psychological role theory, was developed at the beginning of the 1990s by social scientists. It provides a strong heuristic framework, but is not very elaborated. At times, positioning theory inspired the conceptual understanding to study positioning dynamics. Positioning theory emphasises that positions add credibility to statements (positionings). In this thesis a position is considered as an accepted or established role, which means that different actors see the same role for an actor. In emerging technologies it can be argued that, many positions still have to become established. This takes time and interactions are needed for actors to position themselves in order to acquire a position. Actors can therefore not position themselves freely, because in gaining a position you need support from others. How you position yourself needs to be in line with what others expect from you to make your positioning credible. It are these dynamics of formation and the stabilisation of positions that determine the relations between actors and their interactions.

2.3.3 Spaces

In this thesis the concept of space is used to address that interactions are organised and that there are different ways in which this can occur. Rip and Joly (2004) provide a patchwork on how spaces can be conceptualised. Spaces allow a variety of actors to assemble for deliberation, negotiation, and aggregation (Rip and Joly, 2004). Spaces should not primarily be understood in the geographical sense (a place), but more in the figurative sense (e.g., space that provides opportunities for interaction). Furthermore, Rip and Joly talk about new multi-actor spaces, which have two components; 1) the interest is on newness, spaces that did not exist before, and 2) the multi-actor component is put to the fore. For emerging technologies both components are of interest, because they shed a light on the facilitation process of new (temporal) actor arrangements.

A distinction has to be made between the occasion for emergence or creation of a space and the space itself. Occasions can be very diverse, of which scientific-technological breakthroughs, a growing interest in valorisation, policy changes, or growing pressures to link ELSA issues with early-stage technologies are examples. A key point is that the occasion provides an opportunity for interactions, which initiates the emergence or creation of a space. Emerging and created spaces are two different types of spaces. Examples of spaces that emerge are new combinations of previously separated technologies (e.g., mechatronics), or the work on nanotechnology, which was first opened up by the scanning tunnelling microscope (STM).[4] Examples of spaces that are created are forums, workshops, conferences, and networks of excellence.

Spaces open up naturally (emerge) or can be designed for a specific purpose. Over time, spaces can shift, get established and close (or be closed). Once opened up, spaces get certain characteristics. Within the bounds of a space, the characteristics are emerging as well (Rip and Joly, 2004). The characteristics determine the boundaries of the space, which actors can be present in the space, what kinds of interactions are possible, and enables and constrains the interactions of actors inside the space. Every space has its own specific infrastructure and goals. The concept of space provides a frame by which these differences can be studied under the same heading. Also, every space has a certain effect, or outcome. Due to the specific characteristics, actors in the space are bound to certain types of interactions. So it can be argued that, there exists a relation between the characteristics of the space and the (possible) effects. This relation will be different case-by-case.

In emerging technologies, actors are confronted with the absence of necessary structures for organised interaction. Old structures do exist, but are often insufficient as new actor arrangements are needed to explore different technology options. It is therefore, that new spaces are of special interest in studying the dynamics of emerging technologies.

Other scholars discuss spaces or related concepts as well. Van Lente and Rip (1998) define space as: a locus for particular kinds of events, an opportunity for particular action, and a gradient for, and thus a constraint on, the range of actions. Heiskanen (2005) talks about discursive space for dialogue between different technology discourses and about interventions, such as CTA workshops, that may create new discursive spaces. Nahuis (2007) discusses settings in which issues are reframed when the issue is displaced from one setting to the other. Nahuis also highlights that settings enable and constrain the actors within. The type of setting, to a certain extent, determines how actors can behave inside the setting. Who is invited, and who is not? What goals are set for the existence of the space and who sets these goals? Spaces do not only enable and constrain actors within the space, but also outside. Not being part of or invited to a space can diminish your role in innovation processes. Clausen and Koch (2002) discuss spaces as occasions where social shaping takes place and can be studied. They state on page 224: "A space for shaping implies a social context, where socio-technical ensembles can be addressed and politicised. Some actors may be included in the space, leaving other excluded." As examples of spaces they name -among others- research laboratories and spaces established through supplier-user interaction. They further note that a space is mainly a result of social processes and that negotiation is taking place inside spaces.

To summarise, the first research question is investigated by focusing on here elements of the dynamics of emerging technologies, namely 1) how over time early entrenchment sets in, 2) how actors relate to each other and how this influences interactions, and 3) how interaction between actors is organised. Each of these elements were conceptualised with emerging irreversibilities, positioning, and spaces respectively.

2.4 Technology Assessment as a form of Strategic Intelligence[5]

In the second research topic of this thesis, constructive intervention in emerging technologies, there is an element of support. Through constructive intervention actors are supported to play their role in innovation processes in emerging technologies. Strategic Intelligence (SI) is an umbrella term that covers approaches that support actors to play their role in innovation processes by providing them with tailor-made information that may help them to develop ideas, visions, and strategies as well as action plans to realize these (Smits *et al.*, forthcoming 2008).

This section will provide a brief overview of Strategic Intelligence and will further argue that the strand of Technology Assessment, and more specifically Constructive TA, provides a suitable frame upon which constructive intervention can build. By discussing different types of CTA, this section will address the distinctive value of the research in this thesis compared with others. Figure 2.2 provides a deduction scheme for the different approaches that will subsequently be discussed in this section. From top to bottom, the scope of the approaches becomes narrower

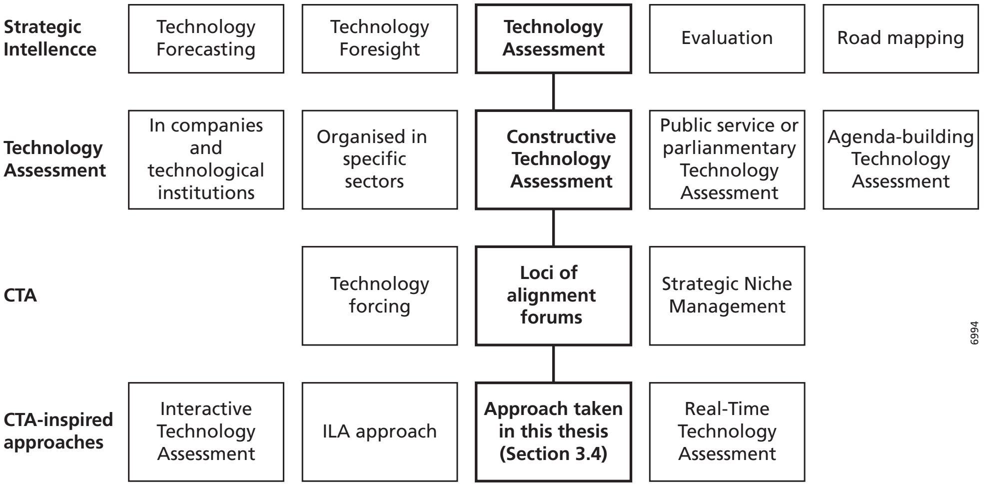


Figure 2.2 Different types of TA in the light of other types of Strategic Intelligence. The line through the centre indicates the deduction taken in this section

and the generalisability of the approaches decreases since they are more and more specifically directed towards certain problems and contexts. The different layers will be discussed from top to bottom below.

Strategic Intelligence (SI) acts on the question *who* needs *what* kind of information in order to let actors maximise their innovation efforts and on the question how this information can be produced. In its various types (Technology Forecasting, Technology Foresight, Technology Assessment, Evaluation, and Road mapping) the focus is always on supporting actors, which implies more than providing knowledge, but can also include intervening in and partly shaping the innovation process. In doing so, SI facilitates various interfaces between actors with different backgrounds and expertises. For example, a Road mapping exercise can draw upon experts in science and industry. The resulting road map provides insights for policy makers into their daily questions regarding how to deal with new science and technology. This example illustrates that Strategic Intelligence bridges – to some extent – the gap between science and industry on one side and policy makers on the other, but also other interfaces can be facilitated.

Five types of Strategic Intelligence can be distinguished: Technology Forecasting, Technology Foresight, Technology Assessment, Evaluation, and Road Mapping. Each type is distinguished by its major task or goal, its field of application, and the kind of (political or policy) issues it addresses. These different types of Strategic Intelligence could only be recognised in hindsight (Smits *et al.*, forthcoming 2008). Each type has its own goals and methodologies. For example, in Technology Forecasting, predicting the future (as best as possible) is put central. Delphi methods and extrapolation are typical methods used in making the forecasts. The different types converge in the sense that each type deals with the same societal question on how to deal with (new) science and technology.

Technology Assessment supports decision-making by assessing specific technologies and the technology options (technology-driven) or societal problems arising from the application of the technology (problem-driven) (based on Tübke *et al.*, 2001). Technology Foresight addresses much wider issues to address the broader impact of technological development, while Evaluation focuses on innovation policy rather than a concrete technology or a problem. Technology Forecasting deals more with predicting the future, rather than assessing options for better exploiting (in a socially and economic way) options while new technologies develop. Road mapping is about planning the future ahead and assigning targets to realize the goals and is used more often in industry rather than outside. In Technology Assessment, the actors are involved in a process from which they get a more complete overview of the available and possible technology options and their feasibility assessed in the light of different aspects (technical, economic, political, and cultural) and by different actors. In Section 1.4 it was argued that constructive intervention can potentially improve the quality of innovation processes. By means of constructive intervention different actors are stimulated to broaden and enrich their views about various technology options and in this way are supported to make more well-considered decisions. It is for the focus on feasibility of technology options that TA fits with the second research question put forward in this thesis.

Going to the second level of Figure 2.2, what types of TA can be distinguished? Technology Assessment is an approach to manage technology in society and comes in many different shapes and colours (Smits and Leyten, 1991:43). Rip (2001) distinguishes five different types (not always fully distinguishable) of TA each with its own audiences. The first type concerns *TA in businesses and technological institutions*. As new technologies arise, assessments are made and input for strategy is generated. Secondly, TA activities are *organised in specific sectors* of which health technology assessment (HTA) is one example and environmental impact assessment (Dale and Loveridge, 1996) is another. They fulfil a function that is specific for that sector, for example HTA focuses on cost-benefit and risk analysis. Thirdly there is, as Rip calls it, *'public service' TA*. This type includes *Parliamentary TA* (Norton, 1996; Vig and Paschen, 1999). It implies the work done by TA bodies as, for example, the OTA in the US, the Rathenau Institute (formerly known as NOTA) in the Netherlands, or the Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag in Germany. Reports are generated – possibly using participatory methods – for political decision-making. The fourth type is *agenda-building TA*, which is oriented to the public arena more generally. This type focuses on agenda building around new technologies and how these technologies should be taken up in society. It is this strand of TA where participatory methods, such as citizen juries and consensus conferences, have been developed in countries such as the Netherlands and Denmark. These TAs can be initiated by a country's TA body. The fifth and last type is *Constructive TA*, which attempts to combine the precise level of analysis of private TA (first type) and agenda building TA from the fourth strand, and includes a variety of actors in its activities. A key component of CTA is broadening the scope of the assessment process or broadening design of new science and technology already at early stages of technological development.[6] It is for this characteristic of CTA that it fits best with the second research topic. Rip (2001) further notices that Constructive TA is still programmatic in parts, but also has developed generic strategies as discussed in 1997 by Schot and Rip.

The just described types of TA are the types that can be distinguished in hindsight today. Box 2.1 elaborates on the history of TA to understand better where it came from and what it intended and still intends to achieve.[7] This elaboration concentrates on the last three types of TA (parliamentary, agenda-building, and constructive TA) as just described.

Box 2.1 A concise history of Technology Assessment

The EU and the US were the prime locations where Technology Assessment (TA) developed. The initial worries behind the emergence of TA were the same, namely worries about negative effects of technology and problems to make technology work. In the US, the Office of Technology Assessment (OTA) was closely linked to Congress. From 1974 to 1995, to a large extent TA in the US was whatever the Office of Technology Assessment happened to be doing. The methods used were often quite formal (e.g., impact assessment) and resulted in detailed reports that could be used in the political decision making processes. In 1995 the OTA ceased to exist owing to political struggles and budget cuts.

The first wave of TA in Europe in the 1970s can be characterised as the entrance of, as Smits and Leyten (1991) call it, the watchdog. Fear of the negative effects of technology acted as a major driving force. Other important aspects in the early days were links with environmental and student movements. In these early days in none of the European countries a TA organisation was founded. A second wave of TA in Europe in the 1980s can be characterised as the entrance of, as Smits and Leyten (1991) call it, the tracker dog. TA was viewed in a broader and more sophisticated way, not simply avoiding negative effects, but instead, pursuing a better integration of science and technology in society. In the same period TA developed more into a policy-oriented instrument. Policy in the broad sense and geared to support various actors. By this, the gap between the societal and economic approach of innovations slowly narrowed. In this period also a number of TA organisations were established, most of them linked to national parliaments (Vig and Paschen, 1999). These TA offices were clearly inspired by the US OTA, but adaptation was needed to the country specific situations (Cruz-Castro and Sanz-Menéndez, 2005). The impact of TA on policy was, however, still rather small. In the early 1990s, European TA experienced a third wave that focused on the further development of the toolkit of the tracker dog and attempts to strengthen links with policy. Keywords characterizing this third wave are participation, demand articulation, and TA as a process. TA was viewed more as a source of Strategic Intelligence, supporting actors to better handle the interface between supply of and demand for technology. Furthermore, in this period a lot of experimentation with TA approaches is visible such as 'interactive TA', 'participatory TA', and 'constructive TA' to improve the quality, impact, and interactive character of TA.[13]

On the third level of Figure 2.2, the three generic strategies for CTA are: technology forcing, strategic niche management, and loci for alignment (Rip and Schot, 1997). In technology forcing, societal goals are set by regulation (e.g., levels of pollutants in motor car exhausts). Consequently, innovation processes have to deal with these policies, which can change the technological developments (Negro, 2007; Suurs and Hekkert, 2007). Secondly, strategic niche management recognises that technologies develop in protected environments. In these environments learning and experimentation can take place until the technology is mature enough to compete under free market conditions. Attempts have been made to take up this approach in transition

Box 2.2 Characteristics of CTA

Constructive TA mainly advanced in the Netherlands (Ornetzeder and Rohracher, 2006). One of the ideas behind TA is to anticipate on societal aspects for technological development to get better societal embedded technology (Deuten et al., 1997). In the light of this, CTA has a few specific characteristics. By striving to *play an active role* in broadening the design of technology options CTA aims at influencing the development of technology via the involved actors (Rip *et al.*, 1995; Smits and Leyten, 1991). It has a strong *process oriented character* and also strives to fulfil a supporting role for actors in the field. In doing so, CTA strives to contribute to the build up of heterogeneous actor arrangements and strengthen their relations on in new technological fields at an early stage. When incorporating a *variety of heterogeneous actors*, it should be noted that these actors have different backgrounds and viewpoints that leads to knowledge gaps and different approaches to assess technologies (Smits, 2000). *Facilitation of interfaces* between the supply of science and technology, and the (often not well articulated) demand for useful applications requires a platform where actors can interact in a constructive way. Furthermore, the development of CTA practices was (and is) *strongly informed by studies of technology dynamics* (Van Boxsel, 1994). For example, the notion of path dependency and the role of niches have been taken up (Rip *et al.*, 1995; Schot, 1992). Links with a Social Constructionist viewpoint (Bijker *et al.*, 1987) are strong as well. Democratizing the process of innovation by incorporating many relevant actors (Bijker, 1995) and broadening design through the actors are important issues for CTA.

management to inform the quest for sustainable energy where in this respect the case of electric vehicles is exemplary (Raven, 2005). Hoogma *et al.* (2002) analysed case studies of experiments for sustainable transport and how these experiments can lead to niches (protected spaces) and further into (as they call it) regimes. One of their conclusions is that a broad involvement of users and outsiders is necessary to make a niche successful. Thirdly, the strategy of 'loci for alignment' attempts to create actual spaces or forums to offer interfaces between different actors in new science and technology. In the light of the second research topic it is this type of CTA that fits for constructive intervention. Bringing actors together at an early stage for interaction is what this CTA strategy is all about. Box 2.2 provides further characteristics of CTA, while Box 2.3 discusses who actually performs CTA activities.[9]

There exist other approaches besides Constructive TA that were developed to support different actors and could focus on interventions in the emerging stages of technological development. Three of such approaches are Interactive TA (Grin *et al.*, 1997), Real-Time TA (Guston and Sarewitz, 2002), and the Interactive Learning and Action (ILA) approach (Broerse and Bunders, 2000). Interactive TA focuses on a joint construction as an outcome or on consensus about a particular problem situation (Grin *et al.*, 1997). It thus focuses on those actors that are involved in the problem. It implies a systematic approach mostly by using interviews (group sessions are also possible), and puts the drives that actors have central and in the light of the problem situation. The outcome is an alternative solution for a concrete problem. There is no explicit focus on emerging technologies, which is more explicit (although not necessarily

Box 2.3 Who performs CTA activities?

A large part of the thesis deals with the development, application, and evaluation of a specific Constructive Technology Assessment approach (second research topic). This approach is designed to involve a broad set of actors without favouring one over the other. Who can be responsible for this type of CTA activities? Often, academic research groups or a government related agency (e.g., TA bodies or other 'intermediary centers') seeking to articulate socially desirable directions for technology development pick up this task (Van de Ende *et al.*, 1998). The independence of academic research groups or a government related agency is favourable, since they have no stake in the outcome of the activities and can therefore fully concentrate on the process. Furthermore, they can take a more general stance such as aiming for higher societal embedment or dealing with societal questions of what to do with new science and technology. Companies, for example, might be less well situated to perform these kinds of interventions themselves, since they would likely favour different actors and outcomes. This does not imply that companies (and other 'outcome dependent' actors) do not benefit from CTA activities (Schot and Rip, 1997). Companies even make use of TA exercises (Rip, 2001), but these are of another type. Specific for companies is that, because of competition, companies might also be reluctant to make their activities visible in an early phase to avoid harm to the company (Jelsma *et al.*, 1995). Further, companies, but especially other actors such as consumer organizations, often lack the necessary expertise, time, and resources to execute CTA activities. On the other hand, these actors might be able to perform CTA activities more effectively than governmental agents due to their central place within technology development (Schot and Rip, 1997). In conclusion, it are most often academic research groups or TA bodies that take up the task to organise CTA activities.

present) in CTA, as CTA focuses on design and development. This is clearly put forward by Schot and Rip (1997:251): "CTA shifts the focus away from assessing impacts of new technologies to broadening design, development, and implementation processes." Further, the research questions put forward in this thesis are about constructive intervention in ongoing processes (see Figure 1.1). In applying constructive intervention there is no explicit aim to contribute to consensus building or solving concrete problems. Consensus building methods are emphasised in Interactive TA, but are of less importance in this thesis.

Real-Time TA is set up as a large-scale research programme that strives to integrate natural science and engineering investigations with social science and policy research from the outset (Guston and Sarewitz, 2002). In contrast, CTA focuses more on strategies and tools to manage technology in society. Or in the words of Schot and Rip (1997:252): "Feedback of TA activities into the actual construction of technology is crucial, and strategies and tools contributing to such feedback make up CTA." Real-Time TA therefore serves another purpose compared to the problem addressed in this thesis: stimulating broadening and enriching by means of constructive intervention. Real-Time TA is a feasible approach to deal with emerging technologies, if only as it is now taken up strongly and institutionalised in the Centre for Nanotechnology in Society at the Arizona State University and the University of California, Santa Barbara. In the words of

Guston and Sarewitz (2002:93): “[…] real-time TA can significantly enhance the societal value of research-based innovations.”

The goal of Interactive Learning and Action (ILA) or Interactive Bottom-Up (IBU) approach (Broerse and Bunders, 2000) is steered towards the involvement of end-users in innovation processes. An exemplary method that is often used in the ILA approach is focus groups (Dürrenberger *et al.*, 1999). As became clear in Section 1.2, in this thesis users are only one of the relevant actors to involve in innovation processes. Naturally, CTA has a broader view and also values contributions of political, economic actors, and societal actors in the broad sense. The ILA approach has a further focus on implementation plans, which are not the direct focus in the research questions put forward in this thesis.

The second research question addressed constructive intervention to improve the quality of innovation processes, which, as emphasised in Section 1.4, is seen as a potentially feasible approach to increase the societal embedment of new science and technology. In stimulating broadening and enriching, there is no need for consensus, as is put forward in Interactive TA. Real-Time TA is a feasible approach for intervening in emerging technologies, but is a much larger scale effort and more focused on the scientific system than what is intended in this thesis. ILA focuses primarily on users, while in this thesis it is stressed that broadening and enriching also benefits from more views than just users. CTA, and particularly the ‘loci of alignment’ variant, is suitable to fully support a research design to answer the second research question. The reason is that this CTA variant combines a focus on early-stage broadening of design and development of technologies, the recognition of a broad range of actors, and the emphasis on feedback in ongoing technological developments.

To summarise, Strategic Intelligence is an umbrella term for approaches that support actors in playing their role in innovation processes by providing them with tailor-made information. A scheme was presented that shows how the CTA approach taken in this thesis can be seen in the light of other approaches; up to different forms of strategic intelligence. Compared to other (CTA-inspired) approaches, the ‘loci of alignment’ variant of CTA is distinctive for its focus on early-stage broadening of design and development of technologies, the recognition of a broad range of actors, and the emphasis on feedback in ongoing technological developments. Therefore, the ‘loci of alignment’ variant of CTA seems to provide a firm basis for the second research topic: constructive intervention with the aim to improve the quality of innovation processes.

2.5 Constructive intervention: to broaden and enrich

Section 1.4 put forward a research question that addresses how to design constructive intervention in order to improve the quality of innovation processes in emerging technologies. This section will provide a conceptualisation of how constructive intervention could lead to higher quality innovation processes. In this conceptualisation, there is particular attention for the actors participating in constructive intervention and how they can broaden their perspectives and enrich their insights into the dynamics of innovation processes (in short: broadening and enriching). Figure 2.3 provides an illustration of these relations: that constructive intervention,

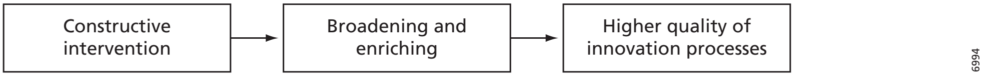


Figure 2.3 Effects of broadening and enriching through interventions on the quality of innovation processes

via broadening and enriching of the involved actors can lead to a higher quality of innovation processes.

Why can broadening and enriching lead to higher quality innovation processes? Section 2.1 and 2.2 emphasised that innovation processes have complex dynamics and, for innovations to occur, configurations between the social and the technical have to be made. Although, these complexities are not always clear or are difficult to comprehend for the actors involved in innovation processes. As being part of a system or process you cannot always comprehend the whole (and only partially what drives you).[10] Furthermore, between different actors there are differences in backgrounds, viewpoints, knowledge, and power that Geurts (1993) addresses as gaps.[11] These gaps can surface as different approaches to assess technology options (Smits, 2000; Garud and Ahlstrom, 1997). Garud and Ahlstrom (1997) introduce a distinction between insiders and outsiders. Insiders work towards the realisation of technology options and are committed to its success (e.g., science and business), while outsiders (e.g., professional users and government) are selectors in the sense of having multiple options of which the technology option under discussion is just one. Rip (2007) makes the same distinction, but uses the terms enactors (for insiders) and comparative selectors (for outsiders) to avoid the static and community-linked connotations of insiders versus outsiders.[12] Given that the eventual outcomes of emerging technologies are still very uncertain, it can be argued that the gaps between insiders and outsiders are relatively large. Rip (2007) further highlights that insiders (enactors of technology; e.g., scientists and businesses) have a concentric bias, meaning that insiders are focussed on only one thing: enacting. These gaps and biases stand in the way of fully understanding the system or processes that actors are involved in and the role of other actors in it. Broadening and enriching -to some extent- bridge these gaps. Broadening is defined as follows:

> *widen the perspectives of actors in terms of*
> *identifying a broader set of actors and aspects*

Actors broaden their perspectives when it becomes clearer for them who the actors and aspects are, and what can be expected from these actors. Enriching is defined as:

> *increasing the understanding of actors in the complex dynamics of*
> *innovation processes and their role therein*

Actors enrich their insights into innovation processes when it becomes clearer for them how different actors relate to each other and what their role in innovation processes is or can be. Broadening and enriching can enable actors to better play their role in innovation processes, which can improve the quality thereof.[13]

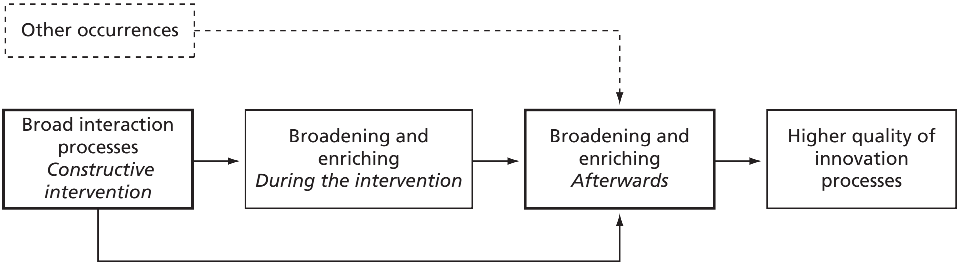


Figure 2.4 Relation between constructive intervention and effects in terms of broadening and enriching

To understand the relation between constructive intervention and broadening and enriching, further conceptualisation is necessary. The intervention described in this thesis is designed as a closed-of setting or forum ('loci for alignment' variant of CTA; see Section 2.4), which for a certain amount of time takes people out of their normal working environment for interaction with other actors. Despite that this closed-of setting exists only for a short while, during this intervention broadening and enriching can occur. To affect innovation processes, it is broadening and enriching that is visible in the normal working environment that is of interest. So, after the intervention is finished. This is schematically represented in Figure 2.4.

During the intervention participants can acquire new information, gain new insights, and reflect upon each others opinions through interaction (also with people they did not meet before). The intervention should be set up in such a way that broad thinking and interaction is stimulated. Broad interactions (between various actors) can elucidate dynamics of innovation processes to the actors that participate in the intervention. Such interactions enable participants to broaden and enrich during the intervention.

After the intervention (a closed-of setting where actors can acquire information, gain insights, and interact) when the actors returned to their working environment, broadening and enriching can occur as well. This will likely be a mixture of broadening and enriching as it occurred during the intervention and effects that occurred after the participants returned to their normal working environment. The second research question addresses quality improvement of innovation processes, which are mainly carried out outside the intervention, but also partly inside the intervention, because the intervention becomes -to some extent- part of innovation processes. It is therefore not so much the exact relation between the effects during and afterwards that are of interest, but more the overall effect: how does constructive intervention contribute to broadening and enriching in the normal working environment of participants?

To gain further insight into 'how to design' (second research question), the design of the intervention can be permutated. Subsequently, the relative differences in effects on broadening and enriching should be attributed to the permutations. When these attributions can be made, lessons can be drawn on how to design interventions that aim at broadening and enriching.

Figure 2.4 indicates that it is not only constructive intervention (and the interactions that occur during the intervention) that can lead to broadening and enriching, also other occurrences can contribute as well. These other occurrences can be anything from reading a news paper to meeting actors at other meetings. The point is, in assessing the effects of the intervention, that there are likely also other occurrences that have an effect, which should be ruled out in an evaluation.

To understand the overall effect of constructive intervention in the normal working environment of participants, there are a few issues that need to be elaborated on. These issues are the intramural effect, different types of impact, and different dimensions of knowledge utilization, which are explained below.

Intramural effect

There is a phenomenon of importance for any organised meeting in a closed-off setting: the so-called intramural effect. Intramural means: 'within the walls of …'. When participants enter a meeting such as the forum that is intended here, something happens. The closed-off setting makes them forget everyday problems when discussing topics and reaching certain goals. In closed-off settings people think more freely than in their normal working environment. People are therefore more easily drawn into conclusions and claims that they wouldn't make otherwise. Things look easy enough in a closed-off setting. Furthermore, the fact that people act differently from their normal situation is advantageous in the sense that they are freer to contribute to the discussion compared to what is possible in the wider world with all its constraints. Issues can therefore be discussed in a richer way and effects can be reached that would have been more difficult or even impossible to reach outside a closed-off setting.

Nonetheless, when the participants return to work, other issues become more important again. During the intervention, some constraints that are present during normal working hours are felt much less, but back to work, they present themselves again to the full. This moderates the effects that were reached during the intervention. So, when the focus is on effects in the normal working environment, measuring broadening and enriching during the intervention would be inappropriate as this would neglect the intramural effect. Assessing broadening and enriching afterwards gives a more realistic image of the effects of the intervention, but introduces effects of possible other occurrences.

Different types of impact

The impact of an intervention on the working environment is not self-evident. This is discussed by Bhola (2000) in his work where he presents 'A discourse on impact evaluation'. Although this work is about how to evaluate the impact of social interventions, it also provides insights into impacts more general. Impact should be understood as: "a mixed bag of the immediate and the delayed, and of the anticipated and the unanticipated." Bhola suggests that there are 'three faces of impact'. For every (social) intervention there are intended outcomes that are incorporated in the design (*impact by design*); in this case broader and richer thinking, acting, and interacting in the normal working environment. Further, there can be effects that occur after the intervention interacts with other interventions (*impact by interaction*). For example, participants meet each other again at another event, which can reinforce the development of shared ideas and visions. Subsequently, this could lead to further action and interaction. New effects can also emerge when the outcomes of earlier interventions interact, and in addition links are being made with wider historical and cultural processes (*impact by emergence*). For example, new insights are repeated at various instances and, over time, become embedded in every day practice. Exemplary in this respect are 'new understandings about how the world works'.

In respect of Figure 2.4, these 'three faces of impact' (one intended and two unintended) make clear that there are not only direct effects, but also interactions with other interventions, events, and the wider social system that are important. In Figure 2.4, these 'other' effects on broadening and enriching are taken up as 'other occurrences'. Further, longer term effects can sometimes only occur as interaction with other interventions are needed to create the right circumstances for change. If the circumstances for change were not right at the time of the 'original' intervention, it does not mean that they will not be right at later stages. So, there is an element of time and timing to be added to understand the effect of interventions. In this, there is also a lesson for designing interventions. When the timing of an intervention overlaps with a 'sense of urgency' (De Bruijn *et al.*, 1998), or when 'there is something at stake' (Robinson and Propp, 2006) in the technological field, chances for impact by interaction and emergence increase.

Dimensions of knowledge utilization

Literature on knowledge utilization can provide insights into how participants in interventions take up and use the information that is provided to them (either directly or in interaction with other participants). Smits and Leyten (1991:103; based upon Knott and Wildavsky) note that there are seven different ways in which utilization of knowledge can take place from social scientists to policy makers, ranging from reception of information towards impact on policy. These ways of knowledge utilization differ in the intensity that knowledge is actually used. For example, if a policy maker receives and acknowledges some piece of information, it does not mean that any further action is undertaken to implement it in policies. Furthermore, Dunn (1980) reports on an extensive case comparison between cases of knowledge utilization between different communities. It is not as much the result of this study that is of interest here, it is more the point that knowledge utilization has many aspects and dependencies that is important. So, the relation between broad interaction processes and broadening and enriching in the normal working environment (Figure 2.4) is subject to contextual and infrastructural aspects at the working environment as well.

Further, Caplan (1979) makes a distinction in conceptual and instrumental use of knowledge. Conceptual use of knowledge affects the frame of reference or the mental model of the processes, of the problem at hand. When knowledge is used instrumentally, it is used practically in gathering information to solve everyday problems. Caplan (1979) concludes that between two different communities especially conceptual knowledge transfer takes place and instrumental knowledge use is much less. For instrumental knowledge practitioners mainly rely on their own community. For the intervention studied in this thesis, conceptual use of the knowledge (directly or through interactions) is more likely to occur than instrumental knowledge utilization.

To summarise, in this section the relation between constructive intervention and effects on the work floor of participants was conceptualised. In doing so, a distinction was made between effects (broadening and enriching) during and after the intervention. The latter are effects on the thinking, acting, and interacting of participants when they return to their normal working environment. This distinction is relevant, because influences on ongoing innovation processes mostly take place at the work floor. Further, three issues were discussed that provided more detailed insight into the relation between constructive intervention and the effect that can be reached. These issues were, the intramural effect, 'three faces of impact', and different dimensions of knowledge utilization.

2.6 Research questions

So far, this chapter provided a theoretical framework and conceptualisation to address the main research questions that were put forward in the first chapter. For the first research question (*How to understand the dynamics of emerging technologies?*), three elements of the dynamics of emerging technologies were derived as relevant from a (social) constructivist point of view. These elements are 1) how over time early entrenchment sets in, 2) how actors relate to each other and how this influences interactions, and 3) how interaction between actors is organised. These elements were conceptualised by emerging irreversibilities, positioning, and spaces respectively.

These linkages between elements of the dynamics of emerging technologies and theoretical concepts to study these elements, addresses a dual research interest. It are not only the elements that are studied to obtain understanding of different parts of the dynamics of emerging technologies, but also the conceptualisation itself that is of interest. The concepts used here are not clear cut and fully developed, which implies that insights into these concepts can be improved as well. To reflect this dual research interest, the following research questions are formulated.

1.1. How can early entrenchment be understood by studying emerging irreversibilities?

1.2. How can relations between actors be understood by studying envisioned future positions?

1.3. How can organised interaction be understood by studying spaces?

For the second research question (*How to design constructive intervention in order to improve the quality of innovation processes in emerging technologies?*), the 'loci of alignment' variant of CTA was derived as a basis to design constructive intervention. A further aim of this thesis is to contribute methodologically to (C)TA, specifically on designing an approach that can stimulate broadening and enriching in the normal working environment of actors. About the methodological contribution, there are two relevant issues. Firstly, the overall effect of the intervention is important, which relates to questions of design, application, and evaluation. To address this issue the following research question can be formulated.

2.1. How to develop, apply, and evaluate a CTA approach for emerging technologies that is productive in terms of broadening and enriching?

Secondly, when permutations in design are introduced, this can lead to differences in the effect of the intervention. Evaluating whether differences in effect can be related to the permutations can provide useful insights into 'how to design' constructive intervention in emerging technologies. This relation is addressed in the following research question.

2.2. What permutations in constructive intervention are insightful for CTA method development and what is the relation between these permutations and the productivity?

Both sets of research questions (1.1-1.3 and 2.1-2.2) constitute the basis to develop the research design.

2.7 Summary

Chapter 1 argued that the understanding of the dynamics of emerging technologies can be improved. To comply with this request, in this chapter three particular elements of the dynamics of emerging technologies were conceptualised, namely 1) how over time early entrenchment sets in, 2) how actors relate to each other and how this influences interactions, and 3) how interaction between actors is organised. In doing so, this chapter set of to discuss three theories from STS literature and also discussed Innovation Studies literature. Emerging irreversibilities, positioning, and spaces were derived as concepts that can capture the three elements. Likely, working with these concepts will not only improve the understanding of the dynamics of emerging technologies, but also provide insight into the concepts themselves, especially because these concepts are not clear cut and fully developed. Research questions that emphasise the relation between the three elements and the concepts were put forward.

The first chapter further argued that broadening and enriching of innovation processes in emerging technological fields is socially relevant as it potentially improves the societal embedment of new emerging science and technology. This led to the question how to design constructive intervention in order to improve the quality of innovation processes in emerging technologies. This chapter picked up this question about design by discussing Technology Assessment as a form of Strategic Intelligence. Strategic Intelligence is an umbrella term that covers approaches to support actors to play their role in innovation processes by providing them with tailor-made information. By relating CTA to other approaches, especially the 'loci of alignment' variant of CTA was found suitable to fully support a research design that can provide answers to the second research question. The reason for this is that CTA combines a focus on early-stage broadening of design and development of technologies, the recognition of a broad range of actors, and the emphasis on feedback in ongoing technological developments. This combination was found absent in other approaches such as Interactive TA, Real-Time TA, and the ILA approach.

It was further argued that the productivity of the intervention can be operationalised in terms of broadening and enriching. A conceptual scheme was developed to relate constructive intervention to broadening and enriching as an overall effect. By permutation of the intervention design, methodological lessons on 'how to design' constructive intervention in emerging technologies that is based on CTA methodology can be drawn. To do this, the relative effects should be attributed to the permutations in design. Research questions were formulated to guide the research design.

Notes

1 Nanotubes were (especially in the late 1990s and early 2000s) and still are used often as examples of one of the first commercially used nanostructures. Nanotubes have a structure that looks like rolled up chicken wire and consists of carbon atoms. They have phenomenal strength, endurance, and conductivity characteristics and are typically used to strengthen materials. Also, attempts are undertaken to build electronic devices based on nanotubes.

2 The reason that the launch of this specialised journal is used for this example is the fact that nanotubes is one of the major topics in this journal, which Roco (1999:1) expresses in the following words: "Research

contributions on nanoparticles, clusters, *nanotubes*, nanocrystals, nanolayers, and macromolecules surrounded either by gases, liquids or solids, are brought together in this single publication."

3 Positioning as such is well-known in marketing, strategy, and business economics literature (Hooley and Saunders, 1993; Lefebvre and Lefebvre, 1993). This literature addresses prospective positioning into current strategies and activities of firms, which are especially forceful in situations of emergence. Knowing how other companies might react to specific situations is a difficult, yet important and strategically valuable matter. In this thesis positioning is more directly linked to interactions between various actors, and not only businesses.

4 To illustrate this example, in presenting nanotechnology, many people (e.g. physicists as well as social scientists) present the scanning tunnelling microscope (STM) as the enabler of nanotechnology practices.

5 This section is partly based on joint work of Ruud Smits, Rutger van Merkerk, David Guston, and Daniel Sarewitz, to be published in Smits *et al.* (forthcoming 2008).

6 There are other types of distinctions made for TA, for example the distinction between awareness, strategic, and constructive TA by Smits and Leyten (1991) (also Van de Ende *et al.*, 1998). How are these types of TA related to the five types in the main text? Awareness TA has a long term perspective and is most strongly related to 'public service'/parliamentary TA. Strategic TA has more a medium term perspective and is related to the sector specific TA, but on a higher lever than HTA for example. Constructive TA in its activities focuses more on the short term and corresponds the most with TA found in companies and (what's in the name) constructive TA as discussed by Rip (2001).

7 This box is mainly based on Smits *et al.* (forthcoming 2008).

8 This shift away from parliamentary TA can be seen in the light of a shift from government to governance. The locus of (political) decision making about (new) science and technology is shifting. Decision making is no longer in the hand of policy makers. So, shifting activities to a broader range of actors is logical for TA where policy makers become just one actor among many. The same design principle is used in Chapter 3, where a CTA intervention is developed.

9 Box 2.2 and 2.3 are mainly based on Van Merkerk and Smits (forthcoming 2008).

10 "We are very much like fish that live in a flowing stream yet cannot see the water. They exist in it all the time and feel the push of the current, but for some reason they cannot *perceive* it. So they develop myths and folktales to explain the force they must constantly fight against." (Shifman, 2000)

11 Five gaps are distinguished between; 1) policy processes and science, 2) different (scientific) disciplines, 3) administrators and citizens, and 4) experts and lay people, and (5) producers and users of knowledge (Geurts, 1993). Bridging a gap however does not imply consensus. It only points at enabling a fruitful dialogue between actors with different frames of reference and interests.

12 Van de Poel (2000) discusses the role of outsiders in technical development such as Societal Pressure Groups (a specific subset of NGOs as a type of outsiders). On page 393 he states that: "The aim of societal pressure groups is typically to change the social world in some way. Usually, they are not interested in technology as such, but more in the way technologies can be used for societal goals, or in the kind of effects technologies may have and which maybe considered undesirable." This quote underlines the comparative selection approach of outsiders.

Furthermore, in de distinction between insiders and outsider one could make a third group: reflectors. Social scientists or innovation scholars also have a (and maybe increasing) role in technological developments (personal communication Harro van Lente).

13 The notion of reflexivity relates to this discussion on the effect of broadening and enriching; when you better understand the world you live in, you are better equipped to act and achieve what you are after. So, broadening and enriching can make actors more reflexive.

3 Research design

This chapter starts with explaining the choice for Lab-on-a-chip technology as a case of an emerging technology (Section 3.1). The remainder of this chapter is structured along the two research topics. For the first research topic (studying emerging technologies in order to obtain understanding about its dynamics) it is first explained how a detailed historical narrative can be constructed for a particular emerging technological field (Section 3.2). Then, in Section 3.3, the focus turns to the three elements of the dynamics of emerging technologies as derived in the previous chapter (Section 2.3). For each of the elements an approach by which the element can be studied is explained.

Two sections (3.4 and 3.5) are devoted to the research design of the second research topic (intervening in emerging technologies in order to improve the quality of innovation processes). Firstly, a particular CTA approach is designed that focuses on stimulating broadening and enriching by means of constructive intervention (see Section 1.4). Secondly, an evaluation scheme is developed in order to assess the effects of the 3-step CTA approach.

3.1 A case study of emerging technology

First some remarks about case study methodology. Yin (1994) states that case studies should be used when a rich description is needed to cover the topic under investigation. By using multiple sources of data (data triangulation) and multiple methods to investigate the case (methodological triangulation) a stronger case can be build (Yin, 1994). When using one case the generalisability of the results is limited. However, there is always the option of analytic generalisation by comparing case study results with literature.

"A case study of what?" is the question to answer. Since the research questions address emerging technologies, the case that is chosen for this thesis should above all be a case of an emerging technology. Emerging technologies are technologies that are not yet socially embedded. This often implies that the technology is still mainly present in the scientific realm. Companies can work on the emerging technology and experimentation can be present as well, but there are not many, or even no, successful products on the market. There exists a wide range of technologies that fit this criterion, such as fuel cells, quantum computing, and pharmacogenomics.

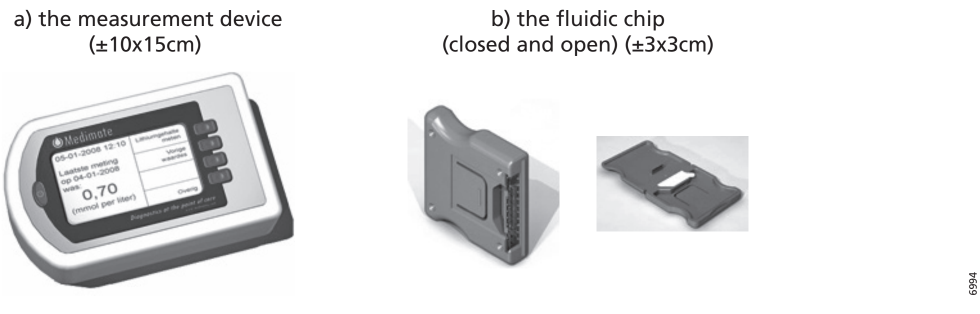
This is still a very wide range of possible cases. What are further selection criteria that can be used to select the case? Firstly, since this PhD project is part of NanoNed, the case should fall within the nanotechnology area and within NanoNed enough research activity should be devoted to the topic. When the latter is the case, this project in the TA programme of NanoNed can link up with other parts of the NanoNed programme. This thesis benefits from such links as experts on the case will be available in the Netherlands.

Secondly, for the type of activities set out in this thesis (especially the second research line), the case should represent an area where not only nanoscience is conducted, but also nanotechnology. What is meant by this is that applications related to the technological area should be (relatively) close to commercialisation. This criterion rules out cases such as quantum computing, which is believed to be far away from any full scale commercial activity. See for example the quantum computation roadmap (ARDA, 2004), which merely addresses scientific aims (until 2012) rather than commercial and industrial aims.

Thirdly, CTA activities are especially useful in cases that are surrounded by a number of controversial issues and from cases where a large number of actors (with their own views and agendas) are interested in these issues. Such cases encompass many topics that could bring actors to the discussion table, such as potential applications, ethical issues, and political issues. Furthermore, in such cases, insights from outsiders that inform the technological developments at an early stage are of high value, since insiders themselves can hardly comprehend all issues and outsiders can reveal some of its complexities. In the first research topic, in its search for understanding the dynamics of emerging technologies, in such a case, the multi-actor and multi-level dynamics of innovation processes are likely to be more visible and can be studied easier.

As will become apparent below, Lab-on-a-chip technology is a case that fits these criteria. To demonstrate that Lab-on-a-chip technology is a case of an emerging technology, first a brief description of Lab-on-a-chip technology is given. Lab-on-a-chip technology has its roots in microtechnology fabrication technologies, which enabled the fabrication of fluidic chips at the end of the 1980s. In a Lab-on-a-chip, fluids are guided through miniaturised channels. The design of the chip determines the chip's capabilities in terms of possible analysis. Often an external instrument or reader is needed to get the analytical results from the chip. Figure 3.1 shows an example of an instrument using fluidic chips that can measure the lithium concentration in blood. The lithium concentration in blood is an important input in the treatment of manic depressive patients the use lithium as a therapeutic drug.

The early laboratory experiments inspired scientists to put forward high goals for the newly emerging technological field, which are still present today: Lab-on-a-chip technology should create complex systems that integrate all necessary analysis steps on one chip, the Micro Total Analysis System (μTAS). Based on these promises, the Lab-on-a-chip field now experienced over 15 years of development, mainly in the academic setting. Nanotechnology enables further



a) the measurement device (±10x15cm)

b) the fluidic chip (closed and open) (±3x3cm)

Figure 3.1 Point-of-care device as developed by Medimate

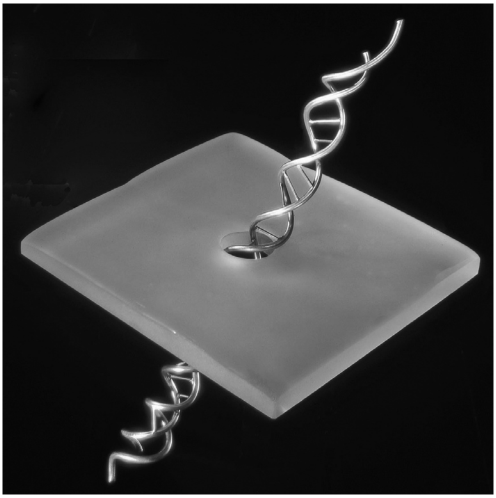


Figure 3.2 Novel analysis concept enabled by nanotechnology DNA analysis can be performed by pulling strands of DNA through a nanoscaled channel. Source: Austin, 2003

miniaturisation. By making the fluid channels and functional features smaller, more accurate and new types of analysis become possible (see Figure 3.2).

Nowadays, a few companies have Lab-on-a-chip based products on the market and several applications of the technology are in use. Clear examples are the Abbott i-Stat,[1] and the BioAnalyzer from Agilent.[2] These applications are mainly used as research equipment, but there are also examples of applications used as bedside monitoring devices in hospitals. There are also a growing number of businesses interested in and working with Lab-on-a-chip technology.

This brief description indicates that lab-on-a-chip technology is a case of an emerging technology. Scientific work still has the upper hand. Although Lab-on-a-chip technology received a fair amount of interest from industry, there are still only a few products on the market. This makes it a technological field waiting for commercial breakthroughs.

A further criterion is that in NanoNed enough research activity should be devoted to the topic. NanoNed has eleven flagships that show the main research topics, such as Advanced NanoProbing and BioNanoSystems.[3] Lab-on-a-chip research falls mainly within the flagship NanoFluidics. In the flagships BioNanoSystems and Chemistry for Single Molecules and Structures there is interest in the topic as well. The flagship NanoFabrication is involved as it also focuses on the production of fluidic chips (Lab-on-a-chips). Hence, within NanoNed, there is considerable interest in Lab-on-a-chip technology.

Lab-on-a-chip technology has many possible application fields ranging from pharmaceutical research tools to on-site testing of environmental pollution. Medical diagnostics has its own specific dynamics that makes it particularly interesting for CTA activities. In health care there are generally many parties involved in decision-making. The end-user is often unclear as the actor that pays for the product is often not the end-user, but the health care insurer or the hospital. Furthermore, health care involves working with people, which gives rise to ethical and legal issues that have to be addressed throughout the innovation process.

Box 3.1 Explorative interviews

As a point of departure in the investigations performed in the field of Lab-on-a-chip technology, two explorative interviews were held with leading scientists. These interviews were held to determine the boundaries of the case study and to fine-tune with experts what is understood by Lab-on-a-chip technology. For these interviews, preparation work was done in the form of constructing mindmaps. Mindmaps are figures that help to organise what relates to the topic that is mapped. Various computer software packages are available that make the construction of a mindmap an easy task. During the explorative interviews, a mindmap of Lab-on-a-chip technology was used to show the interviewee what the interviewer defined as Lab-on-a-chip technology. The interviewee could then comment on this. These comments provided insight into the field of Lab-on-a-chip technology and were helpful in determining the boundaries of the case study.

When during this PhD project the case of Lab-on-a-chip technology was selected, explorative interviews were held with leading scientists to improve the general understanding of Lab-on-a-chip technology and to reflect this understanding with experts in the field. Box 3.1 explains how these explorative interviews were held.

3.2 Historical narrative

A historical narrative that describes the emergence and evolution of the technological field up to the present is insightful for both research topics. A detailed and rich description of the history of the case is useful to get an oversight of the technological field in general and to provide a first glance on the overall dynamics that shaped the field over the years of its existence.

Emerging technologies exist in an open-ended and still very fluid state. Constructing a detailed and rich historical narrative of a technological field of such a state is a complex activity. There are many tentative research results and directions in which the emerging technological field (could) develop(s), but no clear directions have formed (yet) that can be traced back easily. However, *expectations* are abundant, which become shared by different actors. This influences the emergence of a technological field. In this process, a wider variety of actors becomes involved on the basis that (aspects of) expectations link up. This results in an increased visibility of the technological field as a whole. Expectations guide the activities of the actors within a technological field, while, in turn, expectations will be (re-)shaped by research results, findings in other technical fields, successful commercialisation, and external trends and forces (Van Lente, 2000). Over time, choices are made and priorities are set, which results in (shared) *agendas*. In new and emerging science and technology, these processes result in an increase in the attention in related journals, conferences on the subject are organised, start-ups are founded, and companies start collaborations. Given that agendas are enacted in the ongoing activities of the field, actors link up with each other in various *actor arrangements*. Actor arrangements indicate interactions between actors that form dynamic, but nascent, linkages. By gathering data about these three elements (expectations, agendas, and actor arrangements) through time, a narrative can be built that indicates which social and technical entities were addressed when. Consequently, in gathering the data, particular types of statements are considered more relevant then others. In emerging technologies the emphasis is on expectations, agendas, and actor arrangements.

In gathering data about emerging technological fields, scientific literature is a good point of departure. In scientific papers, expressions of expectations, agendas, and actor arrangements can be found. Review papers are texts that provide a higher level view of the technological advances. To get a more complete view of the actors that become involved and the issues they address also other data sources should be used. Data sources can be manifold, but at least (when available) company websites, websites from industrial consortia, reports from consultancy and venture capital firms, information about actual use, and governmental reports should be traced. In order to enable a description of the developments over time, all data should be marked with the period in which it appeared. Interviews with different actors can be used to corroborate the data found through desk research and to further complete the data.

When the data is gathered, the analyst ends up with a heterogeneous set of data. In making sense of the data in the first place, but also to support the historical narrative, a mapping tool can be of help. Such a tool should be able to depict social as well as technical entities over time. In this respect some scholars write about the construction of socio-technical maps (Gow, 2003), but none really shows a socio-technical map. Given that literature does not provide a tool that can be picked from the shelf, in this thesis a tool for socio-technical mapping is developed. This will be done in Section 4.1. What should be design criteria for such a tool? Firstly, socio-technical maps should be able to describe developments over time. Secondly, the tool should be able to illustrate the socio-technical character of technological developments. Thirdly, the map should be able to locate and distinct between different types of actors.

3.3 Three elements of the dynamics of emerging technologies

In Section 2.3, three elements were derived that each describes a different part of the dynamics of emerging technologies. For each of these elements a theoretical concept was derived to capture the element of interest. In this section, for each of the elements and related concepts, a research design will be developed.

3.3.1 How early entrenchment sets in: emerging irreversibilities

Actors in their daily operations make choices, interact with other actors, some do research, while others develop, use or regulate products. As a result of these various activities, although fragile and tangible at the early stages, technology is developed in certain directions, networks are formed, and investments are made. Over time, a certain amount of standardisation starts to occur in solving research problems, in developing certain types of products, and later, using particular products in specified practices. Some actions and interactions become self-evident, while others are ruled out. Over time, reasons to change them diminish, but when an attempt for change is made, this requires effort. More effort is needed when large investments were made and technological developments have significantly advanced. Further, changing direction in such situations often implies taking a step backwards.

This kind of processes is what entrenchment is all about. Entrenchment is not caused by a single process or activity; it is a mix of social relations, materiality, financial commitments, and search heuristics that become more and more fixed. From a constructivist point of view, entrenchment has an influence on the actions and interactions of actors, and also, actors contribute to entrenchment. To capture these influential dynamics, in Section 2.3 the concept of emerging irreversibilities was proposed. The focus remains on actors: emerging irreversibilities are patterns that have enabling and constraining effects on actors.

In achieving certain goals, actors (can) link up with emerging irreversibilities, which lowers -as it were- the effort needed to take actions and to interact, but at the same time increases the effort necessary when something else is attempted. Referring back to the case of 'a growing attention into a certain research topic (nanotubes)' (see Section 2.3.1), it was indicated that for scientists it becomes easier to refer to the notion that research on nanotubes is important. Consequently, the growing attention for research on nanotubes triggered the launch of a new journal. Another effect of the growing attention is that it makes it easier for scientists to acquire funding for research on nanotubes. In this way, the emerging irreversibility can become stronger over time. In this process, other actors become involved as well, hence the multi-level and multi-actor characteristics of innovation processes.

To study the dynamics of emerging irreversibilities the patterns that constitute emerging irreversibilities should be made visible. Patterns in how actors interact, arrange themselves in networks, search for solutions, and take decisions (see Section 2.3). It should also be demonstrated which types of actors become influenced by the emerging irreversibility over time. An empirical point of departure for this study can be a detailed historical narrative. In such a narrative, patterns that were influential in the development of technological field can be found. These patterns are (possible) emerging irreversibilities that have to be further investigated to better understand its dynamics.

In further investigating possible emerging irreversibilities, the focus should be on how they influence (enable and constrain) actors operating in the emerging technological field. This influence likely changes over time as the emerging irreversibility can become stronger (or weaker). It can be argued that possible signs of strength are when a larger diversity of actors is influenced (multi-actor dynamics) and/or the influence spreads through different levels (multi-level dynamics).

The kind of data that is needed to investigate emerging irreversibilities should comply with the just described dynamics. The focus is on the actors and the statements that all involved actors make. At the same time the data should be representative for what is actually happening. Then, the same logic as described in Section 3.2 applies. Expectations are abundant and translated into (tentative) agendas, which leads to (new) actor arrangements. The empirical base for constructing the historical narrative can therefore be used as a point of departure to investigate the dynamics of emerging irreversibilities. For each emerging irreversibility that is investigated it should be assessed whether this is enough data. If not, additional data should be gathered, which can be done through further desk research that is complemented with interviews.

Graphically showing the dynamics of emerging irreversibilities can make the dynamics more insightful. Mapping over time which actors are influenced by the emerging irreversibility and how the influence spreads through different levels can support the argument behind it. Literature does not provide a tool that is directed at this purpose, although there are models in literature that take a multi-level perspective on technological development (Geels, 2002a; Geels and Schot, 2007). The emphasis in this work is on dynamics of technological transformation, where multiple niches can trigger regime change up to changes in the technological landscape. In this thesis the emphasis is on actors operating and interacting on and across different levels (e.g., research groups and science community). A tool should therefore be developed to support studying these dynamics of emerging irreversibilities, which will be done in Section 4.2. Such a tool should be able to distinguish between different levels where influence takes place. Furthermore, the tool should be able to locate different actors and show the actors that become influenced over time.

3.3.2 How actors relate to each other: positioning[4]

Positions are accepted or established roles; meaning that different actors attribute the same role to an actor (see Section 2.3.2). It can be argued that in emerging technologies positions are not (yet) established and gaining a position takes time and requires interactions. In interaction, actors use positioning (expression of position) to express the roles of selves and others. Over time, after many interactions took place, positions can be recognised that further determine possibilities for actions and interaction.

Here, there is a special interest in positioning in the future. Expectations and visions determine for a large part the dynamics of emerging technologies (Brown *et al.*, 2005). In expectations and visions, positions are expressed. Expectations -so to say- capture how actors envision the outcomes of positioning-in-interaction up to a certain date. For example, a company expects that health care professionals want to use the product that they are developing once it is made ready for sales. In this example the company positions health care professionals in need of their product once it is ready, which is a projection into the future. This type of positioning that is placed in the future will further be called prospective positioning.

For actors to acquire a position there has to be convergence in how multiple actors envision you, although convergence is not enough. For an actor that is active in an emerging technological field, it is a good start when other actors agree on the position that you should fulfil. However, the position granted to you should also match with the position you had in mind to achieve your goals. In other words, a match between self positioning and other positioning is important as well.

For the analyst, positionings are a source to study the roles that actors give to each other or expect the other to get. Roles that actors expect for each other in the future, as expressed in positionings (position statements), are used in present day interactions as well. Referring back to the expectation from the company given above; how the company positions the health care professional likely determines for a large parts how the company interacts with health care professionals. The company, regardless of the actual need of health care professionals for the product, will approach health care professionals if they do need the product. This example illustrates that prospective positionings are expressions of how actors relate to each other, also in the present. Due to the high uncertainty in emerging technological fields, divergence on prospective positions can be more or less expected in emerging technological fields, and studying them explicitly can give insight into the relations between actors at the level of the emerging technological field.

In order to gain insight into how actors relate to each other, a systematic study based on envisioned future positions, or prospective positioning, can be used. This study should enable an analysis of whether multiple actors envision the same or different roles for each other. The data needed for such a study should consist of many prospective positioning statements from various actors in which self and others are expressed. Through desk research, such a dataset is not easily available for a wide variety of actors. Especially in emerging technologies where mainly researchers and developers are active (compared to, for example, users and regulators), gathering data through desk research is less likely to result in comparable data for all actors.[5] Performing interviews is a more feasible way to gather such data. Now, it happens to be that during the intervention (second research topic) many interviews are performed. In these interviews socio-technical scenarios (coherent and rich stories about the future) are constructed by various actors. How the socio-technical scenarios are constructed is explained in Section 4.3. In general scenarios indicate how different actors interpret particular visions on the future. Socio-technical scenarios emphasise that a broad set of actors and aspects (and the relations between them) is important when considering the future. Self and other positionings are therefore likely to be found in socio-technical scenarios. To cover a representative set of actors, the origin of the interviewees should be broad in the sense that technological (e.g., scientists), economic (e.g., businesses), political (e.g., ministry representatives), and socio-cultural (e.g., end-users) actors should be interviewed on the topic.[6] The socio-technical scenarios gathered in the second research topic are therefore a rich data source consisting of many statements in which self and other positioning are expressed.

Before a systematic analysis can be performed, a database of positioning statements that can be found in the scenarios should be made. Only those statements about the same topic should be entered in the database. A database entry holds: 1) the actor that makes the positioning statement, 2) the actor that is positioned, 3) the activity and or artefact that the statement is about, 4) additional reasoning (when given), and 5) examples (when given). For example, a company (1) can make the following positioning statement: "General practitioners (2) use portable devices for measuring blood values (3), because it will help them with screening patients (4)." (numbers indicate database entries) The actor that made this statement (a company), positions general practitioners and expects that they will use portable devices for measuring blood values for a certain reason (help with screening patients). The topic here is Point-of-Care testing (Price *et al.*, 2004; Price and St John, 2006), which is a generally recognised vision in the field of Lab-on-a-chip technology.

To analyse the data, the database entries are sorted by the second column of the database (other positionings). This visualises per actor all positioning statements about the various actors. The result of sorting positioning statements in this way is shown in Table 3.1. When the first and second columns list the same actor this is a self positioning statement, otherwise it is a statement of other positioning.

Further, two types of data presentation are proposed to support the analysis. As a first type of data presentation a table can be made that provides an overview of two measures that are of interest in this analysis: *convergence* of other positions and *match* between self and other positioning. The first measure can be assessed by combining all other positionings about one actor. In Table 3.1 it is indicated how actor2, 3, and 4 position actor1. Convergence can be assessed by analysing whether in the third and the fourth column, for actor2, 3, and 4, the same issues are addressed. When this is the case, actors2, 3, and 4 agree on the position of actor1 and the position of actor1 is convergent. The position is divergent when there is disagreement in the other positionings.

The second measure indicates whether a convergent position matches with what the actor thinks his own position should be (self positioning). In Table 3.1 the self positioning of actor1

Table 3.1 A database of positioning statements sorted by other positioning (including an example)

Actor making the statement	Actor that is positioned	Activity or artefact	Additional reasoning	Examples
Actor1	Actor1	~	~	~
Actor2 *(large company)*	Actor1 (general practitioners)	uses Point-of-care testing devices	supports decision making	anaemia
Actor3	Actor1	~	~	~
Actor4	Actor1	~	~	~
Actor1	Actor2	~	~	~
Actor2	Actor2	~	~	~
Actor3	Actor2	~	~	~
Actor4	Actor2	~	~	~
…	…	…	…	…

is given in the third and fourth column of the first row. The issues addressed in these columns can match or mismatch with the convergent other positioning. By performing an analysis of both measures for all actors, a complete overview of convergence in the envisioned positions and matches with self positioning can be provided. The table that presents these results should also provide explanations about the content of the convergence and match. Such a table is shown in Table 3.2.

A second type of data presentation is obtained by plotting all other positionings in a network diagram. To do this, software from social network analysis, such as NetDraw (Borgatti, 2002), can be used. In such a diagram the number of different positionings attributed towards each actor is shown as well.[7] This type of data presentation allows for an assessment in terms of symmetry (or asymmetry) in the overall pattern of positionings. Complete symmetry means that all actors address each other in their scenario. This does not say anything about the content of the other positioning (as analysed with the first type of data presentation; Table 3.2). It does provide an overview of whether different actors address each other or not. Furthermore, as the positioning statements in the database are all about the same topic, such a diagram provides insight into which actors are positioned the most in relation to the topic. The diagram therefore provides additional results compared to the first type of data presentation. There are different

Table 3.2 Structure of the results table in the first type of data presentation (including an example)

Actor	Position (convergence of other positioning)	Match of position with self positioning
Actor1	*Convergent or divergent?* Explanation	*Match or mismatch?* Explanation
Actor2	*Convergent* Will use Point-of-care testing devices extensively	*Mismatch* Will not accept the use of Point-of-care testing devices
…	…	…

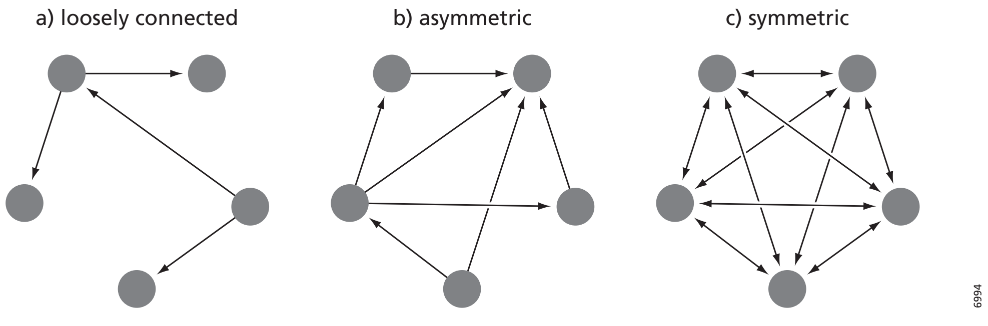


Figure 3.3a–c Possible patterns in other positioning

types of patterns that can be made visible with such network diagrams. Figure 3.3 provides a few possibilities.

Figure 3.3a represents a situation where some actors position others, but there is no clear pattern. The actors are loosely connected to each other. Figure 3.3b shows a higher degree of other positioning. This is an asymmetric situation in the sense that one actor is attributed a key position (top right), while this actor does not position others. The third pattern is completely symmetric (Figure 3.3c). All actors position each other and are positioned equally. When the positions are also convergent (to be assessed with the first type of data presentation) there is no misunderstanding over who should do and is doing what. The latter can be seen in the semi-conductor industry, where exists a clear division of labour between universities, research institutes, and different companies (producing equipment to make chips or producing the chips themselves). There will be no difference in answers when you would ask what the other parties' roles are in the overall field of computer chip manufacturing and every actor will likely attribute a role to every other actor. Emerging technologies, can be assumed, start from the other extreme (Figure 3.3a). Parties might even be unaware of each others possible roles. These possible patterns do not represent a necessary order in the evolution of patterns in positioning. They are merely examples of patterns that could be found in the data.

To conclude, when presenting the data (a set of self and other positionings from various actors about a certain topic) these two types of data presentations enable an analysis of how various actors position selves and others. The results of such an analysis can provide insight into how actors relate to each other.

3.3.3 How interactions are organised: spaces

Section 2.3.3 emphasised that the concept of space is used to study how interaction is or gets organised. Many different spaces exist in which organised interaction occurs. However, for actors operating in emerging technological fields, these existing spaces might not be sufficient to achieve their goals as a new situation requires different interactions or different ways in which interactions should be organised. This is one of the reasons why actors create new spaces. New spaces can also emerge more spontaneously. New spaces are of particular interest in understanding the dynamics of emerging technologies (see Section 2.3.3).

To obtain better understanding of the concept of space and the dynamics of spaces, Rip and Joly (2004) call for collecting interesting historical and contemporary cases of spaces. To study these cases they provide a protocol. This protocol distinguishes different elements, namely structures and dynamics, socio-cognitive dynamics, and outputs. The protocol further lists various items under each element. Applying this or an equally detailed protocol would imply an extensive study of (preferably) historical and international comparable cases (Rip and Joly, 2004).

In this thesis it is not the intention to conduct such a detailed study of different spaces. The intention here is to indicate that the concept of space (and especially new space) has some potential in understanding how interactions are and get organised in emerging technological fields. In line with this goal, the method to study spaces can be kept simple. A method that supports the analyst in getting an idea of what is at stake and what the dynamics are is sufficient. In studying spaces, there are at least three aspects that should become clear, namely 1) the occasion for the space to emerge or to be created, 2) the characteristics of the space, and 3) the effects of the space. These aspects are elaborated below.

For both types of spaces (created and emerging) there is an *occasion* for the space to be opened up. Thus, recognising and describing the occasion is a first step in studying and understanding a new space. The occasion for new spaces can be very divers (see Section 2.3.3), such as a scientific-technological breakthrough or policy changes that aim to establish more intensive science-industry collaborations. Rather then looking for the occasion, the analyst can also analyse opportunities for new interactions to occur.

Every space that is opened up gets particular *characteristics*. These characteristics indicate the shape that the space gets. A short-list of characteristics that can be described for every space is helpful. In every space *actors are involved*. This is the reason why the concept of space is used here to begin with; actors interact in spaces. Who is involved and who is not, determines what is possible inside the space. Furthermore, every space has a *boundary*, which can either be physical (a location) or figurative (space that provides opportunities for interaction). Interactions inside the space are bound by an *infrastructure* that determines the possible types of interactions to occur. The period in which a space exists can differ as well, which makes *temporality* a characteristic of spaces.

Given that the concept of spaces is very broad in the sense that it captures a wide range of situations and phenomena, so are the possible *effects* that spaces can have. Here, the focus is on the effects that spaces have on actors and the interactions between actors. Further, created spaces can have a specific goal or purpose, and it can be analysed whether this goal or purpose is reached and had an effect. There can also be unintended effects that the creator(s) of the space did not expect. Such a specific goal or purpose is absent for emerging spaces.

Thus, in studying spaces a relation is sought between the occasion of the space, the characteristics, and the effects. These relations are illustrated in Figure 3.4. When this scheme is completed a basic understanding of a space is obtained. The data needed to describe the three aspects highlighted in Figure 3.4 are case specific. Data can be gathered by desk research, interviews, ethnography, recordings of interactions, and further documentation about the space. The analyst has to decide in a case by case manner what kind of data is needed to study the space.

To summarise the research design for the first line of research, Section 3.1 started with a description of the arguments underlying the choice for Lab-on-a-chip technology as the leading case in this thesis. This choice was made upon predetermined case selection criteria. Further, a method was developed to construct a rich and detailed historical narrative of emerging

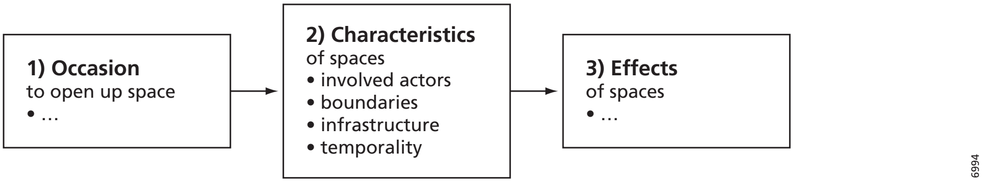


Figure 3.4 Scheme to study a space

technological fields. It was argued that a tool that is able to map the socio-technical entities that become part of a technological field over time, would support the historical narrative. Such a tool will be developed in Section 4.1.

Then, for each of the three concepts a method was developed to study it. Possible emerging irreversibilities can be found in the historical narrative. To understand the dynamics of these possible emerging irreversibilities, they should be further investigated. For this, additional data gathering might be needed. A mapping tool that is capable of depicting actors that are influenced by the emerging irreversibility at different levels can be supportive in studying the dynamics of emerging irreversibilities. Such a tool is developed in Section 4.2. By gaining insight into the dynamics of emerging irreversibilities, early entrenchment can be better understood.

For studying positioning in emerging technological fields, it was argued that prospective positioning statements can be used. These statements are found in the scenarios constructed by different actors as part of the research design in the second research topic. Two types of data presentation were offered to analyse patterns in prospective positioning statements: a table presenting convergence and match for each actor, and a network diagram indicating the number of different positionings attributed to each actor. With these types of data presentation, results can be generated that indicate whether positions of various actors converge and whether the convergent positions match with the self positioning of these actors. Positionings also influence how actors interact with each other in the present, and with this method, an attempt is made to analyse how actors relate to each other.

For studying spaces, a simple scheme was developed that enables the analyst to describe the basic aspects of any space: the occasion, the characteristics, and the effects. A short-list of four characteristics was developed as well. With this method, a description of a space can be made and the analyst can gain basic insight into how interactions are organised in the space.

3.4 Tailoring Constructive TA: a 3-step CTA approach

The CTA approach that is designed in this section is focused on stimulating broadening and enriching in the normal working environment in order to improve the quality of innovation processes. In doing so, an alternative route is explored to circumvent the Collingridge dilemma (see Section 1.4). The context in which the CTA approach is applied is very specific, namely an emerging technological field. This implies a need to tailor CTA methodology for this specific purpose into a dedicated approach. In terms of design, the CTA approach should enable participants to broaden their perspectives and to enrich their insights into the dynamics of innovation processes (see Section 2.5). One of the ways by which this is picked up is by using socio-technical scenarios in the approach. Socio-technical scenarios are used to support actors in getting a broad view on the topic and to formulate their thoughts on the future developments in a structured manner. Thus, formulating a scenario to some extent contributes to broadening and enriching. As a side effect, the formulation of socio-technical scenarios will likely support actors in dealing with the high complexity of technology developments in general, and specifically with the high uncertainties in emerging technological fields (Section 1.3).

The intervention comprises three steps (a 3-step CTA approach), which is presented in Figure 3.5. This 3-step CTA approach is introduced briefly below.

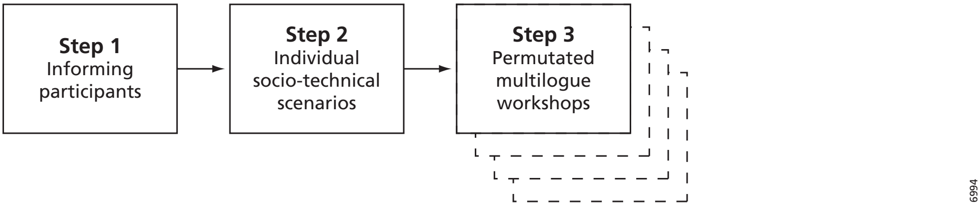


Figure 3.5 Steps taken in an intervention using the 3-step CTA approach

The *first* step focuses on levelling the knowledge gaps between the heterogeneous participants that partake in the intervention. This is done by providing information about previous developments (both scientific and broader) of the case. The *second* step involves the formulation of individual socio-technical scenarios. Through the formulation of the scenarios the participants become (more) aware of their visions and ideas, and of which aspects are linked to the different technology options they have in mind. The *third* step consists of workshops where the participants actually meet. During a workshop, the participants get the opportunity to share their ideas and opinions, and to reflect on that. The workshop design is permutated in order to gain insights into 'how to design' interventions for emerging technologies (see Section 3.4.4).

The topic of the intervention is similar to the case for the first research topic: Lab-on-a-chip technology. However, for a practical reason here the scope of the topic is further reduced. The reason is that, when the topic is too broad, it will be more difficult for the participants to have a useful discussion about possible technology options. Lab-on-a-chip technology has different application areas such as environmental monitoring, medical diagnostics, drug screening, and the production of fine chemicals. In the Netherlands, the health care industry (not pharmaceutical) is well developed. Furthermore, Dutch research institutes focus more on medical applications than on other topics. Therefore, the topic was further defined as Lab-on-a-chip technology for medical diagnostics. Box 3.2 explains how the participants were invited.

Box 3.2 Inviting participants

The set of participants consisted of scientists, businesses, (potential) professional end-users, policy makers, investors, and in this case on medical applications, insurance companies. Invitations were sent out as the scenario interviews and other interactions (e.g., telephone calls, emails, and meetings at conferences) preceded, which means that the actors were invited while the project was running.

When visiting participants for the scenario interview, the CTA analyst gets to know the field better. In this way the project can build extensively on the knowledge from the field. For example, interviewees expressed opportunities for biotechnology companies to use Lab-on-a-chip technology for developing medical applications. Subsequently, these companies were invited, which enlarged the scope of the project and at the same time served the Lab-on-a-chip field by involving a broader set of relevant actors into the project.

When invited, the participant is asked to partake in a sequence of activities, from informing and the scenario interview up to a follow-up interview. This likely increases the commitment of participants to the project.

3.4.1 Step 1: informing participants by providing information

Emerging technological fields are subject to a high uncertainty about outcomes (innovations), yields, and strategies to be taken. Moreover, not all actors have equal knowledge about technological developments and the interests of different professional environments (e.g., science, business, end-use, and government). It is unclear who is and should be doing what to make technology options commercially and socially successful. In addition, potential users (and society more broadly) are often largely unaware of the possibilities and their consequences. For CTA activities, the existence of these knowledge gaps implies that the participants should be informed about the past developments of the field. This should preferably be based on an in depth case study of initial structures and roles (e.g., Van Merkerk and Robinson, 2006). These initial roles and structures provide information on the state of the emerging technological field. For example, the different focus points in ongoing research, the extent to which companies are involved, and whether products are already in use and where.

Box 3.3 Informing participants

The CTA analyst writes two 3-page documents. One general text describing the history of the field and the actors that got involved over time (until 2005). Another text describes the scientific advances. Both texts are based on an in-depth study of the development of the Lab-on-a-chip field (Van Merkerk and Robinson, 2006), which included around 20 interviews and extensive desk research. The participants are asked to read these texts to prepare themselves for the scenario interview (see Section 3.4 and 4.3).

Providing such *information* is the first step in the 3-step CTA approach. This provision of information has two reasons: 1) to decrease the information asymmetry among the actors that is naturally present in any emerging field, and 2) to provide information that was not readily available before, but is needed for the participants to develop their visions and build their arguments upon. An example is an overview of previous technological advances provided to non-technical actors (e.g., end-users and governmental agents). Box 3.3 explains how the participants were informed.

3.4.2 Step 2: individual socio-technical scenarios

The second step concerns the *development of individual scenarios*. Since many expectations are out there and visions are often not well articulated, making them explicit (by embedding them into a scenario) helps to reduce uncertainty for the actors. Others need help to develop a vision to begin with. Scenarios are capable of doing just that (capturing expectations, visions, and expertise into consistent and rich stories) (Geels, 2002b). Scenario development supports actors to deal with uncertainties and to make their expectations and visions explicit. It is therefore a valuable tool to use in CTA exercises directed towards emerging technological fields, because the uncertainties in such fields are high and expectations play a major role in decision-making.

In constructing scenarios actors can envision and virtually test the dynamics of innovation processes regarding potential technical options, and it can become clearer how different actors and aspects influence each other. Participants develop their own scenario on the basis of their expertise, visions, and expectations. When scenarios are created, actors have to think and rethink the future developments of the technology. Geels (2002b) discusses that scenarios help to structure one's mind about the future. Also, as Van Lente *et al.* (2003, based on Schwartz, 1991) point out: "scenarios are a tool for ordering one's perceptions about alternative future environments in which one's decisions might be played out." This then also strengthens the awareness of the participants about their own perspectives and the possible futures that they have in mind, and possibly reduces a certain amount of uncertainty that they are faced with.

There exists abundant literature on how scenarios can be developed of which the most famous (and most often used) originate from the work done in companies such as Shell (Schwartz, 1991). These Shell-type methods usually include many steps in which the problem situation is analysed and results in using an axes-technique to present a variety of scenarios as outcomes. These scenarios represent the extremes of the main drivers that were recognised during the construction processes. However, in this CTA approach a scenario method is needed that can be used during a one to two hour interview. Shell-type methods are not suitable under such time constraints as they require much more time to go through all the steps. Moreover, in this CTA approach the focus is on broadening and enriching, which requires a scenario method that captures a broad variety of aspects. Socio-technical scenarios address this issue, because they balance different aspects (technical, economic, political, and socio-cultural), and -important- emphasise the relations between them in order to highlight the mutual interaction between the technical and the social domain. Under the condition of limited time expenditure, in Section 4.3 a simple tool is developed that is used for the construction of individual socio-technical scenarios. An example of a socio-technical scenario is given in Box 4.2. The individual socio-technical scenarios provide a common ground for discussion in the next step of the approach: multilogue workshops. All participants broadly addressed different aspects and are therefore prepared to discuss technology options broadly in a workshop as well.

Vision assessment is another approach to capture future developments and can be combined with TA activities as is developed recently in the (to CTA related) ILA approach in Roelofsen *et al.* (forthcoming 2008). In this work visions are considered as desirable futures that are shared by a collection of actors (Grin and Grunwald, 2000). Within this approach the emphasis is on assessing desirable future visions for ecogenomics from the perspective of a broad range of actors,[8] and subsequently integrating these visions in order to construct a shared vision on desirable directions for science and technology developments in the area of ecogenomics.

Comparing this approach from Roelofsen *et al.* (forthcoming 2008) with the 3-step CTA approach the following differences can be observed. In the 3-step CTA approach the focus is on preparing the actors individually for interactive meetings rather than constructing a shared vision, i.e. no consensus is advocated. The socio-technical scenarios pay explicit attention in balancing technical, economic, political, and socio-cultural aspects as well as the relations between them. In this thesis there is further attention for driving forces and barriers that originate from the different aspects. In this way the scenario becomes a balanced and more probable scenario. Visions assessed in the ILA approach are not balanced in such a structured manner.

3.4.3 Step 3: multilogue workshops

The reason to organise workshops as part of this CTA approach is that face-to-face interactions stimulate participants to broaden their perspectives and to enrich their insights into the dynamics of innovation processes. Through interacting with each other the participants get the chance to reflect upon each other's (and their own) visions and opinions. To stimulate such interactions the individual socio-technical scenarios are used during the workshop. These interactions have the shape of a multilogue: a discussion among more than two people. By structuring the meeting, the CTA analyst can -to a certain extent- steer the discussions and outcomes. For example, it makes quite a difference whether the structure of the meeting is designed to broadly explore a range of technology options as is the case here, or solving an impasse in a certain debate, or reaching consensus about a certain topic or problem. Box 3.4 explains the design of the multilogue workshops for the 3-step CTA approach.

Box 3.4 Multilogue workshops

In striving for broadening and enriching, there should be ample time reserved for discussion. It is through face-to-face interaction that participants can gain insights into the interests and views of other actors and can alter their views and opinions accordingly. Preferably, a meeting like this consists of a diverging phase to broadly explore different technology options, and a converging phase to give enough inducement for the participants to draw conclusions (e.g., on the feasibility of different technology options) (De Bruijn *et al.*, 1998). The discussions do not have to result in consensus.

Every participant attends one workshop (out of four), which lasts for a full afternoon. A workshop comprises four rounds. The first two rounds focus on discussing the scenarios.[27] In these rounds the participants start to know each other. The third round is a brainstorm in which the participants are asked to formulate technology options (diverging phase).[28] To the participants, a technology option is explained as a combination of an application and a specific market or practice. For example, an instrument that measures a protein that is indicative for a heart attack (application) for general practitioners (practice). In the fourth round, the potential for convergence is explored by scoring the preferred technology options of the participants on feasibility and desirability with a prioritisation matrix. A discussion is held about the results of the prioritisation matrix. This converging round provides the participants with an overview of which technology options are held most desirable and feasible by the group of actors that are present at the workshop. This design does not guarantee that convergence is reached. However, the participants can become more knowledgeable about each others perspectives and can take these into account in the development of their plans.

A Group Decision Support System (GDSS) is used to support the workshops.[29] The use of the GDSS is directed towards making the multilogues more efficient. In this way the system is used to speed up the discussion or to guide it in a certain direction through polling on discussion points, brainstorming, or scoring technology options. With the system in use, the participants have equal opportunity to give input. Although the workshops are held with the support of the GDSS, the focus remains on the discussions. The GDSS also serves as a way to document interactions.

At the end of the workshop the participants are asked to fill up a questionnaire. This questionnaire assesses whether the participants (immediately after the workshop) have the feeling that the workshop will affect their work in the coming months and whether they are interested in follow-up activities (and if yes, what kind of activities).

Soon after the last workshop, the participants are provided with a report describing the results and discussions in all four workshops. In this way, all participants become knowledgeable about the results in the other workshops.

To support and prepare participants in the period before the workshops, a website (with a password protected section) is set up to give information about the project, to provide a timeline and list of participants, and to distribute (anonymous versions of) all the individual scenarios (grouped by actor). The latter enables participants to read scenarios from other actors before going to one of the workshops.

Before the setup of the workshop is used in the intervention a test session is organised. In this test session colleagues of the CTA analyst act as the various actors. By testing the workshop in this way, the facilitator gets a good feeling about the timing of the different rounds, how the tools of the GDSS should be explained, and whether the setup of the workshop is clear to the participants.

3.4.4 Workshop permutations: use of scenarios and actor composition

One of the aims of the research design is to develop a CTA approach that can provide methodological lessons. Research question 2.2 (see Section 2.6) puts forward which permutations will be informative for CTA method development. In developing a research design to answer this question, the relation between the design and the effects should be conceptually understood. In Section 2.5, a conceptual scheme was developed that provides such understanding (Figure 2.4). In Figure 3.6 this conceptual scheme is specified for the 3-step CTA approach. The prime

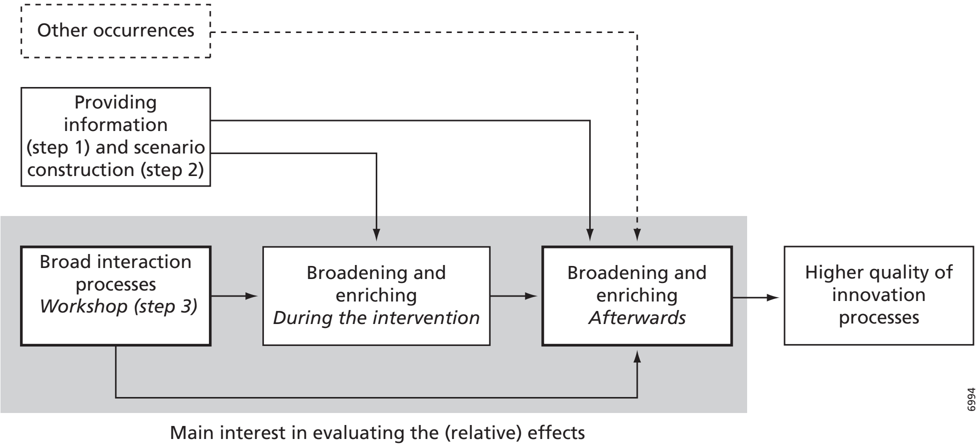


Figure 3.6 Conceptual scheme of effects for the 3-step CTA approach

interest in evaluating the approach is on the effects afterwards, when the participants returned to their normal working environment (see Section 2.5).

Different interaction processes can lead to different effects during and after the intervention. Interaction processes are partly determined by the setup of the workshop, but also by who is present at the workshop, and by the tools that will be used. In short, when adding permutations to workshop design, this can lead to different interaction processes and subsequently lead to different effects in terms of broadening and enriching.

In order to be able to draw methodological lessons, the permutations should likely lead to differences in interaction processes. Many permutations can be chosen that fit this criterion. However, the choice is stronger if the permutations are also linked to core aspects of the approach taken in this thesis. Two of such permutations in workshop design will be discussed below.

In explaining the second step of the approach, it was emphasised that socio-technical scenarios are used to support actors in getting a broad view on possible future developments. It was further explained that socio-technical scenarios can support actors in dealing with the high complexity of technology developments in general, and specifically with the high uncertainties in emerging technologies. Socio-technical scenarios are therefore used to prepare the participants for the group meetings and to take the first steps in broadening and enriching. It remains, however, a question in what way the scenarios can best be used as input during the multilogue workshops (step 3). When during the workshops scenarios are used in different ways an answer to this question might be given. To address this issue the following permutation is proposed: scenario presentation versus issue selection. When scenario presentation is used, a participant explains his or her scenario to the other participants. After the presentation there is ample time for discussion. This is repeated in the second round of the workshop. The scenarios chosen for these rounds should differ significantly in content and originate from participants with different backgrounds. In this way a broader set of aspects is introduced in the discussion, which may contribute to the divergence of the first two phases of the workshop and the richness of the discussion (see Box 3.4). Two (out of four) workshops use the individual socio-technical scenarios in this way. The two other workshops use issue selection, where the issues come out of an analysis of the socio-technical scenarios by the CTA analyst previous to the workshop (see Box 3.5). This analysis surfaces 'the issues on which the scenarios (and thus the participants) differ the most'. Arguably, issues upon which the participants differ provide occasion for discussion. During a workshop (in the first round) these issues are listed and (with the GDSS, see Box 3.4) the participants can choose the issue they, as a group, want to talk about.

Box 3.5 Analysing socio-technical scenarios as input to issue selection workshops

The list of issues from which the participant can choose in the issue selection workshops are those factors on which, in the socio-technical scenarios, the participants differ the most. Data gathering is performed in the same way as for the analysis of prospective positioning (see Section 3.3.2), with one difference. The database for analysing prospective positioning consists of statements about a single topic. In this analysis all topics are included, which implies that all positioning statements are subtracted from the individual socio-technical scenarios.

In the analysis the statements in the database are grouped by similarity in topic and by the actor that made the statement. By doing so, for different topics, the analyst can trace whether the various actors differ (or not) in their opinion about the topic. By systematically going through all the topics in the database, those topics upon which the participants differ the most can be identified.

The result of this permutation is that the discussions are initiated in different ways. This can have an effect on the outcome of a workshop since the start of a discussion can influence the course of a discussion and the interactions during a discussion. The mechanism behind this effect is that interactions build upon each other which may result in a sort of 'conversational path dependency'.

The outcomes of an intervention can also be influenced by the set of actors to which the intervention is made available. Arguably, the interactions during a workshop depend on the actor composition that is present at a workshop. The question is: does a broad actor composition stimulate broad interactions? At one extreme, when only one type of actors is present, interaction processes are likely to be less broad compared to a heterogeneous set of actors (the other extreme). With a heterogeneous set of actors, a discussion topic can be informed by the perspectives of the various actors that are present. However, it remains a question whether a heterogeneous workshop, in terms of actor composition, would be more productive compared to a narrower actor composition. Therefore, the actor composition is permutated as well.

In deciding which permutation in actor composition should be made, Section 2.5 emphasised that a distinction between insiders and outsiders is valuable for emerging technological fields (Garud and Ahlstrom, 1997). Insiders work towards the realisation of technology options and are committed to its success (e.g., science and business), while outsiders (e.g., professional users and government) are selectors in the sense of having multiple options to solve their problem of which the technology option under discussion is just one of the possible solutions. In emerging technological fields insiders and outsiders likely still stand relatively far apart. This means that they are not very knowledgeable or even unaware about each others interests, while in the future there might be overlapping interests. Taking up this distinction in actor composition, this leads to a permutation of insider versus mixed workshops, where the actor composition in the insider workshop consists of enactors (mainly scientists and businesses) and the mixed workshops incorporate a much broader set of actors consisting of insiders and outsiders (from scientists to end-users). Hence, two workshops include a broad set of actors and two other workshops focus on a more specific set of actors.

Figure 3.7 combines both permutations in workshop design, and provides a glance of the application of the intervention by also indicating the actors that were actually present in the four workshops.

		Actor composition	
		Insiders	Mixed
Use of scenarios	Scenario presentation	1 4 scientists 1 research institute 6 companies 1 business consultant	2 2 scientists 3 companies 2 health care professionals 1 institute 1 health care insurer 2 policy makers 1 venture capitalist
	Issue selection	3 6 scientists 1 research institute 5 companies 1 business consultant	4 2 scientists 3 companies 3 health care professionals 2 institutes 1 health care insurer 1 policy maker 1 venture capitalist

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Figure 3.7 Four permutations of the multilogue workshop

Other permutations are possible such as workshops with and without the prioritisation matrix (round four of the workshops; see Box 3.4), workshops with participants that did and did not formulate a socio-technical scenario, or workshops with only outsiders. The chosen permutations, however, address design issues that are considered core to the goals of the approach as laid out in Section 1.4. To permutate this aspect of the approach seemed valuable for CTA methodology development. On the second permutation, the distinction between insiders and outsiders is particularly valuable in emerging technologies. The reason being that relations between insiders and outsiders are relatively underdeveloped compared to later stage technologies.

To summarise this section, the three steps that make up the 3-step CTA approach are providing information, constructing individual socio-technical scenarios, and multilogue workshops. This design is aimed towards broadening and enriching by facilitating actors to engage in broad interaction. For example, socio-technical scenarios take a broad perspective on technological developments and innovation processes, which further stimulates broad interactions during the workshops. The workshops (step 3) are permutated to be able to draw methodological lessons regarding the use of pre-constructed individual socio-technical scenarios to support constructive intervention and on the effect of different actor compositions.

3.5 Evaluation scheme

Just like innovation processes, (C)TA activities are context dependent. This context dependency implies that case-by-case decisions have to be made on which effects should be assessed during the evaluation. Here, the 3-step CTA approach was designed to stimulate actors to broaden their perspectives and enrich their insights into the dynamics of innovation processes. The evaluation will be devoted to determine whether broadening and enriching occurred in the normal working environment, which will contribute to answering the second research question. There are two types of effects that should be assessed: the overall and the relative effects (see Section 2.5).

Assessing the overall effects is problematic, because an absolute value of broadening and enriching is difficult to define. What can be evaluated is whether broadening and enriching occurs at all. On this issue, the body of TA literature can provide indicators that can be related to broadening and enriching, which will be elaborated in Section 3.5.1.

To assess the relative effects, an evaluation scheme is developed below. This evaluation (Figure 3.8) comprises three phases that are linked to the conceptualisation scheme of the effects (see Figure 3.6).

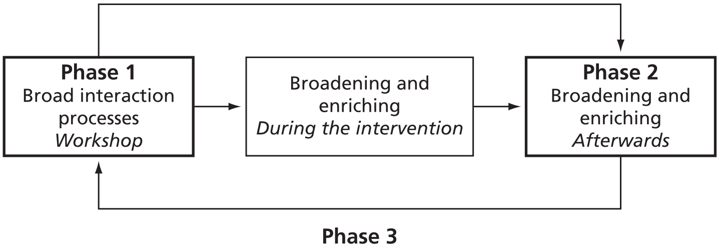


Figure 3.8 Three phases of the evaluation or relative effects (subsection of Figure 3.6)

In the first phase, differences in interaction processes during the workshops will be determined. The second phase will assess differences in effects in terms of broadening and enriching after the participants returned to their normal working environment. Phase 3 combines the results of the first two phases and focuses on differences in broadening and enriching that can be attributed to differences in interaction processes, and with that the workshops design. Section 3.5.2 will elaborate on these phases.

3.5.1 Evaluating the overall effect

In assessing the overall effects of CTA activities, TA literature provides two sets of indicators. Firstly, Decker and Ladikas (2004) give three indicators to operationalize knowledge uptake and use, namely ‘raising knowledge’,[12] ‘forming attitudes/opinions’,[13] and ‘initialising action’. Table 3.3 provides descriptions of the indicators for knowledge uptake and use, presents descriptions thereof, and uses stylized quotes as examples.

Table 3.3 Indicators for knowledge uptake and use

Indicator	Description	Stylized quote as example
Enhancing knowledge	Factual information that is taken up	By a health care professional: "Making a new scenario, I would include the distinction between acute and non-acute diagnostic tests." The participant adds information to his scenario
Changing attitudes and opinions	Changes in previously held views	By venture capitalist: "I now take more the perspective of the customer. This became apparent to me, because there were various actors present during the workshop." The participant now takes other actors more seriously
Initialising action	Action or interaction undertaken when the participants returned to their working environment	By a scientist: "I am now working on a new research plan." An idea from the workshop is changed into action in the normal working environment

A second set of indicators can be found when looking at the quality of the effects reached through an intervention. Criteria that determine the quality of CTA activities have been proposed and discussed before by different scholars (Schot and Rip, 1997; Schot, 2001; Genus and Coles, 2005). They see anticipation, reflection, and learning as important quality indicators for CTA activities. Table 3.4 provides descriptions of these quality indicators, presents descriptions thereof, and uses stylized quotes as examples.

Table 3.4 Indicators for the quality of CTA activities

Indicator	Description	Stylized quote as example
Anticipation	Whether and how participants take longer term effects into account. Relevant trends and expected future changes are used in the present when assessing technological opportunities	By a health care professional: "There is a lot of research on biomarkers in the years to come that can be incorporated in Lab-on-a-chip devices." Future research results can be anticipated by designing Lab-on-a-chip devices for biomarkers
Reflection	Insights can be gained by looking at one's own perception from another angle or viewpoint. Reflection is therefore a reassessment of your own actions, which can be triggered by interacting with others	By a scientist: "In my work I now also think about what the user would benefit from my inventions." The scientist reflects on his own practice, which might change the choices he makes in, for example, writing research proposals
Learning	New understandings that can be either more factual (new or adapted insights) or more towards the understanding of the underlying dynamics of technological development and innovation processes	By a company: "Companies should have contacts with research groups for their basic research." The company learned about the role that another actor can play in innovation processes

Both sets of indicators give indications for broadening perspectives and enriching insights into the dynamics of innovation processes. That a participant broadens his or her perspective can be observed, for example, when a participant obtains new facts from actors they are normally not in contact with (enhancing knowledge and factual learning). When the learning content deals with how innovation processes can go, also enriching is achieved. An example of another effect indicator is, when a participant changes his opinion in the sense that health care insurers are important to consider, because they fulfil a selective role for health care applications. This example shows that a changed opinion can both indicate broadening (now also considering health care insurers) and enriching (the role that health care insurers can play in innovation processes).

It therefore depends on the content of the effect indicator whether broadening or enriching can be observed. In principle all six effect indicators can contribute to broadening and enriching. In assessing the relative differences, all six effect indicators will therefore be combined and considered as a proxy for the relative differences in broadening and enriching. Combining the six effect indicators to a proxy for broadening and enriching can be seen as a grey box. Not black, since there is a certain amount of understanding how to measure broadening and enriching, i.e. the six effect indicators offered by TA literature. Also not white or transparent, since the relations between the effect indicators and broadening and enriching, are not fully understood and conceptualised.

In assessing the overall effect an assessment is made of the effects *after* the intervention, when the participants returned to their normal working environment. For this, the participants have to be contacted again some time after the intervention has taken place. Not too soon, as the participants have to experience work for a while to be able to assess the effects that the intervention had on their thinking, acting, and interacting. Follow-up interviews held by telephone can be used for this purpose. Box 3.6 explains how the follow-up interviews are conducted for the evaluation of the intervention described in this thesis.

During a follow-up interview the participants are asked about the effects that the intervention had on their thinking, actions, and interactions. The questions are not directly related to the six indicators, but are more directed at what actually happened and changed, and which effects can be related to the intervention two months earlier. A follow-up interview thus assesses the effects of the intervention on everyday working activities of the participants. The evaluator then has to go through the answers and attribute these to the six effect indicators. For example, when participants express that they now take into account more actors and more aspects (and give example thereof), this indicates that their attitudes and opinions changed.

In attributing data to the different content indicators, some pieces of data might be indicative for knowledge uptake and use (‘enhancing knowledge’, ‘changing attitudes and opinions’, or ‘initialising action’) as well as for a quality indicator (‘anticipation’, ‘reflection’, or ‘learning’). For example, a piece of data that indicates factual learning might also be indicative for enhancing knowledge. Having said this and recognising that both sets of effect indicators have different functions in the analysis, the six indicators are kept separate in assessing the effects.

To summarise the evaluation for the overall effects, it was argued that two sets of effect indicators can be used to assess whether broadening and enriching occurs in the normal working environment of participants as a result of the intervention. In this way a combination of the six effect indicators is used as a proxy for broadening and enriching.

Box 3.6 Follow-up interviews

Two months after the workshops, interviews by telephone are conducted with all (fifty) participants. A follow-up interview comprises three parts. The first part focuses on 'what happened after the intervention'. A period of two months is taken between the workshop and the interview to make sure the initial enthusiasm is gone, and participants can really think back what the intervention means in their work and whether it changed their thinking. Questions are asked whether the participants initiated new actions or interactions after the intervention (e.g., new projects or collaborations), whether the participants now take into account more actors and aspect, and whether they made strategic changes.

The second part assesses whether the participants want to make changes to their individual socio-technical scenario. The scenarios are an indication of the expectations and visions that the participants have on the future socio-technical state of Lab-on-a-chip technology for medical applications. The follow-up interviews can identify whether the participants want to deviate from their scenario and whether this change was caused by the intervention. Practically, when the appointment of the interview was made the participants were asked to read their scenario again as a preparation for the interview.

Third, questions are asked whether the participants experienced any changes in the way they perform and interact in their work (e.g., when talking to colleagues or assessing opportunities for collaboration). Answers to theses questions can indicate subtle changes to how participants, for example, integrate learning effects into everyday working activities.

During the follow-up interview the interviewer repeatedly asks whether the effects expressed by the participants are directly related to the intervention. This is important, because most of the questions can also be answered generally, which would indicate the effects of 'other occurrences' (see Figure 3.6) in two months of work rather than effects of the intervention. Further, the interviewer repeatedly asks the interviewee to give examples and further explanation. This is necessary to improve the quality of the data and not just get socially acceptable answers. Putting all answers in a spreadsheet gives the evaluator more overview, which helps to find differences between the four different workshops.

3.5.2 Evaluating the relative effects

In assessing the relative effect, actually the following question is proposed: can differences in productivity between the workshop permutations be attributed to differences in interaction processes? A method to answer this question comprises three steps; 1) assessing differences during the workshops, 2) assessing differences afterwards, and 3) comparing during and afterwards to assess whether differences during can be attributed to differences afterwards. These three phases are explained below.

Phase 1: differences in interaction processes

Section 3.4 argued that differences in workshop design can lead to differences in interaction processes. Many kinds of differences in interaction processes are possible, for example, discussing, negotiating, finding solutions, quarrelling, problematising, or contesting. Here, there is no particular focus on certain kinds of interaction processes. What is important is whether differences can be observed that are caused by the differences in workshop design.

The data of the first phase consist of transcripts of the four workshops. Sound recordings and camera footage are ideal for transcribing a workshop. When from the sound recording it is difficult to recognise who says something, the camera footage can support the transcribing procedure, because the postures of the participants can indicate the person that talks. It is also helpful to have an observer present at the workshops (preferably the same for all workshops) who makes notes. These notes can give a good overview of what happened during the meetings, provide points of departure for assessing differences, and also to have an extra pair of eyes and ears for the evaluator, which is always helpful and welcome.

Once the workshops are transcribed, the analysis of differences in interaction processes comprises two parts. Firstly, the transcripts are read carefully for a number of times. Whenever a certain passage of the text can be linked to a difference in design this is noted down. The evaluator then assesses whether or not the same link can also be found in the other workshops. In fact, the evaluator investigates whether workshop design has an effect on how participants interact during the workshops.

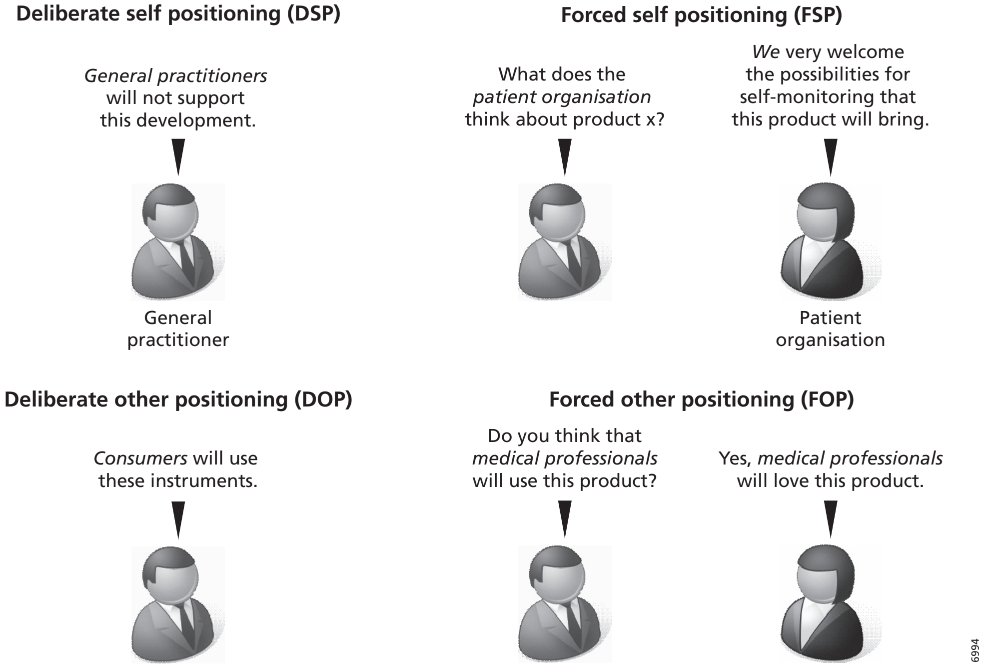


Figure 3.9 Illustrations for different types of positioning

Secondly, positioning is an important aspect of interaction (see Section 2.3). Positioning statements can therefore be used to analyse interaction processes during the workshops. The analysis concentrates on those statements (in the conversation) where individuals state the (future) role for themselves or others or express their opinion about a technology options. Analysing conversations with a focus on positioning emphasises the relations between various actors and the relation between actors and technology.

In making an analysis of positioning statements there are different types of positionings to take into account (Harré and Van Langenhove, 1999). Firstly, there is a difference between self and other positioning (see also Section 3.3.2), which makes a distinction between statements about one's own role or the role of somebody else. Secondly, a positioning statement (self or other) can be made on request (forced) or without (deliberate). For example, in the forced situation a request can be made to a person to express himself about another actor. In this case, the resulting positioning statement will be of the type forced other positioning (or FOP). Figure 3.9 illustrates the four different types of positioning statements. One statement can imply multiple types of positioning. Thirdly, a distinction can be made between positioning and counter positioning. Counter positioning indicates a statement that is made out of disagreement with the statement to which it relates.

The workshop transcripts record all statements that are made during a meeting. To perform the analysis, all positioning statements in the transcripts are marked with a code that represents the type of positioning statement (DSP, FSP, DOP, or FOP; see Figure 3.9). It is also noted down whether the statement is a reaction to another statement and whether it is an instance of counter positioning. When all statements are marked, the evaluator goes several times through the data and notes down any patterns that can be found as well as questions that are triggered by going through the transcripts. This approach makes the analysis highly iterative. The patterns that are found in this way can be indicative for certain interaction processes.

Phase 2: broadening and enriching after the workshops

This phase assess the effects in the same way as the assessment of the overall effects, although this time the focus is on differences between the workshop designs. For each of the six effect indicators, differences will be sought and discussed. These effect indicators, in two sets of three, were 1) enhancing knowledge, changing attitudes and opinions, and initialised action (indicators for knowledge uptake and use), and 2) anticipation, reflection, and learning (quality indicators for CTA activities).

To assess the relative differences, the results of each effect indicator can, relative to one another, be presented in a table. Outlining such a table then provides the results for the relative effects in terms of broadening and enriching.

Phase 3: attribution stories

In this phase of the evaluation, the various differences found in relative effects (broadening and enriching) (phase 2) are compared with the differences found in interaction processes (phase 1) (see Figure 3.8). The evaluator searches for matches between the different workshops. For example, assume that two of the four workshops show higher results on broadening and enriching. Are there then also differences in the interaction processes that can account for these differences? If yes, the evaluator continues, discussing whether it is plausible that there is indeed

Table 3.5 Successive steps in the evaluation of relative effects

Phase	Explained in	Concept	Evaluation steps	Data sources
1. During the workshops	Section 3.5.1	Interaction processes	Observing workshop dynamics Positioning analysis	Workshop transcripts
2. Two months after the workshops	Section 3.5.2	Broadening and enriching	Indicators for knowledge uptake and use Quality indicators for CTA activities	Follow-up interviews and socio-technical scenarios
3. Comparing during and afterwards	Section 3.5.3	Attribution	Attributing differences in broadening and enriching to differences in interaction processes during the workshop	All available sources

a causal link between the interaction processes and the overall effects. The result is presented as an attribution story.

In constructing attribution stories, the analyst attempts to relate the effects of the different workshops to differences in design. This can lead to plausible argumentation that a certain relation indeed exists. The attribution stories are also an important basis to draw methodological conclusions, for example, on which design leads most likely to the greatest effect in terms of broadening and enriching.

To summarise the evaluation of relative effects, a table can be presented that indicates the three faces (in five successive steps) to perform the evaluation of the intervention that makes use of the 3-step CTA approach (Table 3.5). The three faces in the evaluation of the relative effects are: assessing difference in interaction processes during the workshops, assessing differences in broadening and enriching afterwards, and constructing attribution stories.

3.6 Summary

This chapter developed the research design for this thesis. Research questions and conceptualisations from Chapter 2 were taken up and methods were developed to address the different research questions. In Section 3.1 a choice was made for the leading case that is used throughout this thesis. The choice was made on predetermined selection criteria and the emerging technological field of Lab-on-a-chip technology was found to fit these criteria.

In Section 3.2, a method to construct a detailed and rich historical narrative was developed. Such a historical narrative is insightful for both research topics. Data for the construction of the historical narrative are expression of expectations, agendas, and actor arrangements. Desk research complemented with interviews is used to gather the data. It was further argued that a tool that enables visualisation of the different entities that become part of an emerging technological field would be supportive in presenting the historical narrative. Such a tool will be developed in Section 4.1.

Then, the research design concentrated on methods to study the three concepts that were derived in Section 2.3; emerging technologies, positioning, and spaces. Each of the concepts will be studied with a different method. Emerging irreversibilities are investigated by analysing the influences that possible emerging irreversibilities have on different actors. Positioning is studied by analysing patterns in prospective positioning statement found in socio-technical scenarios from various actors. To study spaces, a simple scheme was proposed that enables the analyst to describe the basic aspects of spaces.

The two remaining sections developed the research design for the second research topic (constructive intervention for emerging technologies). In Section 3.4 a 3-step CTA approach was developed that is aimed at stimulating broadening and enriching. This aim is taken up in the approach by facilitating broad interactions for various actors. Individual socio-technical scenarios are used to prepare the actors for multilogue workshops. During the workshops these scenarios come back and are discussed again.

Testing the feasibility of the 3-step CTA approach is an important aspect of the research design. Therefore, in Section 3.5 an evaluation scheme was developed to assess the overall effect of the intervention in terms of broadening and enriching as well as the relative effects between the four workshops. To assess the overall effect, a proxy of two sets of effect indicators is used, namely 1) indicators for knowledge uptake and use, and 2) quality indicators for CTA activities. By evaluating the overall effects an assessment is made about the feasibility of the approach. The evaluation scheme for the relative effects comprises three phases: assessing difference in interaction processes during the workshops, assessing differences in broadening and enriching afterwards, and constructing attribution stories.

Notes

1 See http://www.abbottpointofcare.com/istat. Last visited August 6, 2007.

2 See http://www.chem.agilent.com/Scripts/PCol.asp?lPage=50. Last visited August 6, 2007.

3 See http://www.nanoned.nl for more information. Last visited September 3, 2007.

4 This section is partly based upon Van Merkerk and Van Lente (forthcoming 2008).

5 Note that this is not a problem for constructing a historical narrative (Section 3.2) or studying the dynamics of emerging irreversibilities (Section 3.3.1). There, the availability of data is part of the dynamics.

6 Ideally, a complete set of scenarios consists of more than one scenario from every actor that is somehow related (and thus can be positioned) to the topic.

7 When there is not an even distribution of the number of scenarios for each actor (for example, more scientists were interviewed compared to health care professionals), there is unbalance in the representation of actors that make up the database. In this case normalisation of the relations in the diagram should be performed by dividing the number of other positionings from one actor, by the number of scenarios from that actor.

8 Ecogenomics (ecological genomics) is the application of genomics techniques in the field of (soil) ecology in order to enhance the understanding of the functioning of ecosystems (Roelofsen *et al.*, forthcoming 2008).

9 There are other approaches where scenario building can also be taken up as an explicit task in multilogue workshops, so-called scenario workshops. In the 3-step CTA approach, scenarios are only used as a basis

for discussion. However, the individual scenarios can become altered owing to the interactions during a multilogue workshop.

10 This is an example of where a CTA can contribute to unlock the creative potential of different societal actors and to embed this potential in the technology development (Smits *et al.*, 1995). In the diverging phase, this creative component potentially increases the number of considered technology options. At the same time, these options can be clarified and elucidated through discussion.

11 A Group Decision Support System (or Group Decision Room) consists of a number of computers that are coupled to a central computer and a beamer. With the system in use, different tools can be used to facilitate different group processes, like brainstorming or prioritisation.

12 The remainder of the text will diverge from the original reference by using the term 'enhancing knowledge' instead of 'raising knowledge'.

13 The remainder of the text will diverge from the original reference by using the term 'changing attitudes/ opinions' instead of 'forming attitudes/opinions'.

4 Tools for studying emerging technologies

In studying the dynamics of emerging technologies or intervening in emerging technologies, the analyst is confronted with complex situations to analyse. Various actors and entities interact in the evolution of emerging technological fields. Not surprisingly, in developing the research design (Chapter 3) it was argued a few times that (mapping) tools could be helpful to support the methodology.

In this chapter, three tools are developed based on the design criteria emphasised in Chapter 3. Firstly, Section 3.2 argued that combining a mapping tool with the historical narrative provides an insightful description of the history of an emerging technological field. Socio-technical mapping was offered as a type of mapping that can be used to dynamically visualise the various social and technical elements in a technological field. In Section 4.1 a tool to construct socio-technical maps is developed. Secondly, a three-level framework (Section 4.2) is a type of map that puts special emphasis on multi-level dynamics, but at the same time recognises multi-actor dynamics as well. Chapter 3 argued that such a tool can help to investigate the dynamics of possible emerging technologies as it can visualise the various actors that become influenced by the emerging irreversibility. Thirdly, to construct individual socio-technical scenarios (Section 4.3) an instrument is developed to support the interview in which the construction takes place. The emphasis in developing this interview instrument is on simplicity, but without loosing a broad perspective on technological developments and innovation processes.

Each of these tools is, when used in this thesis (see Chapter 5 and 6), useful in supporting the analysis and/or the gathering of data. These tools also have value more generally. They can be used in other studies as well and can therefore be considered as a result on its own.

4.1 Socio-technical mapping

A socio-technical map presents, over time, the elements (societal as well as technical) that become part of a technological field. The relevance of socio-technical mapping has been referred to in the literature (Gow, 2003; Rohracher, 2001; Guston and Sarewitz, 2002). However, a socio-technical map is never presented in a graphical form. This section is based on earlier work by Van Merkerk and Robinson (2006) that made an attempt to close this gap.

The use of 'social maps' is more common (Boon *et al.*, 2007), also in technology assessment projects (Smits and Leyten, 1991; Van Boxsel, 1994). Social maps often indicate the actors that are involved in a certain problem situation and the interests of the various actors in the present. Socio-technical mapping has a different function, because it concentrates on reconstructing the evolution of a technological field and preferably indicates the interactions between the social and the technical. Socio-technical mapping can be supportive in unravelling the dynamics of emerging technological fields.

What should be presented in a socio-technical map? Section 3.2 provided the design criteria. Firstly, socio-technical maps should be able to describe developments over time. Secondly, the tool should be able to illustrate the socio-technical character of technological developments. Thirdly, the map should be able to locate and distinct different types of actors. 'The social' can be presented by focussing on the actors that become involved (in one way or the other) in the technological field. 'The technical' can be presented by artefacts that give direction to the technological field. Furthermore, particularly for emerging technological fields, visions are forceful in guiding actions and interactions. Visions are therefore included in socio-technical mapping as well. To study the developments of an emerging technological field over time, different socio-technical maps can be drawn for different periods. Figure 4.1 gives an empty socio-technical map that allows for visualisation of the various entities over time.

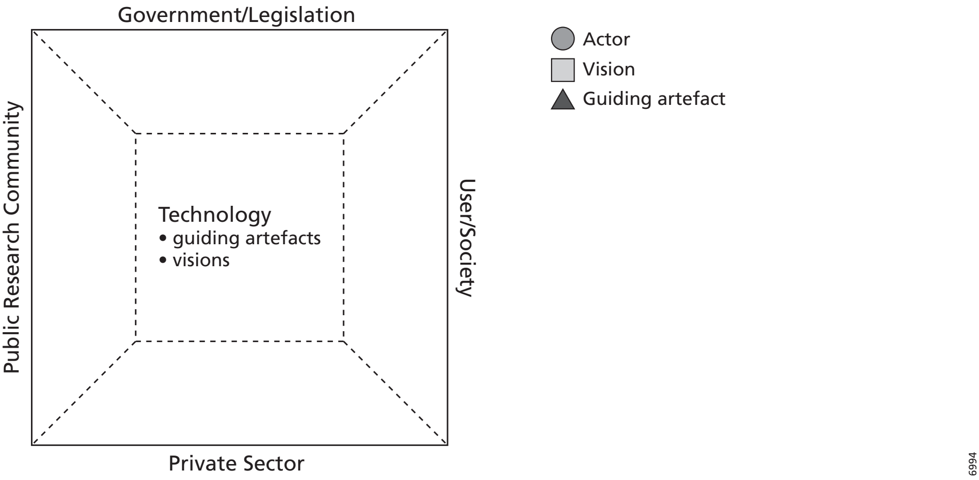


Figure 4.1 Empty socio-technical map.
The dimension of time is brought in by constructing different maps for successive periods

In this mapping tool different types of *actors* are distinguished. The four outermost sections are arenas where public researchers, actors from the private sector, the government and legislative bodies, and the (possible) end-users of technology options can be found. With this subdivision of actor groups, socio-technical mapping attempts to include all actors that become part of a technological field and to structure them in relevant categories. *Visions* refer to expectations that are shared by multiple actors. A vision addresses a possible future state in which the technology is included. An example for Lab-on-a-chip technology is 'integration', which emphases that different analytical steps (e.g., filtering, separation, and detection) should be implemented on one chip to give Lab-on-a-chips the necessary functionality. *Guiding artefacts* are those technological elements that guide the developments of the emerging technological field. An example for Lab-on-a-chip technology is 'DNA analysis'. The realisation of chips that could perform DNA analysis enabled further developments in the technological field. It also guides the constant developments of other methods to perform DNA analysis on a chip. Visions and guiding artefacts are depicted in the central box in Figure 4.1.

A socio-technical map can be divided into five areas depicting four different types of actors around a central box housing the visions that circulate in the field and the technological artefacts that guide the field. By constructing multiple maps for different periods, the dimension of time can be accounted for. Of course, maps that are structured otherwise are possible, but this map is simple and is therefore considered as a point of departure for socio-technical mapping. This version of socio-technical mapping is sufficient to support the construction of a case history and to reveal basic socio-technical patterns as addressed in the research design (see Section 3.2).

In gathering data to fill up a socio-technical map, for emerging technologies scientific literature provides a good point of departure. Scientific articles describe the progress that is made scientifically, and also provide data for determining the guiding artefacts and visions. Other data sources can be reports (e.g., from consultancy firms, research collaborations, or governmental agencies), news releases from businesses, and information about actual use. Interviews can be used to triangulate the data. In the various data sources the analyst looks for expressions that indicate when a social or technical element of the socio-technical map becomes articulated in the technological field. The unit of analysis are statements made by different actors through different media. Statements give more information than just keywords (Robinson *et al.*, 2007) and therefore provide a richer description of what is 'going on'. The topic of the statements can then be plotted into different socio-technical maps for different periods. Chapter 5 will present socio-technical mapping for Lab-on-a-chip technology.

For the analysis of the data, a database is constructed that provides the data to complete the socio-technical maps. A database entry holds 1) the actor that makes the statement, 2) the data source, 3) the year in which the statement is made, 4) the statement, and 5) the type of statement (expectation, agenda, or actor arrangement; see Section 3.2). In analysing the database, every statement was summarised with a keyword that describes the topic of the statement (sometimes one statement can get multiple keywords). The keywords are then clustered to make the number of keywords workable without loosing the content. These keywords can then be plotted into the socio-technical map by using the symbols (circle, square, and triangle) as shown in Figure 4.1. Hence, when a symbol is plotted in the socio-technical map this means that in a certain period of time, in the documented material, statements were made about the topic. Interrater interpretability was performed by coding the statements with two people.

4.2 Three-level frameworks

Three-level frameworks were designed and tested in the work by Van Merkerk and Van Lente (2005) on tracing emerging irreversibilities. In the work of Van Merkerk and Robinson (2006) three-level frameworks were used to investigate the dynamics of emerging irreversibilities. It is this use of the tool that was referred to in Section 3.3.1. Regardless of the use of three-level frameworks it is considered as a tool "[…] useful to organise the data and to structure it into a credible story." (Van Merkerk and Van Lente, 2005:1109)

The development of this tool started by recognising that there exist different levels of activity. Three interrelated levels are distinguished here: (i) locally, within a research group or company, (ii) more in general, within a scientific community or industry, and (iii) more global and diffuse, in society at large (see Figure 4.2). The vertical dimension lists the three levels of aggregation. The first level describes the processes that are present within and between research

	Public	Private	
Society	• NGOs • Governmental agencies • Spokespersons	• NGOs • Governmental agencies • End-users	Society
Scientific community	• Research consortia • Scientific communities	• Venture capitalists • Consultancy firms • Company networks	Industry
Research group	• Scientists	• Companies	Companies

6994

Figure 4.2 The three-level framework and the location of different actors

groups and companies. Research is conducted on very specific and widely varying subjects. Also, research groups work together on certain topics that can be picked up by a large established company or start-up. The second level refers to a scientific community, with its conferences and journals. In industry; industry networks, venture capitalists, and consultancy companies display their particular activities. The third level relates to the societal level, where governments, interest groups, and other societal actors articulate the social, political, and economic aspects of the

	Public	Private	
Society	• Reports by NGOs • Reports by governmental agencies • Spokesperson statements	• Reports by NGOs • Reports by governmental agencies • Reports related to end-use	Society
Scientific community	• Review articles that give an overview of the developments in the field • Reports on research consortia	• Reports that translate technological developments into market potentials (for example from venture capitalists) • Articles addressing the market potentials of technological developments (for example from consultants)	Industry
Research group	• Articles in scientific journals	• Press releases of individual companies • Articles that address the developments and potentials of applications	Companies

6994

Figure 4.3 Typical data sources for statements in each cell of the three-level framework new technological field. The horizontal dimension distinguishes between different core areas of technological activity: public and private related activity. Figure 4.2 also indicates in which cell statements of different actors can be expected.

Using a three-level framework naturally invites the analyst to gather data for every cell in the framework. This implies that heterogeneous data sources need to be employed. The unit of analysis are statements made by different actors through different media. Desk research is used to gather the statements and interviews can be used for triangulation and further insights. Figure 4.3 completes in the three-level framework with typical data sources for each cell.[1] The topics of the statements (or of combined statements) are plotted in the socio-technical map for presentation. In gathering the statements, the three-level framework also functions as a device to determine which data sources can be used.

4.3 Interview technique for constructing individual socio-technical scenarios

As part of the 3-step CTA approach individual socio-technical scenario are constructed. Section 3.4 listed design criteria for developing this interview technique; it should stimulate the interviewee to address a broad variety of aspects and the relations between them. Socio-technical scenarios address this issue, because they balance different aspects (technical, economic, political, and socio-cultural), and emphasise the relations between them, and in this way highlight the mutual interaction between the technical and the social domain. Furthermore, the scenarios should be constructed under the condition of limited time expenditure. One interview with a duration of one to two hours should do. This section presents an interview technique that enables to do so.

Constructing socio-technical scenarios by means of interviews can be performed as follows. A first step in scenario building is usually an analysis of the past (Van der Heijden, 1996; Postma and Liebl, 2005; De Jouvenel, 2000). How did the current situation come into existence? For example, the 3-step CTA approach as a first step provides information about the topic and the previous developments. The interviewees are asked to read this documentation prior to the interview.

Then, the scenarios are constructed in face-to-face interviews. The interviewer uses a scenario map showing four boxes (Figure 4.4);[2] representing technological, economic, political, and socio-cultural aspects. In close interaction the scenario is built up by repeatedly questioning the interviewee about these different aspects and how these aspects interrelate – a step that is not uncommon in scenario methods. Wack (1985:146), for instance, notes that making the interrelatedness of different aspects clear is the power of using scenarios. During the interview, the interviewer writes down the answers as keywords in the four boxes of the scenario map (Figure 4.4) and asks further questions about the coherence of the scenario. In this way, a scenario that balances technological, economic, political, and socio-cultural aspects, is created. Figure 4.5 indicates the locations in the scenario map where keywords of different issues are noted down.

Literature on scenario building further stresses the importance of finding (the most relevant) driving factors (e.g., Van der Heijden, 1996; Van Lente *et al.*, 2003; Postma and Liebl, 2005). The interviewee is therefore stimulated to articulate these issues as well. Colours are used to characterise the type of issue on the scenario map (fact (blue), barrier (red), or stimulating factor (green)). Arrows are drawn in the scenario map to indicate relations between different issues.

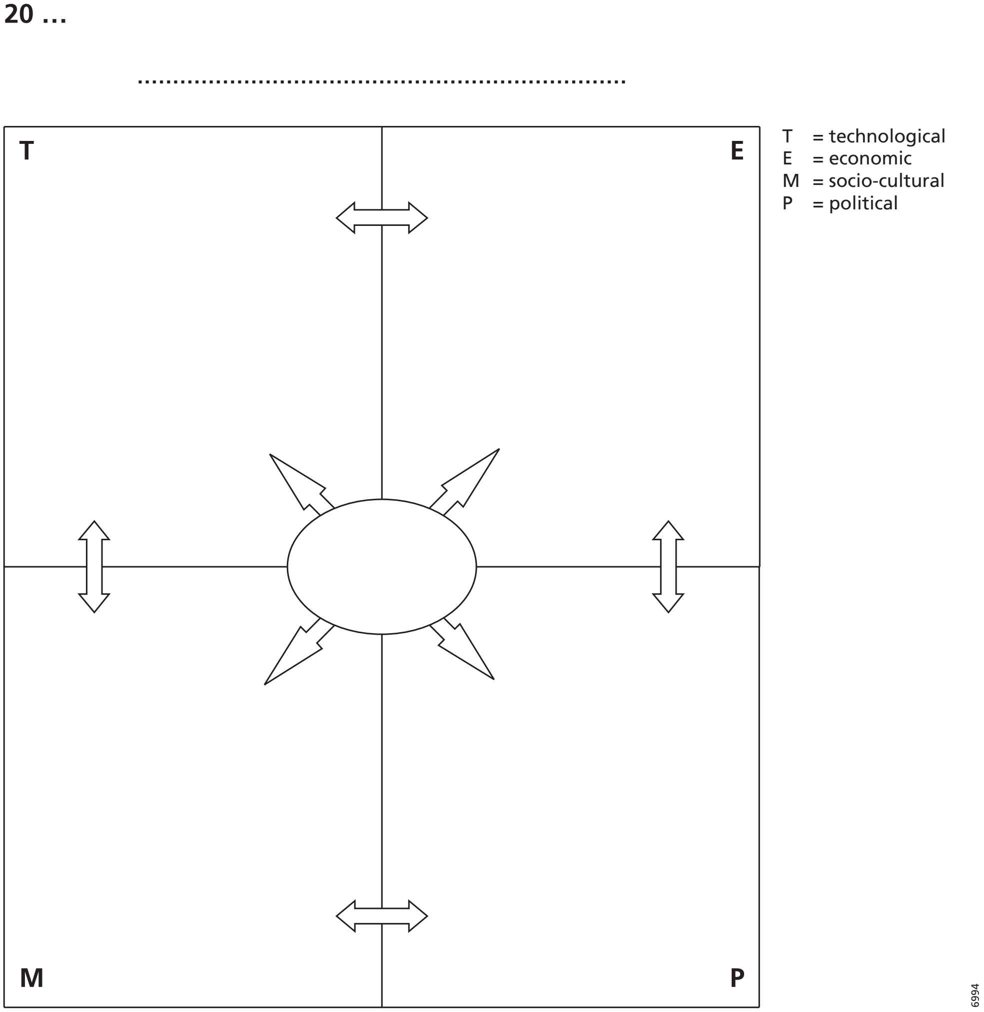


Figure 4.4 Empty scenario map with four boxes containing different aspects.

Figure 4.6 provides an example of how a scenario map looks like after a scenario interview. To finish, the scenario map, the interviewee is asked to summarize the scenario with a title. This sequence is performed for a future situation in 2010 and is repeated for 2015. The scenario is then written down as a one to two page story and is sent back to the interviewee for approval, which finalizes the scenario. Box 4.1 elaborates on the course of a scenario interview with this interview technique. An example of a socio-technical scenario for the emerging Lab-on-a-chip field is given in Box 4.2.

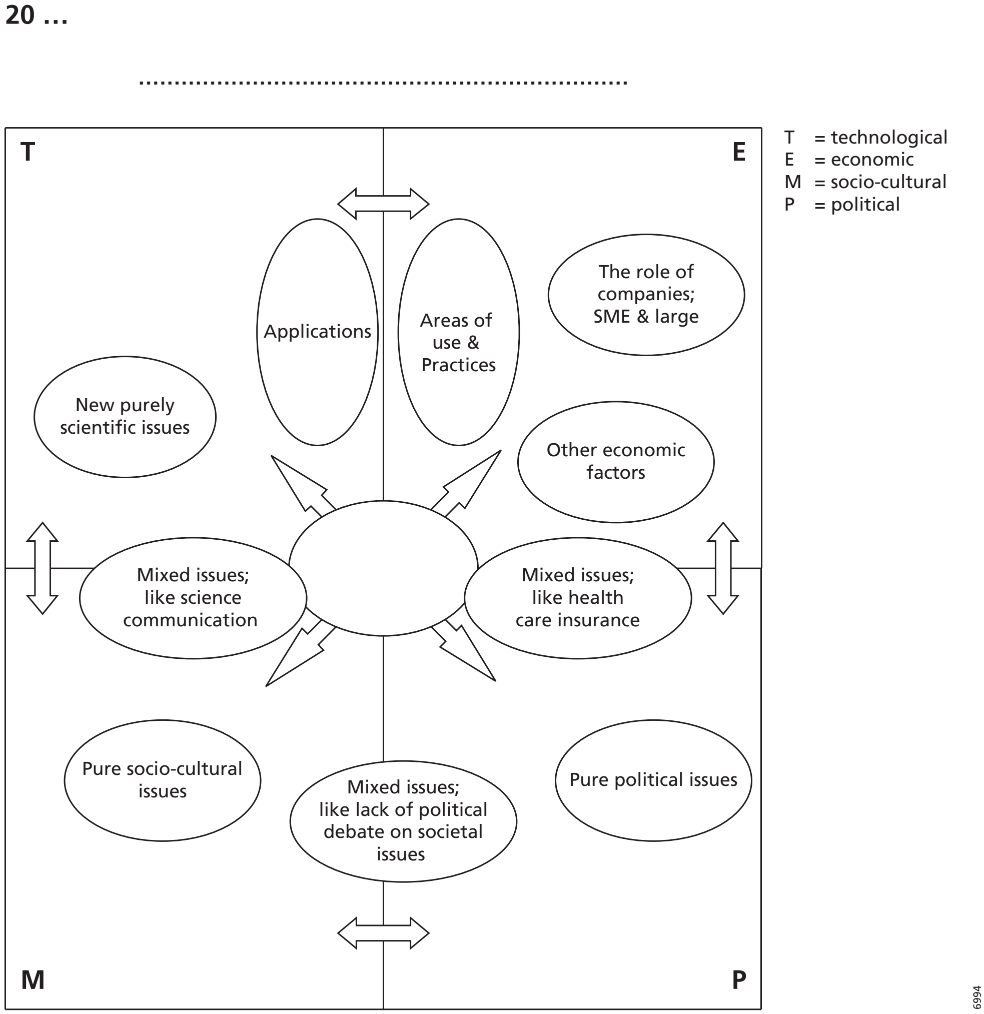


Figure 4.5 Indication of topics in the scenario map.

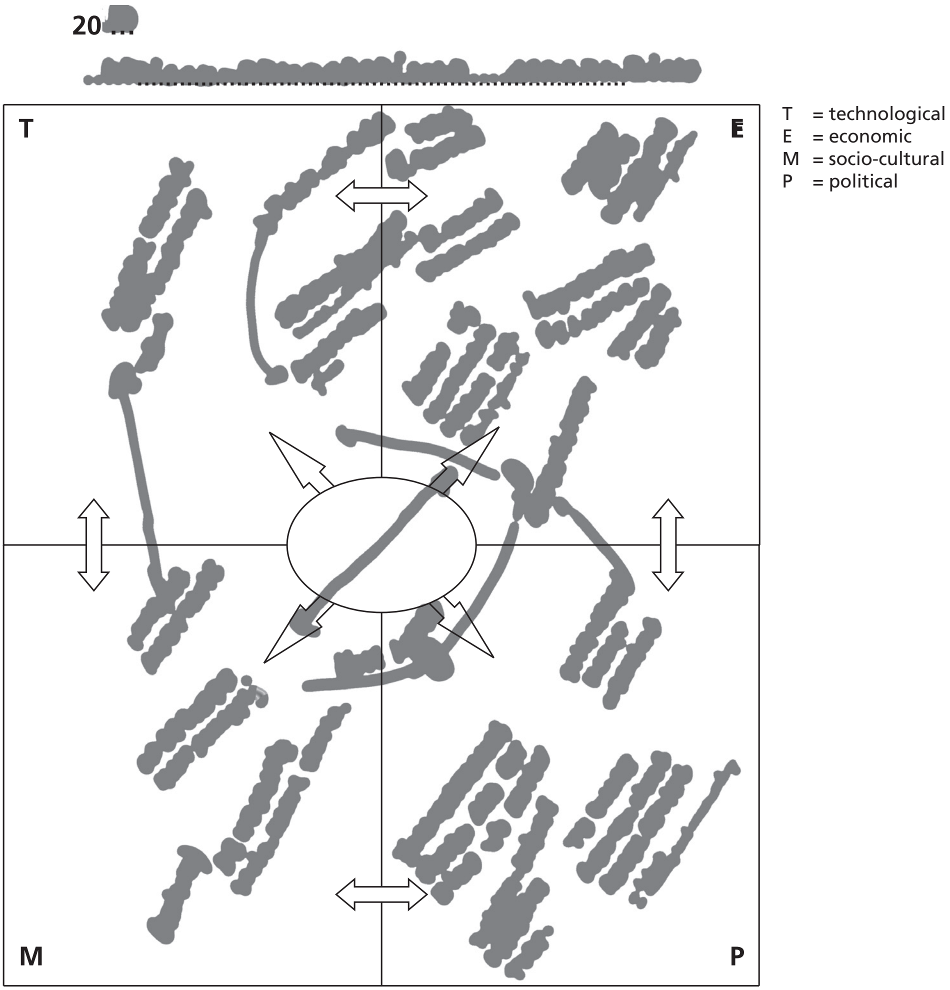


Figure 4.6 Example of a scenario map after a scenario interview. The image is blurred for reasons of privacy

Box 4.1 The course of a scenario interview

In this box, a virtual example of the course of a scenario interview, using the interview technique as developed in this section, is given. Differences in the approach of the interview will be highlighted when the interview technique is used with different actors.

The interview starts with explaining how the scenario map is used, what the different colours of the used pencils mean, and roughly what the course of the interview will be.

When interviewing a scientist, the interviewer starts with a question such as: "Which health care applications of Lab-on-a-chip technology do you think will be on the market in 2010?" This is a question that addresses the top-left section of the scenario map (see Figure 4.5); an area where the scientists is likely familiar with and knows a lot about. When interviewing a policymaker this question would, in most cases, be inappropriate. Technological developments are not the policymaker's prime expertise. A more appropriate question would be: "What changes in the Dutch health care system do you expect over the coming 5 years that will be initiated by policymakers?" With this question an issue is chosen that addressed the political arena (lower-right section of the scenario map). Especially for outsiders (see Section 2.5), of which the policymaker is an example, it is important to start the interview with a question that can be answered based on their own expertise. The interviewee might be insecure whether he can really make a scenario for Lab-on-a-chip technology, and an appropriate first question is crucial in taking away this feeling.

Once the first question is answered the interviewer starts asking questions about areas in the scenario map that are located next to what was addressed in the first question. In this way the scenario map becomes filled up with keywords as the interview progresses and the scenario gets more and more complete. Depending on the interviewee, the interviewer has to keep on asking the next question or the interviewee starts to fill up the scenario map automatically.

Throughout the interview the interviewer asks questions about the relations between the different items mentioned by the interviewee: "You just mentioned that small companies will be the first to market Lab-on-a-chip applications. Are that the applications you mentioned will be on the market by 2010?" This stimulates the interviewee to think and answer in a coherent way. Furthermore, questions are asked about plausibility: "You just mentioned that health care professionals will stand against the developments in Point-of-care testing. Is it then plausible that all the applications you mentioned will really be on the market by 2010?" Asking questions about the plausibility further improves the coherence of the socio-technical scenario.

Box 4.2 Scenario of one of the participants – October 2005
Translated from Dutch to English

Title 2010: Frequent analysis on location
In 2010, there will be a range of measurement instruments on the market for measuring blood values. These instruments are capable of measuring one or a couple (lightly integrated) blood values. Different techniques are used to make these instruments. Typical *blood values* that can be measured are ions (e.g., sodium, potassium, or lithium), glucose, cholesterol, haemoglobin, and specific proteins. With these measurements one can, for example, assess the function of different organs (e.g., the kidney, thyroid gland, or liver). These *portable instruments* are combined with methods to retract blood in a painless

manner. Ambulances and *general practitioners use this equipment*, but also in remote areas these instruments are of use. They will also be used by patient to support therapies. In this way, the patient can control a couple of blood values that are indicative for his or her condition. Another application of Lab-on-a-chip can be found in laboratories. Here instruments are used that measure proteins on the basis of cells. This method is used to study cells in a precise manner, which will result in novel insights.

Science will reach much progress in the pre-treatment of whole blood samples on chip. One can think about concentration steps, mixing, selection of substances, etcetera. Next to this, there will be more knowledge how to bind proteins selectively on surfaces. The latter is important for the development of so-called protein chips, generally recognised as the successor of the DNA-chip. There will also be prototypes developed for an integrated generally usable 'check-chip', which can be used to perform a wide range of measurements on one chip to check a patient on the most important health parameters. There will also be prototypes developed for implants. These implants can perform measurements and deliver the right drug dose at the same time.

In industry large companies will form combinations with SMEs. The reason for this is that large companies will recognise the strength of small companies in the area of innovation. Thus, large companies will wait consciously until a product is ready for mass production until they buy it. In this way, the SMEs will remain to exist. Pharmaceutical companies can start to play a big role, but whether they will indeed enter this market will depend on the specific application. Their consideration is whether they expect to sell more drugs by also selling specific diagnostics.

In society and politics there is a drive for better health care. This implies more efficiency and lower costs. Health care insurers will have the same wishes. The latter can have a positive outcome for the introduction of instruments based on Lab-on-a-chip technology. Although, in places where practices have to change one can expect resistance. Clinical laboratories do not gain when measurements are performed outside the laboratory. For specific application patient groups can play an important role. Lobbying towards the government can speed up the development and introduction of specific applications. In society, these days, there is much habituation in accepting new technological developments rapidly. Especially in combination with a societal focus on 'quality of life', portable diagnostics, which contributes to this, will be embraced. Citizens will often be willing to contribute part of the payment.

Title 2015: Home care

In 2015 Lab-on-a-chip will be a mature technology. For consumers there is a general 'check-chip' on the market to check the most important health parameters at home and the general practitioner uses a more complex version for the same purpose. Taking measurements with portable instruments in now common practice and socially accepted, and there will be a saturation of the market. A combination with telemedicine is established to enable online connection with your doctor who can assess the measurements directly. In these developments, the general practitioners laboratory will play an important role. In this laboratory the instruments will be smaller and quicker because of fluid chip technology. Dosing and monitoring of drugs happens mostly with implants. However, it remains a question whether implants will really take over the market. It is difficult to predict whether there is enough societal acceptation for implants. Because the costs of measurement instruments dropped drastically, also the use in developing countries increases considerably. This implies that larger areas can be opened up for health care applications.

The division of labour between large and small companies is stronger than ever. Small companies are the main drivers for large companies. Large companies let small companies initiate all new developments and only do production and marketing themselves. There are also a few strong pharmaceutical players active in the market. The chance exists that some of these players will block parts of the market on those areas where they expect a drop in drug sales. The role of government will become stronger. It is difficult to foresee whether this has a positive or negative influence on the application of Lab-on-a-chip systems in different health care practises. Much will depend on how cheap the eventual measurements with these kinds of instruments will eventually become.

4.4 Summary

This chapter presented three tools that can be supportive to study emerging technological fields or to gather data. These tools are not only supportive to the research performed in this thesis, but also have a value of their own because they can be used in other studies as well.

Socio-technical mapping was developed as a tool that is able to visualise the different social and technical entities that become part of emerging technological fields over time. It was argued that literature addresses the value of socio-technical mapping, but never actually presents socio-technical maps. In an attempt to close this gap, a simple mapping tool was developed. The tool is capable of visualising different actors, visions, and guiding artefacts, but, for example, does not show the relations between these entities. It was indicated how the heterogeneous data that is gathered by desk research and interviews can be analysed.

In developing the three-level framework it was emphasised that technological developments take place at different interrelated levels. Three interrelated levels are distinguished here: (i) locally, within a research group or company, (ii) more in general, within a scientific community or industry, and (iii) more global and diffuse, in society at large. By completing a three-level framework for a particular topic, the analyst is supported by a visualisation that indicates the actors and issues that are articulated at different levels over time.

Then, an interview instrument that enables the construction of socio-technical scenarios was developed. In socio-technical scenarios, different interrelated aspects (technical, economic, political, and socio-cultural) are addressed in a balanced way. The result is a rich and coherent story of the future that can be formulated in a one to two hour interview. The interview instrument uses a scenario map that during the interview gets filled up with keywords and linkages between these keywords. An example was given of a completed scenario map and a written down scenario. It was also described how the course of an interview is structured.

Notes

1 Review articles are placed at the level of the technological field, because they give an overview and describe trends at the level of the field, in contrast to 'standards' scientific articles, which describe the results of one or a few research groups.

2 Using an empty sheet or map such as the one used here is inspired by Soft Systems Methodology (Checkland and Scholes, 1999). Usually socio-technical scenarios are described in texts. It could, however, be useful to use pictures as a medium (Duke, 1974). The problem by drawing a picture of socio-technical scenarios is the huge amount of data that should be incorporated in the picture. From management literature the same problem is known when (problematic) situations in organisations have to be analysed. A methodology that deals with this problem is Soft Systems Methodology (SSM) (Checkland and Scholes, 1999:xiii): "SSM was developed in the 70's. It grew out of the failure of established methods of 'systems engineering' (SE) when faces with messy complex situations. The methodology focuses on letting actors learn from experiences." In SSM, the problem of imagining a complex (future) situation is tackled by using – so-called – rich pictures. "The reason for this (drawing pictures, ed.) is that human affairs reveal a rich moving pageant of relationships, and pictures are a better means for recording relationships and connections than is linear prose." (page 45) The rich picture represents the problem situation itself by relating all relevant entities of the system.

5 Dynamics of emerging technologies

This chapter reports on and discusses empirical findings by investigating three particular elements of the dynamics of emerging technologies, namely early entrenchment, relations between actors, and organised interaction. These elements were derived in Chapter 2 and a theoretical concept was allocated to each of the elements. The first element addresses how in emerging technological fields, over time, early entrenchment sets in. Entrenchment is a result of ongoing interactions between actors and the decisions that are taken in relation to technological developments. As a result certain patterns (e.g., collaborations or search heuristics) emerge that make some actions and interactions easier, and constrain others. These patterns are possible emerging irreversibilities. Asking the question to what extent these patterns are actually irreversible is the litmus test of how influential the pattern actually is.

The second element emphasises that interactions between actors make up a large part of the ongoing processes in and around technological developments. In understanding interactions, it is important to know how actors relate to each other, and which roles and positions are emerging in the emerging technological field. In expectations and visions, the future positions of actors are manifested. In emerging technological fields, actors mainly act and interact upon expectations and visions. It therefore makes sense to study projected, or prospective, positions.

Thirdly, interactions between different actors often do not simply occur, they are organised. Organised interaction can take on many different forms and shapes. The concept of space is used to capture the different forms of organised interaction. The effects of (new) spaces emphasise that organised interactions have an influence on the dynamics of emerging technological fields.

The chapter starts with providing an overview of the case of Lab-on-a-chip technology by describing the history thereof. Due to the complexity of technological developments this is not a trivial activity. The historical narrative is therefore supported by figures that depict the historical developments. The historical narrative and the figures point out how, over time, an emerging technological field is made up by all kinds of entities, such as artefacts, visions, and actors. The history serves as a first round in understanding the dynamics in the emerging Lab-on-a-chip field and functions as a background for the reader.

When it is considered to be necessary, the tools that were developed in Chapter 4 will be used. The data that was gathered will be mentioned for each element separately. This makes the aim of this chapter twofold; 1) to provide empirical data to construct a historical narrative and to investigate the three elements by which the understanding of the dynamics of emerging technologies can be improved, and 2) to use and test the tools that are expected to be supportive in studying emerging technologies. After each section the findings will be summarised in bulleted form.

5.1 The history of Lab-on-a-chip technology[1]

Case specific data

Telling the history of any emerging technological field is complex as the elements that built up the story are heterogeneous. Different actors, visions, and research results are all part of the overall story. To tell the history, case specific data should be gathered. In the field of Lab-on-a-chip technology the following data sources were covered. All volumes (since the end of the 1980s) of the journals Lab on Chip, Analytical Chemistry, Science, Nature, and Electrophoresis were investigated on articles dealing with Lab-on-a-chip technology. Explorative interviews (see also Box 3.1) indicated that these are the most influential journals in the area of Lab-on-a-chip technology. A distinction is made between normal and review articles. When found necessary (e.g., when indicated as influential and relevant during interviews), papers from other journals were added in the data gathering process. To this dataset, non-scientific texts were added, for example, white papers from consultancy or venture capital firms, reports from consortia on Lab-on-a-chip technology, information from companies developing Lab-on-a-chip applications, advisory reports for governmental agencies, and texts that mention the use of Lab-on-a-chip based applications. For the non-scientific texts interviews are especially useful to find and triangulate relevant data sources.

The data was triangulated through semi-structured interviews with 20 experts from the field. These experts were scientists, businesses, and (potential) end-users. These interviews were structured to gain insights into the expectations, agendas, and actor arrangements present in the field of Lab-on-a-chip technology (see Section 3.2). Sabeth Verpoorte (professor at the University of Groningen) fulfilled the role of informant. This means that she was interviewed more often, also to reflect on findings during the analysis.

Socio-technical mapping is a tool that helps to make sense of these different entities by organising them in succeeding figures of different periods of time (see Section 4.1). By doing so, it can be pointed out which entities become influential over time. In this way, socio-technical maps are used to support the historical narrative. Section 3.2 explained the types of data to collect in a database, namely statements that express expectations, agendas, and actor arrangements. Such statements were subtracted from the abovementioned data sources. The resulting database consists of approximately 1000 statements. The database is necessary to determine the influential entities and to determine which entities should be assigned to which period. To enable easy comparison between the historical narrative and the socio-technical maps, the historical narrative is elaborated in periods of 5 years (until 1990, 1991-1995, etc.).

The history

Lab-on-a-chip technology had its roots in microtechnology fabrication technologies,[2] which enabled the fabrication of the first fluidic chips at the end of the 1980s.[3] These early laboratory experiments inspired scientists to articulate high goals for the field, which are still alive and circulating today (Manz *et al.*, 1990): Lab-on-a-chip technology should create complex systems that integrate all necessary analysis steps on one chip; called a Micro Total Analysis System (μTAS). By these goals, the agenda was set to miniaturise existing diagnostic laboratory instruments. At first, mainly analytical chemists where attracted by the development of microfluidic systems. In these early years the analyses are performed on substrates made of glass or silicon. One of the leading pioneering scientists was Manz, who was at that time working at the analytical research lab of Ciba Geigy, a Swiss pharmaceutical and chemical group. This indicates the involvement of established companies. Also in this period the first start-up is founded, i-STAT, but it was not until 1992 that they launched their first product.

In the early 1990s high expectations were raised about the possibilities of performing (bio) chemical analysis at any location and at any time (Erickson and Wilding, 1993). For example, total blood analysis at the patient's bedside (Point-of-care testing). Further, in 1993 Harrison and Manz revealed a breakthrough in the journal Science with a successful miniaturisation of the analytical technique capillary electrophoresis (Harrison *et al.*, 1993). They articulated their expectations as follows on page 897: "The application of micromachining techniques to the miniaturization of chemical analysis is very promising and should lead to the development of analytical laboratories on a chip." Typical advantages of chip-based analysis systems are speed, less sample needed, and possibly portable.

In this period the research mainly concentrated on demonstrating that different analytical steps can be performed with fluidic chips. Examples are: sample injection and separation by electrophoresis (Harrison *et al.*, 1992; Harrison *et al.*, 1993), optical detection (Verpoorte *et al.*, 1992), and Polymerase Chain Reaction or PCR, a DNA multiplication technique (Woolley and Mathies, 1994).

In the mid 1990s other scientific communities, such as synthetic chemistry and biology, were attracted to the field. They foresaw that this emerging technology could aid them in their work and/or enable new lines of research. As a reflection of these developments the term Lab-on-a-chip (which is a broader notion than µTAS) became used more widely. Synthetic chemists were interested because of the initial developments in microscale reactors on chips (Haswell, 1997), which resulted in a publication in the 1999 July edition of Science by the group of Whitesides (Kenis *et al.*, 1999). For biologists, the possibility to analyse and experiment with living cells (cellomics) on a (often polymer) chip was the main features. Further, chips made from polymer are linked with low cost production and make disposable chips a more feasible technology option (Becker and Gärtner, 2000; Verpoorte, 2002; Klank *et al.*, 2002).

On the side of the private sector venture capitalists start to invest in companies that develop Lab-on-a-chip products. For example, Caliper Life Sciences receives venture capital from ARCH Venture Partners and Fluidigm (founded in 1999) manages to attract venture capital as well. In 2000 the public/private development network LICOM (the Liquid Handling Competence Centre) gets established. Pharmaceutical companies and hospitals start using the first applications, for example, the BioAnalyzer from Caliper, which fulfils a role in genomics based research.

In 2002, Quake's group reported the possibility to produce large-scale integration of microfluidic chips, which is in analogy with electronic integrated circuits (Thorsen *et al.*, 2002). This then reinforces expectations, as Quake formulates it himself on page 584: "The rapid, simple fabrication procedure combined with the powerful valve multiplexing can be used to design chips for many applications, ranging from high throughput screening applications to the design of new liquid display technology. […] the ultimate complexity and application are limited only by one's imagination." This development is of special interest to pharmaceutical companies. Over the last 5 years nanotechnology is entering this field. It offers improvements to existing chip components, but also provides novel concepts, for example, for separation and detection (see Figure 3.2).

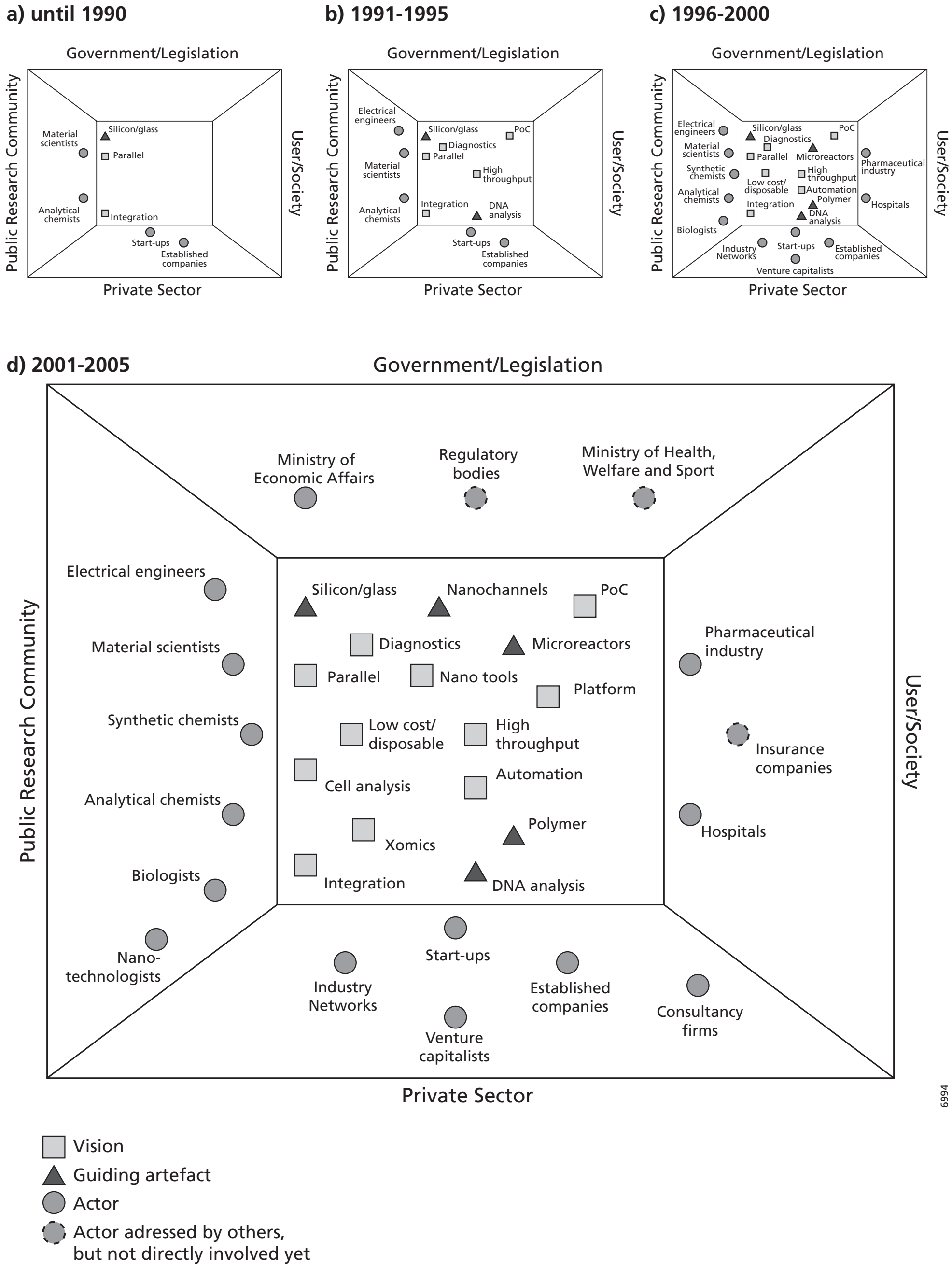


Figure 5.1a-d Socio-technical maps for the emerging Lab-on-a-chip field divided in different periods

In this period, consultancy companies, such as Yole Développement, are attracted to the field as well. In 2001 three partners from the LICOM development network together with Yole Développement, execute a European funded project (IST programme of the European Commission) to construct an, as they call it, explorative technology roadmap for microfluidics. The Europractise network (annual report, 2003)[4] and the FlowMap consortium (consisting of three LICOM partners and Yole Développement)[5] in their Microfluidics roadmap express the need for microfluidics platforms, which could potentially remove techno-economic obstacles. Cientifica, a consultancy firm focussed on nanotechnology, addresses nanofluidics in relation to possibilities for fast DNA analysis in 2003 (Hollister *et al.*).

Large electronics companies such as Philips and Siemens become involved and start to develop their own applications. Also more start-ups are founded, such as Epocal in Canada, which is founded by Imants Lauks for whom it is his second Lab-on-a-chip company (after i-STAT). Production oriented companies for microfluidics also start to emerge. They provide business-to-business solutions for companies that want to develop Lab-on-a-chip products. An example is Micronit in the Netherlands.

Further, governmental programmes are funded that specifically address micro- and nanofluidics. For example, in the Netherlands the MicroNed and NanoNed programmes (funded by the Ministry of Economic Affairs) have dedicated sub-programmes for Lab-on-a-chip technology. Also the Process-on-a-chip project is launched on chip-based microreactors.

In 2003 and 2005, the Dutch Ministry of Health, Welfare and Sport receives two advisory reports (Raad voor de Volksgezondheid en Zorg, 2003; Roszek *et al.*, 2005) that mention Lab-on-a-chip technology. Insurance companies and regulatory bodies are addressed by others (for example in Collins *et al.*, 2003; Nanomarkets, 2005), because the functionality of Lab-on-a-chip applications touches upon self-monitoring and genomics information, issues that can have far-reaching consequences.

This history of Lab-on-a-chip technology reports on an emerging technological field that is becoming more established. Kalmholz (2004) reports a similar trend by studying the number of publications and patents in microfluidics. He shows a growth in microfluidics publications from a few in 1990, via ±50 in 1998 to almost 600 in 2003. The first patent dates back to 1993, which grew to ±20 in 1998 and further to almost 350 in 2003. The present situation can be characterised by the first successful applications (e.g., laboratory electrophoresis chips, portable blood analysis systems, and production platforms) together with an intense search on where the state of the art technology can be used and stimulate more economic activity. The same trend of an emerging technological field that becomes established is also visible in the socio-technical maps, which are shown in Figure 5.1.

From the socio-technical maps it becomes clear that the emerging Lab-on-a-chip field is influenced by all sorts of entities, such as different actors, artefacts, visions, R&D results, and applications. What is noteworthy is that the field has grown in terms of different types of actors (e.g., biologists or start-ups) and no type of actor has retreated from the field. Indeed, innovation literature stresses that in later stages of the evolution of technological fields a shake-out of technologies and involved actors occurs (Utterback, 1994). In this case, it means that 'no shake-out' indicates the emerging state of the field. Even though there is limited evidence of commercial exploitation of the developed technology to date, the ongoing growth of the emerging Lab-on-a-chip field indicates resilience to make the promises come true and to sustain the visions. The state of the field is still merely scientific, but has also attracted a certain amount of business interest. The latter led to some commercialisation and use at professional practices. At the same time, commercialisation and actual use are far from common. It is therefore that standardisation is called for (Tüdos *et al.*, 2001; Paegel *et al.*, 2002; Hong and Quake, 2003; Ducrée and Zengerle, 2004), but is however not (yet) realised.

During the interviews a few interviewees mentioned that they worry about the future of Lab-on-a-chip technology. These interviewees have the feeling that the developments do not go fast enough. In response of this, a scientist mentioned that they (the research group) are now actively looking for collaborations with health care professionals; to find out what applications will be feasible from a users perspective. This scientist further mentioned that these kinds of interactions are needed to make the Lab-on-a-chip technology a success. On the other hand, there is an increase in companies working on Lab-on-a-chip applications. Even if some will fail, it does mean that more applications will come to the market. This increase in company interest further indicates that industrial parties believe that Lab-on-a-chip technology developed far enough to translate it to commercially viable products. However, there remains, however, a certain amount of dissention in how different actors assess the brightness of the future for Lab-on-a-chip technology.

From the text above, the following finding can be reported:

- The Lab-on-a-chip field has grown in terms of different types of actors and no type of actor has retreated from the field. This underlines the emerging character of the Lab-on-a-chip field.

5.2 Investigating emerging irreversibilities[6]

Case specific data

In this section, emerging irreversibilities are studied. The database that was constructed for the history of Lab-on-a-chip technology functions as a point of departure to identify and to investigate possible emerging irreversibilities. When during the analysis further questions arose about the dynamics of the emerging irreversibility, additional interviews were conducted and further desk research was performed.

5.2.1 In search of emerging irreversibilities

Emerging irreversibilities are patterns that enable and constrain actors in their actions and interactions. Based on the historical narrative, questions can be asked why certain elements become part of the technological field and why new actors became involved. Such questions can suggest patterns that are influential on certain actors in the emerging technological field. These patterns are possible emerging irreversibilities. A few of these possible emerging irreversibilities are briefly described below.

In the mid-1990s venture capitalists become interested in funding companies that develop Lab-on-a-chip applications. In the following years this interest of venture capital firms increases. Indeed, when looking at venture capital investments over the years, more Lab-on-a-chip companies received venture capital. Starting with Caliper Life Sciences,[7] and later followed by businesses such as Amphora, Epocal, Inc., Nanostream Inc., and Fluidigm. Fluidigm now reached its fifth round of venture capital and raised about $100 million. The amount of venture capital for Fluidigm is impressive, but of more importance here is the persistence of venture capital firms to keep investing round after round. This implies that the investing firms do not loose faith in commercial potential of Lab-on-a-chip technology.[8] This sequence of events is a pattern that points out that an increase in available financial private resources (see Table 2.1) is a possible emerging irreversibility. Arguably, the persistence of venture capital firms and the attention that it brings with it makes it easier for other start-ups to raise money for Lab-on-a-chip products.

In the Lab-on-a-chip field, high throughput analysis has been on the agenda almost since the start (e.g., Woolley and Mathies, 1994). For a large part the demand for high-throughput analysis systems can be found in the area of DNA analysis. DNA analysis often requires the analysis of a large number of DNA strands, which can take a long time to analyse when the analysis instruments are not directed at high-throughput analysis. Speeding up DNA analysis has scientific as well as economic benefits. When nanotechnologists started to work on Lab-on-a-chip systems, it was therefore not surprising that they linked up with the demand for improved DNA analysis instrumentation (Campbell *et al.*, 2004; Hollister *et al.*, 2003). This combination of elements (high-throughput, DNA analysis, and nanochannels) shows the resilience of the Lab-on-a-chip field to keep focussing on the realisation of high-throughput DNA analysis. In the absence of a 'killer application' (Whitesides, 2006), this is a vision that actors keep hanging on to. This continuous drive to realise a certain vision is a possible emerging irreversibility as actors do not need to explain why they work on improving the throughput of DNA analysis, which enables actors to explore opportunities and acquire resources to do so.

In the early 2000s consultancy companies enter the emerging Lab-on-a-chip field (e.g., Yole Développement). One of the activities that consultancy companies unfold is that they generate market reports and make them commercially available for interested actors, such as companies or investors that are active in the field. These market reports provide company profiles and trend analysis. Consultancy companies write these reports to make a profit. Thus, by doing so, consultancy company recognise that the emerging technological field gained enough momentum and interest from different actors that, selling these reports, might provide them with a profit. These consultancy companies estimate that there is an increasing interest of private parties in the commercial exploitation of Lab-on-a-chip applications, of which the market report is a commercial expression. This type of increased interest is a possible emerging irreversibility as it can give confirmation to actors in the Lab-on-a-chip field that they are on the right track.

These examples indicate possible emerging irreversibilities. The dynamics of two other possible emerging irreversibilities will now be discussed in the following two sections, namely 1) the use of polymer chips, and 2) the relation between synthetic chemists and microreactors. A three-level framework is used to visualise the dynamics of possible emerging irreversibilities.

5.2.2 Polymer chips

Until 1996 glass and silicon were used to produce fluidic chips. To make structures in glass or silicon specialised facilities, such as a cleanroom,[9] are needed. Using a cleanroom is expensive and cleanrooms are not widely available. This is constraining when scientists or businesses want to start working on microfluidics. Kan *et al.* (2004:3570) express this issue as follows: "The need for specialized facilities for fabrication prohibits the widespread use of this technology by researchers." When polymers, rather than glass or silicon, are used to make fluidic chips, this constraint can be overcome. Polymers were recognised as an option for fluidic chips before, which is shown in the patent by Ekstrom *et al.* (1990). However, the possible feature sizes were disappointing.[10] Later, new techniques made it possible to make smaller feature-sizes with polymers (Effenhauser *et al.*, 1997), which reduced this disadvantage. Furthermore, Becker and Gärtner (2000:25) state: "[…] more and more academic groups are realizing the great potential for simple and fast in-house production of design prototypes with polymer fabrication methods." Also, the possibility of low cost production of disposable chips was mentioned often. Kan *et al.* (2004:3570) phrased this as follows: "The use of plastic and elastomeric microfluidic devices promises lower manufacturing costs, and could allow the creation of disposable and adaptable genotyping devices." Lee *et al.* (2003:6544) also address this issue: "The cost of fabrication in PDMS is low compared to that for many materials (e.g., glass or silicon) commonly used in microdevices […]."[11] The result was that from 1996 onwards, more research groups started to use polymer for producing their chips. The following statement from Becker and Gärtner (2000:20) links up with this issue: "A process that has found widespread use mainly in the academic world is the casting of silicone-base elastomers [a type of polymer, ed.]." Becker and Gärtner (2000:25) describe it as follows: "The driving force behind this development, on the one hand, is certainly the commercialization of microfluidics with its applications in genomics, drug discovery, and diagnostics. These areas all demand a high number of devices at low cost. Ultimately the devices will be used in disposables."

There is a difference in the use of polymer among the various (scientific) disciplines involved in Lab-on-a-chip technology (the left side of the socio-technical map; Figure 5.1). Biologists and chemical analysts often use polymer, while synthetic chemists use it seldom. The reasons for this difference can be found in the material properties. Synthetic chemists perform reactions on chips, and polymers can become part of the reactions, which is unwanted. How different polymers influence the reaction exactly is often unknown, which makes that synthetic chemists go for the safe choice, which is glass that does not have these disadvantages. Biologists are used to work with polymer vials and dishes, which makes their adaptation to polymer chips easy. An additional advantage for biologists is that polymers are permeable to gasses and it is therefore easier to keep biological samples (especially cells) alive on chip, because the necessary gasses can simply diffuse through the polymer chip to the biological sample.

Besides their advantages, polymers still have their drawbacks, such as the fact that the polymer can react with other chemical substances. As a response to this, research groups started to work on finding other polymers that suffer less from these drawbacks or to find other solutions. For example, solutions are being sought in coating or treating the channel surfaces (Lee *et al.*, 2003).

Consequently, biologists were drawn to the Lab-on-a-chip field as there is now a relatively cheap and easy to use solution for experimenting with fluidic chips. Other actors outside the academic world recognised the advantages of using polymers as well. Companies stepped into the field and used polymer to develop their products, which was also recognised by the consultancy company Yole Développement. In 2003 Yole Développement reported on a number of those companies that generally use the argument of low cost production (Yole Développement, 2003), high-throughput screening, and disposability of the chip for using polymers. Examples of the listed companies are Gyros AB (founded in 2000) and DiagnoSwiss S.A. (founded in 1999). Gyros AB develops and produces micro analysis systems based on a proprietary technology platform based on polymer (Gustafsson *et al.*, 2004). DiagnoSwiss S.A. commercialises polymer immunoassays that are suitable for mass production.

Thus, around the existence of making chips of polymeric materials, there is a pattern of drawing new actors into the Lab-on-a-chip field. The three-level framework is helpful in illustrating these dynamics as well (Figure 5.2). As the first uses of polymer start in the lower left corner of the framework, over time, actors from other levels become involved. Eventually, consultancy firms operating at the industry level recognise the use of polymer chips. There are no expressions found for the relevance of using polymers at the societal level.

	Public	Private	
Society	• No developments related to microreactors	• No developments related to polymers	Society
Scientific community	• ±2000: multiple review articles are published on using polymers for microfluidics	• 2003: recognition of the possibilities by consulting companies	Industry
Research group	• 1996 onwards: growth in the number of research groups (including biologists) that use polymers for chip fabrication • ±2000: research groups start to commit themselves to improve the characteristics of polymers and the production of polymer chips	• Companies use polymers for chip manufacturing	Companies

6994

Figure 5.2 Three-level framework visualising the dynamics around polymer chips

Biologists start to use fluidic chips for their experiments as they recognise the advantages that come with it. It was argued above that -among other things- low costs experimentation with less demand on specialised facilities was a reason for biologists to step in. In 2000 review articles start to appear which assess the advances made and indicate that the scientific community values polymer chips as an important contribution to the field. Companies become interested as well to use polymers for the fabrication of fluidic chips. The latter is then pickup up by consultancy firms that use the process material to characterise businesses active in the field of Lab-on-a-chip technology, or as stated in Yole's white paper (2003:4): "Regarding the processed material, it is mainly Si/glass and polymer *which are equally used* (italics added, ed.). For example, companies such as Seyonic (CH) and Microfab (D) are processing Si and/or glass materials while IMM (D), bioMérieux (F), Steag microParts (D), Diagnoswiss (CH) are using polymers." This quote also shows that glass and silicon as process materials are not completely replaced by polymers. Polymers or glass/silicon have their own advantages and disadvantages, but together make the number of different actors interested in the Lab-on-a-chip field larger.

On the other hand, polymer also constrains, because, for example, the limited possible feature-size or the influence on chemical reactions causes particular actors to continue to use glass or silicon. In addition, new agendas were set to come up with solutions for the drawbacks of using polymer.

Given that biologists often use polymers for experimenting with living biological samples, would it be easy for biologists to use other materials? Arguably, it is easier for biologists to use polymers these days, as the body of literature for experimenting with biological samples on polymer chips is larger than for glass or silicon chips. Consequently, if a biologist would want to use glass or silicon, he or she would have more work in getting the experiment going as he or she can build less on the experiments described in the literature. Furthermore, when for economic reasons the primary choice for new groups is polymers, the build-up of knowledge on the polymer side will likely increase rapidly. These mechanisms increase the tendency to choose for polymer, which would reinforce the effect that polymer chips have on choices made in research directions. What is argued here is that a pattern is forming, a search heuristic: for a biologist that experiments with living biological samples the preferred choice is polymer. Each time this search heuristic is used, the pattern is reinforced and it becomes stronger.

Another argument for actors to use polymers is that it is considered to enable low cost production and is therefore suitable for mass production (Becker and Gärtner, 2000). Companies such as Epocal, Inc. (CA) and DiagnoSwiss S.A (CH) indeed do use polymers for this reason. There are however other examples, such as Caliper Life Sciences (US), Philips (NL), Micronit (NL), and Medimate (NL) that keep using glass even though the eventual focus is on mass production. As far as a search heuristic would exist to use polymer for low cost chip production, which in scientific literature is frequently used as an argument in favour of polymer, it does not show when looking at the materials that companies use for making microfluidic chips.

Are the patterns observed in the case of polymer emerging irreversibilities? It was argued that the mere existence of the possibility to make chips from polymers drew new actors to the Lab-on-a-chip field. This as such is not irreversible, but certainly influenced the actors operating in the field, if only by enabling cheap ways for experimenting with Lab-on-a-chip technology. It was further argued that for biologists, the use of polymers can be seen as a search heuristic for experimenting with living samples. There is now a choice to be made between glass/silicon and polymer, which did not exist prior to the mid-1990s. The existence of this choice is irreversible as such, but black-boxing of this choice for certain technical solutions would indicate emerging irreversibility as well. It was argued that a search heuristic for this choice is emerging in favour of polymer for experimenting with living biological samples. However, evidence that this search heuristic was black-boxing was not found. On the issue whether cheap mass fabrication with polymer can be considered as a search heuristic in favour of polymer, no convincing evidence was found.

To summarise, it was argued that the existence of polymers as an alternative material to make chips certainly influences the decisions of -at least some- actors in the Lab-on-a-chip field. Whether such effects of the use of polymer can be typified as an emerging irreversibility is not convincing. Nonetheless, over time, when there would be a further build-up of knowledge and use, the choice for polymer can become more forceful, black-boxed, and by that more irreversible.

5.2.3 Synthetic chemists and microreactors

Synthetic chemists are interested in and concerned with the way reactions occur, develop, and can be controlled. Understanding and using this knowledge for industrial production is part of their core activities. Scaling down the reactors in which reactions take place has specific advantages for certain classes of reactions. For example, reactions can be much better controlled giving no (or hardly any) waste and a purer end-product. Pharmaceutical and fine chemical production could benefit from these advantages. Another advantage is that dangerous (e.g., toxic or explosive) reactions can be much better controlled and thus safely produced. Before the work on microfluidic chips started, downscaling reactors was a common trend in the -what can be called-traditional microreactor community consisting of synthetic chemists.

Microreactors -on microfluidic chips- are generally defined as reactors that have microstructures for chemical reactions (Yoshida *et al.*, 2005). The possibility of microfluidic microreactors was first demonstrated around 1997. In a review paper by Haswell (1997) a microreactor design as part of an analytical system was described. During the early stages of microreactor development a merge between the technological field of microreactors with that of Lab-on-a-chip became attractive. For example, Jensen (2001:293) wrote in a review on microreactor technology: "The merging of μTAS techniques with micro-reaction technology promises to yield a wide range of novel devices for high throughput screening, reaction kinetic and mechanism studies, and on-line monitoring of productions systems". This statement further indicates that the merge is considered fruitful, both for analytical and synthetic purposes.

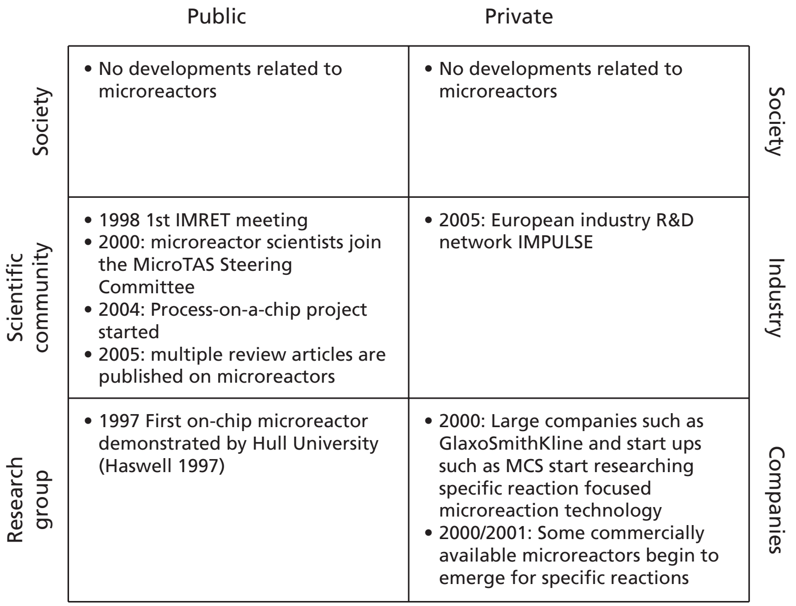
Back to synthesis; microreactors promise many practical advantages over traditional batch-scale synthesis (Haswell and Skelton, 2000), including handling of highly explosive chemical reactions, control of highly toxic chemical reactions, easy modulation, and parallelisation possibilities for scaling-out towards industrial production.[12] In addition, many multi-phase reactions (sequence of reaction steps) could be carried out effectively in microreactors, which would otherwise be problematic or impossible in a batch method (Yoshida *et al.*, 2005).[13]

Over the last 15 years, the traditional microreactor community performed considerable research on micro-scale structured devices for applications to chemical synthesis (microreactors). A large amount of academic research, as well as eight IMRET events (International Conference on Microreaction Technology), have created a substantial scientific activity in the field of microreactors (Bayer *et al.*, 2005). In addition to the growth in R&D on microreactors in general, actors working on microreactors (synthetic chemists) became embedded as a new type of actor in the emerging Lab-on-a-chip field. The latter was triangulated in an interview with Sabeth Verpoorte (University of Groningen, the Netherlands) (24th of June 2005) where she mentioned that the Steering Committee of the MicroTAS Conference (the leading conference on microfluidics/Lab-on-a-chip technology) encouraged conference participation of research groups working on microreactors by inviting two key microreactor scientists to participate in the Steering Committee in 2000-2001. This active construction of ties between formerly quite separate actors influences the field of Lab-on-a-chip technology. Another example that microreactor scientists are now embedded in the Lab-on-a-chip field is the Dutch Process-on-a-chip programme. Process-on-a-chip is a government sponsored research programme that started in 2004. The name of the programme demonstrates the link between microreactors (synthetic processes) and Lab-on-a-chip, as Process-on-a-chip is derived from Lab-on-a-chip. In the words of Jan van Hest (project leader of Process-on-a-chip; interview, 6th of April 2005): "[…] Lab-on-a-chip still has the analysis/characterization and not the reaction. And to call this Process-on-a-chip we go a step further […]" The research performed in the programme -among other items- combines synthesis and characterisation on chip, which is exemplary for the physical integration of microreactors in Lab-on-a-chip technology. The argument just provided indicates that the ties between the field of microreactors and Lab-on-a-chip exists physically and programmatically, and are embedded in actor arrangements as well.

The dynamics go further as some companies start, although with varying degrees of commercial success, to develop microreactors. In the pharmaceutical industry there have been a few cases of companies employing small-scale structured devices on production scale; most notable by Siemens Axiva, Merck, Clariant, and Degussa (Bayer *et al.*, 2005). Start-up companies have been working on microreactors as well. An example is Micro Chemical Systems, Ltd. (MCS). Founded in 2001 by Stephen Haswell; it has created a number of technologies including, in collaboration with GlaxoSmithKline, a microfluidic reactor.[14]

Next to the developments in the field of Lab-on-a-chip technology, research and development of microreactors continues in the field of large-scale industrial chemical processing. Exemplary for these developments is the launch of a European consortium with the acronym IMPULSE (Integrated Multiscale Process Units with Locally Structured Elements). The consortium aims at the integration of process equipment (such as microreactors, heat exchangers, and thin films) to obtain improved performance for the whole chemical synthesis process. Part of the R&D efforts in the IMPULSE consortium concentrates on microfluidic microreactors.

Following the dynamics as just presented, the following pattern emerges, which is also shown with the three-level framework in Figure 5.3. Two previously separated rather scientific technological fields start to overlap. The binding element is the microreactor concept. As a result, groups working on microreactors become embedded in two technological fields, namely



	Public	Private	
Society	• No developments related to microreactors	• No developments related to microreactors	Society
Scientific community	• 1998 1st IMRET meeting • 2000: microreactor scientists join the MicroTAS Steering Committee • 2004: Process-on-a-chip project started • 2005: multiple review articles are published on microreactors	• 2005: European industry R&D network IMPULSE	Industry
Research group	• 1997 First on-chip microreactor demonstrated by Hull University (Haswell 1997)	• 2000: Large companies such as GlaxoSmithKline and start ups such as MCS start researching specific reaction focused microreaction technology • 2000/2001: Some commercially available microreactors begin to emerge for specific reactions	Companies

Figure 5.3 Three-level framework visualising the development of microreactors

(traditional) microreactors and Lab-on-a-chip technology. These groups act as a node between these two fields. With the growing importance of microfluidic microreactors in both fields, they are becoming increasingly bound together. Businesses working on microreactors start to emerge as well and there is interest from large established companies in developing and using microreactor technology. On the level of the industry, by the establishment of the European industry R&D network IMPULSE, there is recognition that microreactor technology by using microfluidics is important. There are no expressions found for the relevance of using polymers at the societal level.

A bond has emerged and grown between two technological fields. The formation of this bond is a pattern that is influential in the interactions between actors of the different fields. This bond also caries with it other ties, the traditional microreactor community, which is connected to the chemical industry. This tie with large-scale fine chemical synthesis brings along an industry that is, through microreactors, supportive to Lab-on-a-chip technology. The question then is: how strong is the bond between the fields of microreactors and Lab-on-a-chip and is it irreversible? In principle it is not irreversible as disappointing research results and results of the involved companies can potentially decrease the strength of the bond. On the other hand, the physical features of microreactors and Lab-on-a-chip technology suggest otherwise. Scientists and business now recognise that the integration of synthesis and analysis is fruitful and often necessary. For analysis, often chemical reactions are needed (e.g., reagents, tagging), and when chemical reactions are performed characterisation of the result (e.g., for process monitoring) is useful as well. Now the two fields continue to meet and work together, physical combinations are made that make a separation of the two communities less likely, especially if in due course more proof is gathered that demonstrates the value and realisation of the microreactor/Lab-on-a-chip link.

Furthermore, the interference of synthetic chemists into the field of Lab-on-a-chip technology shaped the expectations of what Lab-on-a-chip should be: synthesis and analysis on a chip, rather than analysis alone. Ongoing technological developments in the field of Lab-on-a-chip are now based on this search heuristic. This search heuristic is, however, not completely black-boxed, because in the interviews interviewees still explained the combination to the interviewer, rather then assuming the interviewer would know and no explanation is necessary. In the coming years, with continuing reinforcement of the combination, it is likely that such black-boxing will occur, which would make the bond irreversible.

From the analysis above, the following finding can be reported:

- No hard evidence could be provided of irreversibility in the field of Lab-on-a-chip technology. In the current state of the emerging Lab-on-a-chip field, technological developments are not all that irreversible. What could be demonstrated is that there are particular patterns which, if they are continued to be reinforced, are likely to become irreversible.
- The strength of (possible) emerging irreversibilities (influential patterns) depends on the reach of the influence to different (types of) actors and to different levels. This can be visualised with a three-level framework.

- The strength of (possible) emerging irreversibilities depends on the period of time and the persistence to stay influential. Reinforcement of the pattern makes the emerging irreversibility endure and makes it stronger.

5.3 Prospective positioning in scenarios[15]

How do actors relate to each other? In emerging technologies, expectations and visions play an important role in the action and interactions of actors (Brown *et al.*, 2005; Van Merkerk and Robinson, 2005). When actors express their expectations or visions, the relations between different actors are expressed as well. Who are the potential users of the different technology options? Will regulatory issues be important in innovation processes? By interviewing actors about how they envision the future of Lab-on-a-chip technology the relations between the interviewee and other actors become clear. This section analyses how different actors envision the roles and relations of others in the light of a particular vision in the field of Lab-on-a-chip technology: Point-of-care testing.

Point-of-care testing was recognised by scientists as an interesting option for Lab-on-a-chip technology almost from the start of the field (Erickson and Wilding, 1993; Harrison *et al.*, 1992). The vision of Point-of-care testing is generally shared among different actors, but how it is interpreted might differ between actors. The analysis performed in this section will demonstrate the existence and content of these differences.

In the present, actors act on the basis of expectations and visions about the future. Section 2.3.2 argued that, because positioning is used in expressing expectations and vision, prospective positioning influences present day actions and interactions of actors. This section does not focus on present day actions and interactions, but systematically analyses how different actors use prospective positioning, i.e. envision the role of others in the light of a particular vision. In this analysis both types of data presentation that were explained in Section 3.3.2 are used.

Case specific data

Prospective positioning statements are the data for the analysis presented in this section. In the second line of research (see Section 3.4), in step 2 of the CTA approach, in interviews socio-technical scenarios are constructed by different actors. Section 4.3 described how the construction of these individual socio-technical scenarios is performed. These socio-technical scenarios are a rich data source for prospective positioning statements from a wide variety of actors. The data source used in this section consists of 54 socio-technical scenarios from various actors that envision the future of Lab-on-a-chip technology in 2010.[16] Figure 5.4 shows the origin of the interviewees in a column chart. In Section 3.3.2 it was explained that, to enable an analysis of patterns in prospective positioning all statements should be about the same topic. Consequently, from the socio-technical scenarios only those positioning statements about Point-of-care testing were entered in a database. The reason to take Point-of-care testing as the topic is that it is a widespread vision in the field of Lab-on-a-chip technology. It is therefore visible in most (if not all) scenarios. From all positioning statements found in the scenarios, 280 out of 660 statements deal with Point-of-care testing. The database for this analysis therefore consists of 280 statements.

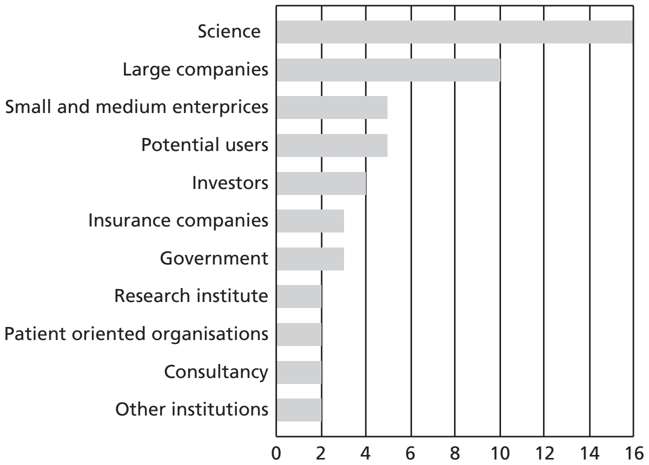


Figure 5.4 Affiliation of the interviewees that developed the socio-technical scenarios

Analysing prospective positioning statements about Point-of-care testing
Point-of-care testing entails the notion that (bio)chemical analysis is not necessarily performed in centralised clinical laboratories (e.g., in hospitals). With Point-of-care testing devices (bio) chemical analysis can be performed at the site where the care is provided. One can distinguish between acute and less acute situations. In the first instance speed of the analysis is of the utmost importance; think of a situation in which a patient suffers from a cardiac infarct or a stroke. In less acute situations speed is used to improve the service and efficiency of health care practices; think of a patient who does not have to wait several weeks for an oncological test result. Patients can use Point-of-care testing devices themselves, for example for drug monitoring. Consumers (without the intervention of the medical community) can use Point-of-care testing devices for self-testing. The use of Point-of-care devices is also envisioned for less developed countries with a lack of health care infrastructure and for employers to perform health checks of new employees. Lab-on-a-chip technology is one of the technologies that contribute to the development of Point-of-care testing devices.

The first type of data presentation is to construct a table that reports on the envisioned positions of different actors (see Section 3.3.2 and Table 3.2). The results for the analysis on Point-of-care testing are shown in Table 5.1. The first column in Table 5.1 shows that in the development of Point-of-care devices based on Lab-on-a-chip technology a wide variety of actors is involved. The involvement can either be in research and development, or in future use, finance, or regulation. Note that in the Dutch health care system there is a strict division between so-called first and second line care. First line care is the care provided by general practitioners. It is therefore the first entry point of patients in the health care system, with the exception of acute care (first aid). The general practitioner acts as a gatekeeper for the second line care, which is specialised health care in hospitals (e.g., cardiology, paediatrics).

The second column in Table 5.1 reports on the convergence in positionings (by others) of the actor in the first column. When these positionings converge, various actors grant the actor a certain position (depending on the content of the statements). Convergence indicates the role that the actor is expected to take in the near future (only scenarios for 2010 are taken into

Table 5.1 Convergence in other positioning and agreement in roles

Actor	***Position (convergence of other positioning)***	***Match of position with self positioning***
Large companies	*Convergent* Will serve the consumer market for self-testing	*Mismatch* Large companies are divided on the scale to which they will focus on Point-of-care and self-testing
Small and Medium Enterprises (SMEs)	*Not enough data* Hardly any role envisioned by others	*Mismatch* SMEs envision that they are active in serving niche markets
Science[17]	*Not enough data* Hardly any role envisioned by others	*Mismatch* Scientists envision that they have a role in enabling Point-of-care applications
First line care	*Divergent* Mainly on the variety of tests that will be in use and whether general practitioners will accept Point-of-care devices	*No comparison possible* General practitioners envision they will use Point-of-care tests
Second line care	*Divergent* Mainly on the variety of tests that will be in use and whether health care professionals will accept Point-of-care devices	*No comparison possible* Health care professionals are divided on the variety of tests that will be in use and whether there are no alternative solutions to Point-of-care devices
Patients	*Convergent* Uses Point-of-care devices to monitor the treatment	*Match*[18] Patients are interested in improving the effectiveness of their treatments
Patient oriented organisations	*Convergent* Can play an important role in stimulating Point-of-care testing	No data[19] Patient oriented organisations do not envision a role for themselves
Government	*Convergent* Efficiency is the steering mechanism, starts debate on ethical issues, and government takes a reactive role	*Mismatch* Government envisions that it stimulates development and use *Match* Efficiency is the steering mechanism
Health care insurers	*Not enough data* Hardly any role envisioned by others	*Mismatch* Health care insurers see a role for themselves in providing health-checks (that could use Point-of-care) and by stimulating experiments
Consumers	*Convergent* Will use health-checks	*No scenarios*
Society	*Convergent* Accepts self-testing and wants more prevention of illnesses	*No scenarios*
Less developed countries	*Convergent* Testing on infection diseases at locations where no infrastructure is available	*No scenarios*
Employers	*Convergent* Uses Point-of-care devices for health-checks	*No scenarios*
Consultancy	*No data* No role envisioned by others	*No data* No role envisioned
Institutions	*No data* No role envisioned by others	*No data* No role envisioned
Investors	*No data* No role envisioned by others	*No data* No role envisioned

account). The third column shows whether there is a match between the envisioned position and self positioning of the actor. If there is a mismatch, the positioned actor positions him/herself different compared to the other actors.

Some cells in Table 5.1 state 'No data'. This means that the actor is not positioned by others (column 2) or that the actor did not express self positioning in the scenario (column 3). When 'No scenarios' is noted down in the third column this means that it was difficult to find representatives of the positioned actor (e.g., society or consumers) and no scenario was constructed. When there is divergence in other positioning in the second column, it is, by definition, not possible to make a comparison with self positioning in the third column. Divergence in other positioning means that there exists a certain spread in the content of the other positionings about an actor. The analyst can therefore not make a comparison with the self positioning of that actor. Thus, when there is divergence noted down in the second column, the third column states 'No comparison possible'.

The second type of data presentation is a diagram that depicts all other positioning statements and is presented in Figure 5.5. A thicker arrow indicates a larger number of positioning statements. This number is normalized by the number of scenarios from that actor. An arrow can be single-headed, indicating that the positioning is on way, or double-headed, indicating mutual positioning. Six out of fourteen nodes have more than ten other positioning statements (or more than three when normalised); these nodes have a lighter colour and are located more in to the centre of the diagram. These lighter nodes indicate that the medical community (both first and second line care), consumers, patients, the government, and society are being positioned more frequently than the other actors. The most statements are directed towards professional use in the first and second line care (more than fifty positionings, or more than ten when normalised), also in relation with other practices of use such as consumers or patients. Science is hardly addressed by other actors to play a role in developing Point-of-care applications. The same holds for SMEs, health care insurers, large companies, institutions, investors, and consultancy.

What patterns can be observed in Figure 5.5? Figure 3.5 depicted possible patterns that might be recognised in such diagrams. Figure 5.5 indicates that the prospective positioning about Point-of-care testing is asymmetric. Asymmetry means that certain actors are positioned, while this actor does not position others.[20] Asymmetry can also exist when an actor positions others a lot and it is not being positioned by others. In general Figure 5.5 shows asymmetry, because many arrows indicate one-way positioning, but a more detailed analysis can be provided. First and second line care are positioned asymmetrically, because they are positioned a lot by others, but they much less position others (more and thicker arrows point towards first and second line care compared to the arrows that point away from the node). The same holds for patients (represented by patient related organisations). Positioning of the government by others compared to positioning by governmental agencies is balanced, but asymmetric as governmental agencies mostly position other actors than those that position the government. Science, health care insurers, SMEs, large companies, investors, and consultancy are positioned less compared to the number of times they are positioned by others. Employers, less developed countries, consumers, and society are asymmetrically positioned as there are no scenarios available from these actors.

Figure 5.5 does not provide insights into the content of the positioning statements, while Table 5.1 provides the content, but no oversight in who positions who. By comparing Figure 5.5 and Table 5.1 it can be noted that the positions of those actors that are positioned the most, the medical

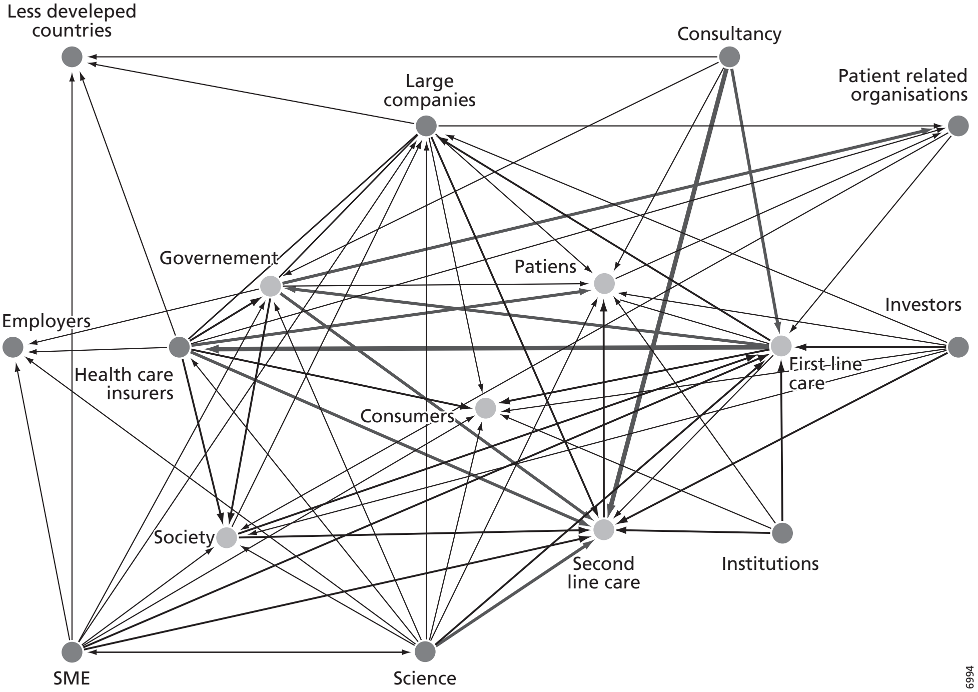


Figure 5.5 Pattern of other positionings or "Who positions who?" The diagram is generated with NetDraw (Borgatti, 2002)

community (both first and second line care), are divergent. Various actors are unsure whether Point-of-care devices will be accepted and used by the medical community. As a consequence of these diverging positions of first and second line health care professionals, achieving agreement with self positioning is not possible. When applications of direct use for patients or consumers are concerned, the other positioning statements converge. Patient related organisations are granted a position (convergent other positioning; see Table 5.1), but they do not see a role for themselves.

For companies, most large companies do not see the consumer market for self-testing devices as very promising, while others expect them to jump into this market. SMEs position themselves as active parties in putting Point-of-care devices on the market, but others do not agree on this, because SMEs are hardly mentioned in the socio-technical scenarios.

These results from analysing patterns in and the content of positioning statements are partly surprising and partly not. Point-of-care testing is a vision that addresses the use of applications that can include Lab-on-a-chip technology. The statements about Point-of-care testing that are found in the socio-technical scenarios are typically expectations about the different possible uses, about producing the devices, about regulating practices of use, and whether there will be acceptance for the new testing devices. That science is not directly related to the realisation of these kinds of visions is therefore not surprising. Science is the source and there is no need to position it, because now it has no direct influence anymore.

Less straightforward are some of the insights into the specific content of the positionings that were reported in Table 5.1. On all application areas where Point-of-care testing devices can be applied first and second line care are positioned the most. However, when looking at the content of the positioning statements there is divergence. Different opinions exist whether first and second line health care professionals will accept Point-of-care testing devices as a feasible technology option. More specifically for second line care, the location in the hospital where Point-of-care testing devices should be used is disputed. Some actors locate applications for acute care at the first aid department, while others believe monitoring of chronic diseases will become the prime focus. There is no dispute over the use and acceptance of Point-of-care testing by patients, consumers, and society at large, even though these actors are positioned frequently.

When there is convergence in the position of a certain actor there can still be a mismatch in whether the positioned actor positions himself in the same way. Such a mismatch is the case for patient oriented organisations. Other actors believe that patient oriented organisations should play an active role in steering in which Point-of-care applications should be developed, but the organisations do not see this role for themselves. As a last example, although health care insurers can play a major role in the use of new technological possibilities by providing reimbursement, this is not visible in the data. Although health care insurers do see an active role for themselves, this is hardly recognised by others.

To summarise, there is no unitary view how the vision of Point-of-care testing should be interpreted. Some positions are clear while others are not. There is especially quite some mismatch between the roles that actors see for themselves compared the roles that others assign. These results are not surprising as the overall pattern of positioning statements shows much asymmetry, which means that many relations are addressed one-way rather than mutually, and that the relations between actors are often undetermined. Some take or want to take certain roles, but these roles are not recognised. This makes that the situation is still very open in how it will develop further. Many relations still have to be shaped and formed as most relations are not fixed in the sense that actors position each other in the same way.

Scenarios are projections into the future, and actors will likely act and interact in line with these projections (see Section 2.3). This implies that there is not just convergence/divergence or match/mismatch in prospective positioning, but that there is an effect on acting. For example, as health care insurers are not recognised as an active party in the future, they will not likely take part in certain innovation processes in the present. Furthermore, as actors will not change their visions, the situation analysed above is what will be enacted and might become reality. This further implies that in the present, actors work in parallel and in different directions, rather than together.

For the field of Lab-on-a-chip technology these results only say something as far as Point-of-care testing devices are concerned. Around this generally recognized vision the relations are still very open. Maybe much more open than actors in the field might think. Some potentially influential roles even go unnoticed to most of the actors (e.g., health care insurers) or are not recognized by the actors themselves (e.g., patient related organisations).

From the analysis above, the following finding can be reported:

- Although a vision can be generally recognised, how a vision is interpreted by different actors is certainly not self-evident.
- The relations between actors are often undetermined and recognised one-way, rather than mutually. This gives a very open situation where many relations still have to and can be formed and shaped.

5.4 Spaces: cases from the field of Lab-on-a-chip

How are interactions between actors organised? Section 2.3 argued that, to gain more insight into this question the concept of space can be helpful. Spaces allow actors to assemble for negotiation, deliberation, and aggregation. New spaces can emerge (seemingly) spontaneously or can be actively created. In this section two cases of new spaces will be discussed in detail; one of each type, an emerged space and a created space. To do this the scheme to study spaces as developed in Section 3.3.3 will be used. The first case is the emergence of the field of Lab-on-a-chip technology and argues how this technological field can be characterised as a space. The second case elaborates on an instance where actors in the field actively create a temporary space (a workshop) to discuss a certain topic. Before discussing these detailed cases and to briefly illustrate the breath of the concept, first a few other examples of spaces in the Lab-on-a-chip field are described.

The recognition that microreactors could also be made by using microfluidics generated space (see also Section 5.2.3). New technological possibilities initiated discussions between different scientists (analytical chemists and synthetic chemists) to find out more about these new possibilities. Later, companies joint the space as they foresaw commercial opportunities.

In the Lab-on-a-chip field the micro-TAS conference is the prime conference. Scientists from all over the world come together each year to present to each other the latest technological advances. When it was first held, in 1994, it was a new space. Now it is an established space that, year after year, is seen by scientists that work on Lab-on-a-chip technology as a must to attend.

Europractice is a European-wide network for microsystems technology and is funded by the EU Information Society Technologies (IST) Work Programme. This funding programme functions as a space for networks to be build. In these networks actors can come together, which can lead to smaller, more dedicated, networks such as Licom (the Liquid Handling Competence Centre). Licom was established in 2000 as a public/private development network, which focuses on enabling microfluidics for industrial actors.

Case specific data

Figure 3.4 indicated which elements can be used to study spaces. To study spaces, data about the occasion, the characteristics (involved actors, boundary, infrastructure, and temporality), and the effects are needed (see Section 3.3.3). Different data sources are used for the two cases of spaces discussed below.

The *emergent* space is the Lab-on-a-chip field that emerged when lithography techniques were used to make fluidic chips, rather than electronic chips. Using lithography techniques for completely different purposes created a new community with a new arrangement of actors. The scale of this space is large and many actors are involved. The data gathering for studying the space of Lab-on-a-chip technology can make use of the data that was gathered for the historical narrative. This data documents the onset of the Lab-on-a-chip field (occasion) as well as the evolution (characteristics and effects). A combination of desk research and interviews were used to gather this data (see Section 3.2).

The *created* space is a workshop that was set up to explore the possibilities for a particular branch in Lab-on-a-chip technology; Lab-in-a-cell technology. Lab-in-a-cell technology uses individual cells as experimentation platform and Lab-on-a-chip technology is used to facilitate such experimentation. Scientists together with potential end-users organised a meeting where interests and ideas could be shared. It is a small scale space which existed only for a short while (although it can be reopened at any time). The data consists of the available documentation about the workshop (the agenda and the list of participants) and interviews.

5.4.1 The space of the Lab-on-a-chip technology field

When lithography techniques were used to create fluid channels to guide fluids, rather than structures to guide electrical currents, a new field emerged: the field of microfluidics. The history of Lab-on-a-chip technology was explored in depth in Section 5.1.

Occasion

New technological combinations were made that created possibilities for new science and technology. To take advantage of the new possibilities new interactions were required, in this case interactions between analytical chemists and material scientists (lithographers). These actors, that were previously unconnected, started to work side by side to explore the new field. Huge promises were articulated of what this new technology could bring to the world; breakthrough (medical) applications were on the brink of seeing the light of day. Such promises can inspire other actors to get involved as well.

Characteristics

The actors that were *involved* in the early stages were mainly analytical chemists and material scientists (lithographers). These actors deliberated and negotiated what could be done with the new technological possibilities. One location where this can be seen is in scientific articles published in this period about the subject. In the words of Harrison *et al.* (1992:1932): “Such systems could lead to “laboratories on a chip” that offer rapid, sophisticated analyses in a mobile package that is free to leave the laboratory. The possibility of mass fabricating devices using integrated circuit and micromachining technologies may lead to low-cost systems with applications ranging from industrial process control to clinical analysis.” When the field developed further, not only more, but also a broader variety of actors became involved (see Figure 5.1).

In the early days of microfluidics, the space was *bounded* to a few places where the research was conducted. A few research centres and an established company (Ciba Geigy, CH) were the prime places where the first publications were made. The *infrastructure* at that time was not very developed. Research had to be published in chemistry journals for instance, rather than in dedicated journals dealing solely with Lab-on-a-chip. Later, the technological field got its own conferences and journals, which provides more structure to interact, at least for the scientific and to a lesser extent industrial actors.

On *temporality*, when the field of Lab-on-a-chip technology was just initiated it could have been a scientific mayfly. As it seems now, this is not the case. As was further indicated in Section

5.1 a few people are worried (especially when it comes to commercialisation) that the days for Lab-on-a-chip technology might be numbered. However, different actors became part of the technological field and the infrastructure of the space became stabilised by journals, a growing number of research groups, R&D work in businesses, and slowly provided evidence that the promises can become reality (applications in use).[21]

Effects

The effect of Lab-on-a-chip technology as a space is that a new technological field was initiated. Figure 5.6 summarises the aspects of Lab-on-a-chip technology as a new space by focussing on the early days.

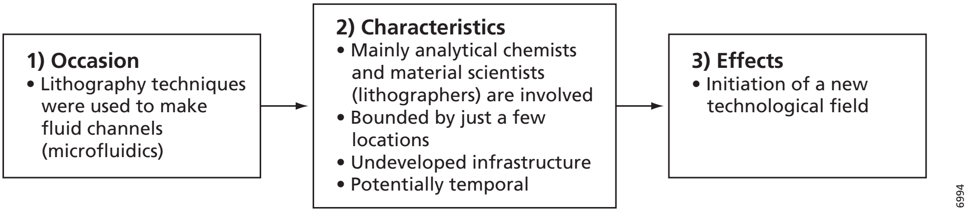


Figure 5.6 Lab-on-a-chip technology as a new space

When more actors became involved and started to interact, the momentum and trust of the overall technological field increased as well. These days the infrastructure is more established, the boundary has widened, and there is involvement of a larger variety of actors. These changed characteristics of the space do not only demonstrate an overall growth of the technological field, but also indicate a larger effect. Instead of an initiated technological field there exists now an established and recognised technological field. Changes in the characteristics -to some extent- seem to correspond with changes in the effects.

5.4.2 The space of a workshop on Lab-in-a-cell

At the 13th of August 2003 a workshop was held at the University of Twente about Lab-in-a-cell technology. Researchers from the University of Twente and medical professionals from the Medisch Spectrum Twente (a regional hospital in the Twente region in the east of the Netherlands) created a temporary space to discuss this particular topic. Recent thinking about Lab-on-a-chip technology created experimentation and expectations about using cells as tiny laboratories as well as using single cells for diagnostic purposes. Lab-on-a-chip technology is used to create the environment for the cells in which they can be studied, used for experimentation, or utilised for diagnostic purposes.

Occasion

The main initiator of this workshop originated from the University of Twente: Prof. Albert van den Berg. In 2003 he won the Simon Stevin price and with this money he started the NanoScan (Nano Single Cell Analysis) project. In the early days of this project he, together with someone from the local hospital (Medisch Spectrum Twente), organised this workshop. The occasion for the space to open up was that in the start-up phase of the NanoScan project Albert van den

Berg wanted an overview of who was doing what in the area of cell analysis (more generally and practically) to see whether, where, and when Lab-on-a-chip technology could contribute. In this sense the workshop was meant to shape the research agenda of the BIOS Lab-on-a-chip group (University of Twente) and to form a bridge between scientists and interested health care experts on cell analysis. This meeting was organised because a comparable meeting about this novel research topic was non-existing, and therefore, the initiators had to organise it themselves. This workshop was therefore deliberately designed by actors in the field. They constructed a space that aimed to function as a bridge between science and end-use, and to give the participants a good feeling about the technology and its possibilities on the one side, and potential uses on the other.

Characteristics

The set of actors that got *involved* in the workshop were specifically selected. In total 54 people were invited with the following affiliations; 32 from the University of Twente, 14 from the Medisch Spectrum Twente, 2 from a company, 2 from the University of Wageningen, 1 from the Netherlands Cancer Institute, 1 from the University of Leiden, 1 foreign participant from Max-Planck Institut, and 1 other medical professional.

The workshop was *bound* to a specific location at the Twente University campus. The programme -one could say- provided the *infrastructure* for interaction. The workshop consisted roughly of four talks and one half an hour discussions at the end.

Further, the workshop was very *temporal* as it lasted just one afternoon. To have the opportunity to easily create a second meeting, this meeting was termed '1st Lab-in-a-Cell Workshop'. The space can be reopened at a time that is convenient for the organisers and when they think it is necessary again, appropriate, or an excellent opportunity arises.[22]

Effects

A general effect for both actors (scientists and health care professionals) was that it opened the eyes on possibilities and opportunities for Lab-in-a-cell technology. The participating scientists gained more insight into the medical possibilities and demands for Lab-in-a-cell technology (which is a subset of Lab-on-a-chip technology). Health care professionals gained more insight into what technologically is and will become possible for performing (single) cell analysis with the help of microfluidic chips. This is a rather general effect, but links up with the aim of the workshop in giving the participants a good feeling about the new technology and its possibilities.

Furthermore, this effect is important in the sense that it opens the door for more specific effects. The workshop stimulated a closer collaboration between the two organising institutions, which shaped the work of a PhD student in the BIOS Lab-on-a-chip group, proposals for research funding were written, getting access to hospital resources (e.g., biological samples) was simplified, joint posters were made, and informative articles in the hospital newspaper were published.

After the workshop both sides knew better what to expect from each other. The workshop worked as a kind of catalyser to intensify person to person relations and in this respect reached its aims, i.e. to form a bridge between science and end-use. The most concrete effect of the workshop is the intensified collaboration between people from the BIOS Lab-on-a-chip group and from the Medisch Spectrum Twente. Figure 5.7 summarises the aspects of the Lab-in-a-cell workshop as a new space.

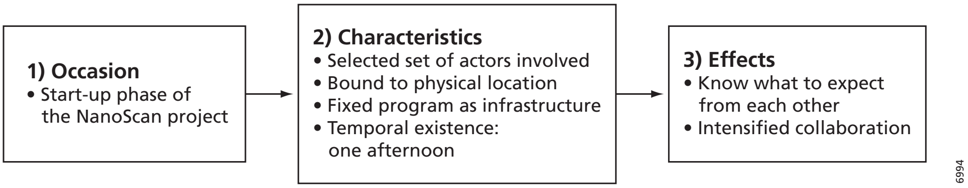


Figure 5.7 The '1st Lab-in-a-Cell Workshop' as a new space

The characteristics of the space describe a typical closed-of setting where people come together, present their ideas, and talk about a certain topic. What makes it a new space is that the selection of actors to organise it for (scientists and health care professionals) created a group of people that do not regularly meet, and certainly not in a structured manner. The effect that after the workshop the participants better knew what to expect from each other can be related to the invitation policy of the organisers. The programme of the workshop (consisting of four lectures and half an hour discussion) was focussed on informing each other. The effect of intensified collaboration does not directly follow from the characteristics. Indeed, when people meet they can decide to do things together, but the programme, for example, was not focussed on finding ground of collaboration.

Both cases indicate that spaces can open up at different levels of aggregation. The first space emerged, because there were scientific advances that gave opportunities to create new artefacts; microfluidic chips. As a result a new technological field emerged. The workshop on Lab-in-a-cell was a small-scale event supporting -in this case- scientists and health care professionals to understand better what to expect from each other. As these cases significantly differ in type and scale, likely the characteristics and effects differ as well, for example, the temporality. For Lab-on-a-chip technology, the space now exists for more than 15 years and is likely to continue to exist due to the momentum that it gained by attracting different actors, producing artefact, sustaining visions, and spawning new commercial activities. The Lab-in-a-cell workshop existed for one afternoon, although its effects had an impact on the ongoing Lab-in-a-cell activities for some of those that were present. It can be reopened when the opportunity or need arises to do so.

Further, both cases demonstrate that, once a new space is opened up interactions take place between actors that previously did not or hardly interacted. In the emergence of the field of Lab-on-a-chip technology interactions between analytical chemists and material scientists were required in order to actually start exploring the field, i.e. conduct experiments by making Lab-on-a-chips. In the Lab-in-a-cell workshop, interactions were more voluntarily, but nevertheless effects are visible that continue after the workshop (when the space is closed). Thus, on a small scale, the interactions that were organised for a moment (during the workshop) have effects on broader dynamics as well, such as the formation of actor arrangements.

From the analysis above, the following finding can be reported:

- In spaces interactions become organised. Actors can therefore use old or create new spaces to organise interactions that they find necessary or worthwhile to explore.

- In both cases the link between the characteristics and the effects could be partially explained.
- The interactions in spaces, when effective, can bind actors for shorter or longer periods of time. Collaborations can be strengthened (case of Lab-in-a-cell workshop) and new configurations of actors that work together can emerge and stabilise (case of Lab-on-a-chip technology).
- Over time, the characteristics can change and with that the potential effects. For example, when companies start to become interested in the Lab-on-a-chip field, the effects can go towards commercialisation. Also, over time, spaces can be closed and opened up again when the circumstances allow to do so.
- The concept of space is very broad and general. It nevertheless increases the comparability of occurrences where actors organise themselves. However, as spaces exist on different levels of aggregation, comparability is not always obvious or useful.

5.5 Summary and reflection

This chapter provided the empirical basis for the first research topic: understanding the dynamics of emerging (nano)technologies. The first section presented an historical narrative of Lab-on-a-chip technology. The remaining three sections further illuminated the dynamics of Lab-on-a-chip technology by studying three relevant elements thereof. Questions about entrenchment, relations between actors, and organised interaction were asked and investigated. For every section, the specific data that was used in that section was explained.

By describing the *historical narrative* it was found that the Lab-on-a-chip field has grown in terms of different types of actors. No type of actor has retreated from the field, which underlines the emerging character of the Lab-on-a-chip field.

By studying possible *emerging irreversibilities* it was found that the strength of (possible) emerging irreversibilities (influential patterns) depends on the reach of the influence to different (types of) actors and to different levels. The strength also depends on the period and persistence, where reinforcement of the pattern strengthens the emerging irreversibility. Furthermore, the patterns that could be found and were discussed turned out to be not all that irreversible. It was observed that the possibility to make fluidic chips with polymers influenced different actors in the Lab-on-a-chip field. However, no black-boxing of choosing polymers for particular problems could be observed. Nonetheless, polymers seem to be the preferred choice for biologists. This is an example of a pattern which, if it is continued to be reinforced, is likely to become irreversible, i.e. the search heuristic becomes black-boxed. In the case of microreactors, synthetic chemists became connected to the Lab-on-a-chip field. This influenced what is now seen as Lab-on-a-chip technology: analysis and synthesis, rather than analysis alone (as was the case when it first emerged). Whether this link is irreversible could not be observed, but each time the link is reinforced (e.g., by expressed expectations, agendas, or actual actor arrangements) it becomes stronger. In terms of entrenchment; the possible emerging irreversibilities did indicate entrenchment, choices and investments were made. How entrenched the field of Lab-on-a-chip technology, with respect to the provided examples, really is, is difficult to say. At least, the influences of polymer and microreactors are not completely irreversible, which means that there is no situation like lock-in. What could be indicated is that certain directions were taken that, at least on the short term, are likely to be reinforced.

Socio-technical scenarios were used to study patterns in prospective *positioning*. By doing so it was found that, although a vision can be generally recognised; how a vision is interpreted by different actors is certainly not self-evident. Furthermore, around the issue of Point-of-care testing the relations between actors were often found to be undetermined and recognised one-way, rather than mutually. This gives a very open situation where many relations still have to and can be formed and shaped.

Interactions become organised in *spaces* which exist on different levels of aggregation. Actors can therefore use old or create new spaces to organise interactions they find necessary or worthwhile to explore. When effective, through interactions in spaces, actor can connect for shorter or longer periods of time. In the case of the '1st Lab-in-a-cell workshop' it was observed that collaboration between the BIOS research group and the Medisch Spectrum Twente was strengthened as an effect of organised interaction during the workshop. In both cases that were studied the link between the characteristics and the effects could only be partially explained. Over time the characteristics can change, and with that the potential effects. This was most clearly observed in the case of the Lab-on-a-chip field, which assorted more effects when it continued to reinforce itself and became more influential over time.

Worthy of note is that, throughout the different sections in this chapter it becomes evident that the current situation is still rather open-ended. This is maybe not that surprising and it was actually part of the reasons why there is interest in studying emerging technologies in the first place. But still, over the course of the Lab-on-a-chip field, many actors got involved, companies are developing applications, and visions endure. The historical narrative supports that there has been quite some build-up in proof-of-principles, commercial interest, and actor arrangements. When looking in more detail to the aspect of entrenchment (Section 5.2) and relations between actors (Section 5.3) it is found that no findings of certain direction that became ingrained in the actions and interactions of the involved actors can be presented. Arguably, actors involved in the Lab-on-a-chip field might not be aware of this degree of openness and flexibility. After all, there has been more than 15 years of technological development already.

More specifically on emerging irreversibilities, when considering early entrenchment in an emerging technological field there are multiple influential patterns that emerge as possible emerging irreversibilities. Patterns can be found in how actors interact, arrange themselves in networks, search for solutions, and take decisions. These patterns are influential (enabling and constraining) for actors operating in the emerging technological field. Multiple patterns can become influential at the same time. In this sense emerging irreversibilities can overlap. For example, when a biologist wants to starts a company using polymers to make the chips and he does this in a situation were there is many interest from venture capitalists, the overall effort to get the company started will likely be easier compared to a situation where one of the elements (polymers as preferred choice for biologists or interest from venture capitalists) is not present. It can be argued that, overlapping emerging irreversibilities further shape the overall thrust and direction in which the emerging technological field is developing.

Each section in this chapter used a particular method, tool, or scheme to support writing a historical narrative or studying one of the three elements of the dynamics of emerging technologies. How did the tools and schemes function?

The *socio-technical mapping* that was reported in Section 5.1 could indicate the entities that became expressed in the field of Lab-on-a-chip technology over time. The same can be done for any other emerging technological field. What the maps do not show are relations between the different entities. This leaves out questions why different entities become involved and why certain relations exist (and not others). Answering such questions can potentially provide more insights into the dynamics of emerging technologies compared to observations that certain entities become articulated in a particular emerging technological field, as was done here.

The *three-level frameworks* could indicate how the influence of an emerging irreversibility spreads out to different levels, and as such acquires strength. For example, as scientific advances start in research groups, later scientific programmes on the topic are set up. What the three-level framework cannot identify are the processes and mechanisms behind these developments, although it does provide enough data to raise these questions (which can then be answered otherwise). Another limitation is that, for example, emerging irreversibilities as search heuristics are not visible in the three level frameworks. Three-level frameworks are useful in supporting investigations of possible emerging irreversibilities, but not much more than that.

The types of data presentation used to study patterns of prospective *positioning* enable what they are supposed to do, present the data in such a way that an analysis of the data and the results becomes possible. More generally, patterns in prospective positioning can best be found when analysing data from a broad set of actors. That this was not always the case in Section 5.3 can be seen in Table 5.1, where not enough data could be provided for the cells to make a judgement on convergence and match. This effect can be reduced when the scenarios from the different actors are more equally distributed. That this was not the case here can be observed in the distribution of scenarios in Figure 5.4. However, an equal distribution is not always possible. For example, it is not possible to get statements from 'society', while society at large does occur as an actor in positioning statements.

The scheme applied to study *spaces* could to some extent link the characteristics to the effects, but does not have enough explanatory capacity to explain the link in detail. In the case of the field of Lab-on-a-chip technology correspondence was found between changes in the characteristics and changes in the overall effect of the space. In the case of the '1st Lab-in-a-Cell Workshop' some of the effects could not be linked to the characteristics. The method provides a simple approach to obtain understanding about the basic substance and dynamics of the space that is studied. The lack of explanatory capacity is not a problem of the scheme as such, because it wasn't designed to be fully explanatory. In order to do gain more insight into the link between characteristics and effects a more detailed method is needed. In developing such a method also a better conceptualisation of the concept of spaces is needed. It goes too far to make this step in this thesis. The findings presented in this thesis might, however, function as a source of inspiration to do so.

Notes

1 This section is partly based upon Van Merkerk and Robinson (2006).

2 There is no broadly accepted definition for Lab-on-a-chip technology. In this thesis Lab-on-a-chip technology is defined as: systems consisting of functional fluid channels designed for a particular purpose. This leaves out microarray technology (glass plates used to detect many different strands of DNA in one analysis) since there is no channel architecture involved in microarray technology. Further, microarray

technology developed as a separate technological field. Only recently it can be seen that Lab-on-a-chip and microarray technology are integrated (Wang, 2000).

3 There are some indications that some earlier work had been done. In 1979, Terry *et al.* presented a gas chromatographer made in silicon, which has channels that guide gasses rather than liquids. Růžička (1983) shows a flow injection analyser that is capable of measuring the flow of mixed substances, but cannot perform (bio)chemical analysis. It was not until Manz and others started to work on the concept of micro total analysis systems that microfluidics could be used for (bio)chemical analysis.

4 EUROPRACTICE is a European Commission initiative, funded by the EU Information Society Technologies (IST) Work Programme. The aim is to improve the competitiveness of European industry by the adoption of advanced electronics technologies. (http://www.te.rl.ac.uk/europractice_com. Last visited August 12, 2007)

5 http://www.microfluidics-roadmap.com. Last visited August 6, 2007.

6 This section is partly based upon Van Merkerk and Robinson (2006).

7 Caliper Life Sciences had its initial public offering (IPO) in 1999.

8 A similar pattern was found in Van Merkerk and Van Lente (2005) in the area of applications of nanotubes.

9 A cleanroom is an environment that has a low dust atmosphere. For the production of chips this is needed, because dust particles can interfere with the production material during the process and cause errors in the small scale structures.

10 Feature-size is the measure of how small the structures in a material can be made.

11 The most used and easiest to use polymer is poly(dimethylsiloxane) (PDMS) (McDonald *et al.*, 2000).

12 It has been shown that 1000 microreactors operating in parallel can produce 1kg of material a day (Haswell *et al.*, 2001).

13 Multi-phase reactions means that in the synthesis of a chemical compound a number of intermediary stages are passed where another compound is created then transformed in a number of steps until the final compound is obtained. In many cases microreaction technology offers the possibility to perform multi-phase reactions that were not possible before.

14 Interview by Douglas Robinson with Stephen Haswell, June 28th 2005, University of Hull, UK.

15 This section is based upon Van Merkerk and Van Lente (forthcoming 2008) and inspired another article (Boon and Van Merkerk, forthcoming 2008).

16 In some interviews, for various reasons, it was not possible to make both time steps. The scenario then only consists of a future image for 2010.

17 Includes two scenarios from research institutes.

18 Patient oriented organisations represent the patients.

19 Patient oriented organisations have a double role; representing themselves and patients.

20 This kind of asymmetry can also occur when the positioned actor was not interviewed for the construction of a socio-technical scenario.

21 Van Lente and Rip (1998) would talk about this situation as a rhetorical space that is opened up. Here, this rhetorical space is the world of Lab-on-a-chip technology, which becomes (can become) a social reality through mutual positioning, agenda building processes, some actual work, and the production of findings and artefacts.

22 There are now plans to organise a '2nd Lab-in-a-Cell Workshop', which is supposed to be national, instead of local as in the case of the first. The NanoScan project also acquired follow-up resources to continue working on the subject of Lab-in-a-cell, which stimulates the realisation of a second meeting.

6 Evaluating constructive intervention for the field of Lab-on-a-chip technology in the Netherlands

In the first chapter it was argued that constructive intervention can have positive effects on the societal embedment of emerging technologies and can contribute to the quality of innovation processes. There, stimulating broadening and enriching through constructive intervention was suggested as an alternative route to circumvent the Collingridge dilemma. Chapter 2 provided the theoretical background for how in this thesis ongoing technological developments and innovation processes are viewed. This had consequences for how the intervention and the evaluation hereof were developed in Chapter 3. For example, interaction between actors is an important unit of analysis for constructive intervention.

In this chapter the evaluation results of an intervention in the field of Lab-on-a-chip technology in the Netherlands will be reported and discussed. This intervention ran between May 2005 and February 2006, and used the 3-step CTA approach. In the evaluation of the intervention there are two types of effects (both in terms of broadening and enriching) that can be evaluated: 1) the overall effect of the intervention and 2) the relative differences in effect between the permutations in the third step of the 3-step CTA approach; multilogue workshops. Section 2.5 explained that broad interaction processes can lead to broadening and enriching after the intervention, when the participants returned to their normal working environment. In Section 3.4 this relation was further conceptualised for the 3-step CTA approach, which is presented again in Figure 6.1.

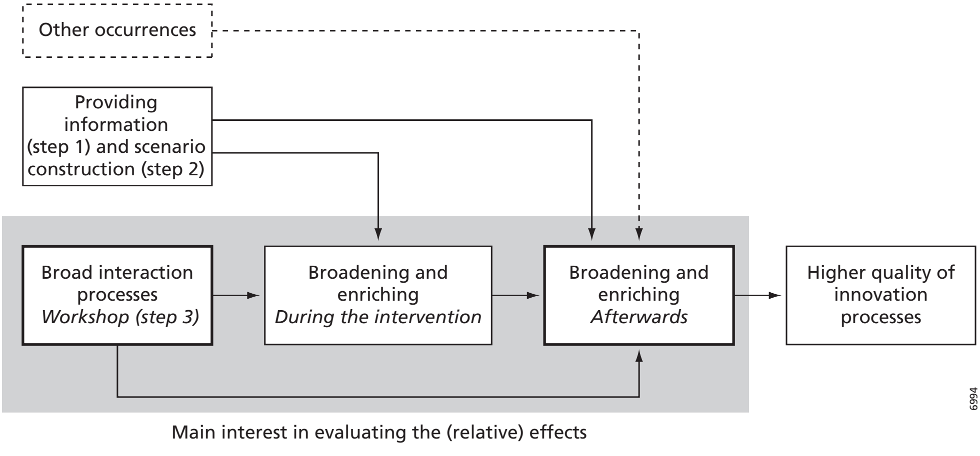


Figure 6.1 Conceptual scheme of effects of the CTA approach (based on Figure 3.6)

This chapter will start in Section 6.1 with an evaluation of the overall effects in terms of broadening and enriching. To take into account the intramural effect the data for this evaluation was not gathered immediately after the workshops, but two months later. In doing so the evaluation concentrates on effects in the normal working environment. The main reason for this is that constraints that are present during normal working hours are felt much less in a closed-of setting such as a workshop. Back to work these constraints present themselves again to the full. Consequently, in order to have an effect in the normal working environment the results of the intervention have to withstand these constraints. Assessing broadening and enriching some time after the intervention therefore gives a more realistic image of the effects in the normal working environment.

Furthermore, assessing the overall effect is difficult as an absolute value of broadening and enriching is hard to define. Section 3.5 offered, from the body of TA literature, six effect indicators that are considered in this thesis as a proxy for broadening and enriching in the normal working environment.

In applying the 3-step CTA approach the third step is permutated. The reason for this is to gain insights into 'how to design' constructive intervention. To identify differences in effects between the workshop permutations an evaluation of the relative effects is performed in Section 6.2.

This evaluation of the relative differences in effects comprises three phases (Section 3.5). These phases relate to the conceptualisation of the effects of constructive intervention. Figure 6.2 shows this conceptualization, the three phases to evaluate the relative effects, and the corresponding section numbers.

In section 6.3 a few remaining observations about effects of the intervention will be discussed. These observations address; 1) a striking difference in the enthusiasm among the participants immediately after the intervention and the effects on initialised action, 2) whether positions of actors can change due to multilogue workshops, and 3) whether the intervention was actually valuable for the participants.

To indicate what actually happened during the multilogue workshops Box 6.1 presents a rich description of one of the workshops. The attendance rate of the workshops was 90%. Box 6.2 will present possible reasons for this high attendance rate. After each section the findings will be summarised in bulleted form.

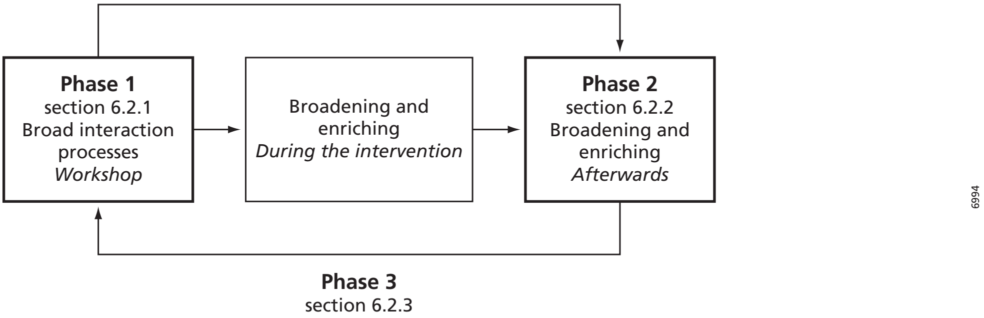


Figure 6.2 Three phases of the evaluation (based on Figure 3.8)

Box 6.1 Rich description of the mixed workshop with issue selection

It is February 1, 2006. At 11.50 am the first participants arrive at the Buys Ballot building at the Utrecht University campus. Sandwiches and refreshments are served before the workshop starts. People introduce themselves; a few already know each other. At 12.30 pm a heterogeneous set of thirteen people enters the room where the workshop will be held. The cameras and sound recorders are already running to tape everything that is said over the whole afternoon.[56] Everybody sits behind a computer screen. There is also a technical person present to operate the computer system of the -so called- Policy Lab. An observer sits with pen and paper at a chair at the side of the room. The facilitator opens the workshop with a word of welcome. "Who are present here today are all experts, everybody in their own field. […] I wish you a pleasant and fruitful afternoon." Then, the participants shortly introduce themselves, including the technical person, the observer, and the facilitator. The room where the workshop was held is shown in the figure below.

A snapshot of the workshop

The participants first need to learn how the computer system works. Facilitator: "You are sitting in front of a computer screen. […] The system is used to make the time spent during this afternoon more efficient." To practice, the participants first get the task to type in what they expect from the afternoon. The results appear on the central screen. People laugh about the funny answers that are given. In a second task the participants get the question: "Where do you think applications of Lab-on-a-chip technology will be used the most in the near future?" In answering this question a list of possible application areas is provided and every participant has three votes to allocate over these options. Again the results appear on the central screen. It is not the intention to stay with these results for very long and discuss them in length, so the facilitator indicates that this is just to practise. With these two tasks the participants experience two of the tools of the computer system and get acquainted with how the system works.

It is now around 1.15 pm, the participants to some extent know with whom they are sitting in the room for the rest of the afternoon and know how to work with the computer system. As this is an issue selection workshop (see Section 3.4.4), the first round of the workshop consists of a selection from a list of ten issues. These issues came out of an analysis of the 54 individual socio-technical scenarios (see Box 3.5). Before the participants can choose from the list the facilitator first asks whether all issues taken up in the list are clear to everybody. Every participant gets three votes for the issues that he or she finds most important to discuss. The table below presents the results that appear on the central screen.

Results of issue selection.

1. What will be the 'real' market in 2010? (consumer/patient/first line care/second line care/science)	8
2. Acceptance and implementation of first line care	5
3. Changes for acute and non acute testing (consumer/patient/first line care/second line care)	5
4. Desirability of self-testing	5
5. Opportunities for reimbursement (at home/first line care/second line care)	4
6. Developing components versus integration (science versus industry)	3
7. Active versus passive government about Point-of-care and self-testing	3
8. Laboratory testing versus decentralisation in second line care	2
9. Opportunities for 'specialties' such as implants, applications for less developed countries, and medical checks for employees	1
10. Privacy and availability of genetic information	0

The facilitator starts the discussion by going through the results. "What will be the 'real' market for Lab-on-a-chip technology in 2010?" In the beginning of the discussion, the consumer market is discussed. A health care professional gives his impression from what he knows from his own practice. Also other application areas such as screening, use by the general practitioner, and the role of the pharmacist are mentioned, but the main discussion topic is about applications for consumers. More than half of the participants actively contribute to the discussion. Due to the heterogeneous set of actors that are present at the workshop a discussion topic can be fed from different perspectives, such as actual use, commercialisation, and health care insurance. After half an hour the facilitator ends the discussion: "It is time for a short break before we continue with the second round."

In the second round the participants can propose the issues that they want to discuss. First they all can type in one discussion topic and then a selection takes place, again by allocating three votes. The facilitator presents the results and the discussion starts. The discussion, however, does not start with the highest item from the list. Instead, the discussion concentrates on the point that the health care market is non-transparent. It is mentioned that development trajectories are long and that validation of the devices is required. Even when technologically there are no problems, it is not said that the application will have a glorious future. On this issue it is further recognised that although some applications have societal benefit, no one develops these applications. It is therefore addressed which actor should take the lead in developing these applications and who should invest in it; large companies, the government? As a result the question remains how to initiate new applications. A comparison is made with the pharmaceutical market where new markets are developed, but other participants go against this comparison as they believe the market dynamics are incomparable. As the discussion progresses a way out of the 'problem identifying' discussion starts to appear. "What if we cooperate to tackle this difficult market?" "Why don't we build small coalitions that develop, use, and finance experiments?" Then, another problem is brought into the discussion, which is the need to conduct cost effectiveness studies. This issue is quickly taken up in the solution that was just formulated. Further, a few participants start questioning a health care professional about what cost effectiveness studies are and what it costs to perform such studies. With this the half hour discussion ends.

The third round is a brainstorm session. The participants are asked to type in as many technology options they can think of. The facilitator explains that a technology option is an application (what is measured or what it is used for) combined with a practice (where the application is used). In the first two rounds various technology options were already discussed. During the brainstorm, the participants can see on their screen with what the others come up with. This inspires other participants to come up with new technology options. After ten minutes the participants generated a list of more than fifty technology options. After the brainstorm there is a tea and coffee break.

After the break, around 3.30 pm, the fourth round starts. The participants are asked to type in their favourite technology option that came out of the brainstorm. This can also be a technology option that another participant came up with. Then, the participants are asked to score the technology options on feasibility and desirability. A score can range from zero to ten. The results are presented on the central screen with the help of a prioritisation matrix. This prioritisation matrix also shows the average scores for the various technology options. By applying this tool the participants get an overview of what kind of technology options are judged by the group to be both feasible and desirable; two necessary aspects of technology options to turn them into innovations. The facilitator goes through the results, starting with the technology option with the highest combined score of feasibility and desirability. A discussion starts when the facilitator mentions the fourth technology options in the list, which is a technology option that is desirable but not very feasible. However, the discussion quickly drifts away to other topics. Different technology options, including existing applications (not necessarily with Lab-on-a-chip technology), are discussed. How these technology options (would or could) work in practice, what they cost or would cost, and what their use is or can be. Again, an atmosphere emerges where things can be settled together; problems can be solved. Then, the discussion drifts away until a participant picks another item from the prioritisation matrix. Different variants of this technology option are discussed. And further: "If we see all these nice applications, and even when they exist: why are they hardly used?" A clear answer does not seem to be available. It has something to do with reimbursement or financial systems in health care more generally, but the impression is that these issues cannot be the whole story. It is more complex and issues are mentioned why this is the case. It is now almost 5 pm, time to end the workshop and have a few drinks before everybody heads home again, but first, the participants were asked to fill up a brief questionnaire.

Box 6.2 Thoughts about the attendance rate

The attendance rate of the invited participants was 90%. There can be different reasons why this percentage is so high. Reasons can be that the participants were invited to a project (with an individual scenario interview, a workshop, and a follow-up interview), rather than a single workshop, which created a certain commitment. The CTA analyst already visited the participants for the construction of a socio-technical scenario, which makes that the CTA analyst and the participant knew each other. Arguably, this increases the chance that participants come to the workshop. Furthermore, for the participants it was clear beforehand that the total amount of time to spend on this project would not exceed a one day investment. It was thus made very clear where the participants were taken part in. Another reason could be that the participants were curious about the scenarios from other actors and how their scenario relates to other scenarios. In a situation of high uncertainty (as in emerging technologies), knowing and reflecting upon other viewpoints can be very valuable. Especially when there will be people present that the participants did not know before. Another reason can be that participants expect to meet interesting people with whom they can strengthen their network or simply because they thought it would be a nice outing to be away from normal work for a while. There can be other reasons not listed here. Most likely, there is not a single reason that can explain the high attendance. The participants were, however, provided with many reasons to attend (commitment to project, interested in other scenarios, networking, nice outing, etc), so the chance that there is a reason to attend was higher.

6.1 The overall effect

This section evaluates the overall effect of the intervention in the normal working environment of the participants. Two sets of indicators from the body of Technology Assessment literature are used: 1) indicators for knowledge uptake and use, and 2) quality indicators for CTA activities. 'Knowledge uptake and use' was operationalised in Section 3.5 with the indicators enhancing knowledge, changing attitudes and opinions, and initialising action. The quality indicators are anticipations, reflection, and learning. Both sets of effect indicators will mainly be evaluated on the basis of the follow-up interviews (see Box 3.6). The socio-technical scenarios are used to assess whether the participants changed their scenario on the basis of the workshops. There exists a certain amount of overlap in the effect indicators, which implies that some questions in the follow-up interviews provide data for more than one effect indicator.

The overall assessment is performed in terms of broadening and enriching, where broadening indicates that participants broadened their perspectives (in terms of actors and aspects), and enriching indicates that the participants enriched their insights into the dynamics of innovation processes. All effect indicators, depending on the content, can indicate broadening and/or enriching. Section 3.5 explained that a combination of the effect indicators is seen as a proxy for broadening and enriching.

6.1.1 Assessing indicators for knowledge uptake and use

In this section an assessment is made of the indictors for knowledge uptake and use; enhancing knowledge, changing attitudes and opinions, and initialised action.

Enhancing knowledge

The multilogue workshops gave the participants the opportunity to test their socio-technical scenarios that they developed in the scenario interview. Two months later a majority of the participants (85%) indicated in the follow-up interviews that their socio-technical scenario (at least on details) changed. This indicates that as a result of the intervention most of the participants -to some extent- enhanced their knowledge about the developments in Lab-on-a-chip technology and related aspects.

Changing attitudes and opinions

In the follow-up interview a question was included asking whether the participants now take into account more actors and/or aspects in their work. A positive answer indicates that the intervention made the participant look differently towards the field of Lab-on-a-chip technology, and the variety of actors and aspects, i.e. changing of attitudes and opinions. For 75% of the participants the answer was positive, which implies that the majority of the participants changed their attitudes and opinions.

Hence, a majority of the participants took up the point that, when assessing technology options, a broader variety of actors and aspects is important to consider compared to what they were used to. For example, participants mention that they realised that there are more success factors than just sound technologies, that they now give talks that address wider issues, and that they should address economic feasibility more directly and preferably in communication with other stakeholders. These are a few concrete examples of 'changed attitudes and opinions' that indicate that participants now 'take into account more actors and more aspects' in their thinking about and working with Lab-on-a-chip technology and its implications.

The follow-up interviews further indicate that there is a relation between positive answers to this first question (whether participants now take into account more actors and more aspects) and two other questions. From the group that answered the first question positively about 40% indicated they now monitor their environment more widely and about 25% indicated that they changed their strategy (in one way or another). For an example of the latter, one of the participants answered: "I have a plan to incorporate more parties in my work, such as the government." When the answer to the first question was negative, no positive answers on the other two questions (about monitoring and strategy) were given.

The follow-up interviews also included a question about whether the participants changed their attitude towards collaboration. About 50% of the participants answered this question positively. Often this change in attitude contained that in future collaborations the participants had the intention to make coalitions with a larger diversity of actors.

Initialising action
On the indicator initialised action almost no effect can be reported. In the follow-up interviews a question was included about whether something happened or changed in the work of the participant. This is an open question and therefore also a short-list of possible actions (such as starting a new project) was used to see whether new actions were initialised. The answers to these questions show that only a few participants arranged appointments with other participants or further elaborated a particular technology option inside their organisation. There were no actions initialised between insiders and outsiders.

The few new actions that did occur were either triggered by the intervention directly or by other activities where participants met again. On the latter, a few participants indicated that this happened when they were at other meetings where they met the same people again and talked about this intervention. This can be understood by noting that multiple stimuli have a likely higher initialising effect for action, which corresponds with the second 'face of impact' from Bhola (2000) (see Section 2.5): impact by interaction. Furthermore, a few participants during the follow-up interview indicated that initialising action can occur, but at a later point in time. In the words of a participant: "There are a few contacts that I would like to contact again. These kinds of things often need some time, so this might come later. That's how it normally goes." The intention may be there, but action is postponed. Another example: a scientist expressed that projects were running and changes are only possible when new projects are initiated. Thus, 'new understandings about how the world works' (changing attitudes and opinions) can trigger new intentions, but action is more likely to happen when there are opportunities for choice, which can take some time.

From the analysis above, the following findings can be reported:

- The majority (85%) of the participants enhanced their knowledge.
- The majority (75%) of the participants changed their attitude and opinion. A changed attitude or opinion can also have an effect on how participants assess future collaborations.
- Initialised action is limited. A few participants indicated that effects were induced by other interventions or might turn up later when the right circumstances for choice arise.

6.1.2 Assessing quality indicators for CTA activities
In this section an assessment is made of quality indicators for CTA activities; anticipation, reflection, and learning.

Anticipation
From the follow-up interviews indications for anticipation can be found if participants take into account longer term developments when they indicate changes in their scenarios. Almost no effects were found when looking for anticipation in this way, although a few statements of anticipation could be found. For example, a participant mentioned as an adaptation to his scenario: "The speed by which applications will come to the market will turn out to be

disappointing." This quote indicates that this participant assessed the pace of developments in the future (anticipation) and subsequently adjusted his expectations.

Reflection

Indications whether the intervention caused reflection can be found in different ways. Reflection can first be elicited from the way answers were given during the follow-up interviews; when participants indicated that they thought about a certain issue in relation to their work. On the question: "Do you now take into account more aspects and actors in your work?"; 75% answered positively, which implies reflection. This is the same result as reported under the effect indicator 'changed attitudes and opinions' (Section 6.1.1).

Reflection can have stronger effects as well. For those participants that answered the abovementioned question positively about 25% indicated that there was also a change (in one way or another) in their strategy. For a strategic change to happen someone has to rethink one or more issues in relation to his or her work. Thus, a change in strategy indicates that reflection did take place.

The follow-up interviews further indicate that about half of the participants now look differently towards collaborations. This result implies that reflection has taken place as it includes considerations about work, namely collaborating. In the words of a participant: "In future projects I would look more carefully to the structure of health care. For this I would include partners that know health care very well."

Learning

Factual learning parallels the effect of enhanced knowledge (85% effect). Some other concrete learning effects surfaced from the answers to other questions. Examples are that some participants learned that solving logistic problems in hospitals can be a great driver for Point-of-care applications. Or, that they leave out certain applications in talking to colleagues, because these applications appeared to be less promising in the workshop they participated in.

In the follow-up interviews the participants were also asked whether they expected to change their reaction on requests for collaboration. About half of the participants expected to do so, often by intending to include a wider range of actors compared to what they were used to. This is a learning effect, because it indicates that after two months the participants still thought that there is something to gain when incorporating other actors in collaborations.

Further, more than 70% of the participants indicated a change in the stories that they tell to colleagues. For example: "I can now be more concrete as I know more examples" or "I add certain things and include other stakeholders when I talk to colleagues about Lab-on-a-chip technology." Such answers indicate that insights were gained, which can be factual (I know more examples) or more about the dynamics of innovation processes (I include other stakeholders).

From the analysis above, the following findings can be reported:

- Almost no effect could be observed on anticipation.
- Reflection occurs a lot. This can also -at least to some extent- affect the participant's strategy and the way participants consider collaborations.
- Factual learning is very common; 85% of the participants experienced factual learning. Learning that more deeply involves how participants work, for example on collaborations,

is found to be less, but still on average about half of the participants experience this effect. About 70% indicated changes in how they tell stories to their colleagues.

6.1.3 Broadening and enriching

Section 3.5 explained that a combination of the six effect indicators is seen as a proxy for broadening and enriching. In this approach broadening and enriching are taken together in evaluating the overall effect. Table 6.1 reports the results on the effect indicators as assessed in the previous two sections.

From Table 6.1 it is not possible to provide an absolute value of broadening and enriching. What the table does indicate is that broadening and enriching in the normal working environment of the participants occurs; maybe not for every participant, but certainly at the level of the group that was present at the workshop. For each of the workshops separately, expressions for at least four of the six effect indicators could be found. These four effect indicators are 'enhancing knowledge', 'changing attitudes and opinions', 'learning', and 'reflection'.

That broadening and enriching occurs in the normal working environment of the participants is an important result of the evaluation so far. This thesis argues that stimulating broadening and enriching is a feasible route to improve the quality of innovation processes. In this way an attempt is made to deal with the Collingridge dilemma in 'managing technology in society'. The results above indicate that broadening and enriching occurs indeed after applying a constructive intervention that uses a specific CTA approach for emerging technologies, the 3-step CTA approach. These results thus indicate that the approach taken in this thesis is feasible.

From the text above, the following findings can be reported:

- The follow-up interviews indicate that broadening and enriching occurs in the normal working environment as an effect of the intervention.
- Given that broadening and enriching in the normal working environment is initiated by the intervention, this is an indication that at an early stage the quality of innovation processes can be improved. With this, it becomes feasible to -at least partly- circumvent the Collingridge dilemma through constructive intervention.

Table 6.1 Results of assessing the six effect indicators

Effect indicator	*Percentage of participants experiencing the effect*
Enhancing knowledge	85%
Changing attitudes and opinions	75%
Initialised action	Limited results
Anticipation	Limited results
Reflection	75%
Learning	Factual 85%, deeper 50%

6.2 Relative effects between workshop permutations

In applying the 3-step CTA approach the workshop design (step 3) was permutated (Section 3.4.4). The reason for these permutations was to gain insights into 'how to design' constructive intervention for emerging technologies. The goal of this section is to obtain understanding about whether the changes in workshop design influenced the overall effects. Such relative differences between the workshop permutations will be evaluated in terms of broadening and enriching. Furthermore, by evaluating the relative effects insights can be gained in how to design constructive intervention in emerging technological fields. For the evaluation of the relative effects Table 6.2 repeats the evaluation scheme that was developed in Section 3.5; now addressing the sections in this chapter (6.2.1-6.2.3) where the different phases are discussed.

Table 6.2 The evaluation scheme to assess relative differences (based on Table 3.5)

Phase	Evaluated in	Concept	Evaluation steps	Data sources
1. During the workshops	Section 6.2.1	Interaction processes	Observing workshop dynamics Positioning analysis	Workshop transcripts
2. Two months after the workshops	Section 6.2.2	Broadening and enriching	Indicators for knowledge uptake and use Quality indicators for CTA activities	Follow-up interviews and socio-technical scenarios
3. Comparing during and afterwards	Section 6.2.3	Attribution	Attributing differences in broadening and enriching afterwards to differences in interaction processes during the workshop	All available sources

The first phase (discussed in Section 6.2.1), an analysis of interaction processes during the workshops comprises two parts: 1) analysing general workshop dynamics and 2) analysing patterns in positioning. The focus is on observations that indicate differences between the four workshops. The data in this phase mainly consists of the workshop transcripts.

The second phase (discussed in Section 6.2.2) focuses on changes in thinking, acting, and interacting of the participants after they returned to their normal working environment. The data mainly consists of follow-up interviews that were held two months after the workshops. Based on these follow-up interviews an assessment is made whether there are differences in broadening and enriching (see Section 6.1.3).

The third phase (discussed in Section 6.2.3) compares the evaluation results of the first two phases: during and after the workshops. It will be discussed whether the differences found in broadening and enriching between the four workshops can be attributed to the differences found in interaction processes during the workshops.

6.2.1 Phase 1: interaction processes during the workshops

The first phase comprises two parts (Table 6.2) that both concentrate on differences in interaction processes that can be observed during the workshops. The first part indicates differences in interaction processes that could be observed by going through the transcripts, following the *workshop dynamics*, and noting down differences in interaction processes. Only those differences caused by the permutations in workshop design are of interest.

The second part consists of an *analysis of positioning* that appears in the workshop transcripts. This part will start with providing fragments of workshop transcripts and will indicate how the analysis was performed. Then, the differences in interaction processes that are found through this analysis are listed and elaborated.

No operationalisation of interaction processes was made beforehand, because otherwise the analysis can become biased towards the operationalisation. This makes that the approach taken here is open ended, which means that a priori all possible interaction processes are included.[2]

Observing differences in workshop dynamics

In Box 6.1 in the description of one of the workshops, different interaction processes can be observed such as 'identifying the problem' or 'coming closer together'. These examples do not directly relate to the setup of the workshop and the differences in setup between the workshops. Those differences in interaction processes are presented below where a direct connection could be found with differences in design of the permutated workshops. These observations were made by repeatedly scanning the workshop transcripts of the different workshops (see Section 3.5).

The first observation is made in the insider workshop with scenario presentation (workshop No. 1). At a certain moment one of the participants says: "According to me, it was my expectation that, when we all entered this room that it was the intention to challenge this type of scenarios. […] That's why I keep questioning your scenario, to make clear what we are really talking about." This quote shows that the participant had a certain expectation towards what was expected from him during the workshop. Then, this participant was confronted with a workshop design where he could actually act like this; he was in a scenario presentation workshop. To explain the importance of this quote, the quote should be put into context. The quote was made in the second round of the workshop where another participant presented his scenario. This scenario was challenged and defended the whole round by the participant that made the quote. The interaction process can be typified as opposition that led to contestation. The value of the quote ("According to me […]") is that it makes a connection between the workshop design (scenario presentation) and the interaction process as observed in the transcripts (contestation). In short: a participant has the attitude that scenarios should be challenged, and when doing so, this can lead to contestation.

Can the same connection be made in the first round of the same workshop (another scenario gets presented here) or during the two other scenario presentations in workshop No. 2? In two of these three other instances the scenario is indeed challenged. Critical remarks are directed at the scenario presenter at the start of the discussion. However, these critiques did not lead to contestation. Thus, in three out of four scenario presentations, a challenging attitude towards the scenario presenter was observed, which seems to be provoked by the design of the workshop (scenario presentation).

A second observation is related to scenario presentation as well. The mere fact that someone presents his or her scenario makes that the discussion stays centred on the scenario and its presenter. It happens that, when the discussion drifts away from the scenario, the presenter or another participant redirects the discussion back to what the scenario was about. In this respect the following quote is exemplary: "But do you [scenario presenter, ed.] think about measuring proteins or other substances?" In this quote a participant asks the scenario presenter whether the discussion topic falls within the scenario. Such a question gives the scenario presenter the opportunity (or actually he is requested) to steer the discussion back to the content of his or her scenario. Another example, but this time from the scenario presenter: "Yes, but I am talking first and foremost about analysis for the first line care. The simple things, Point-of-care, simple things, not those […]" By saying this the scenario presenter tries to bring back the discussion to the topics addressed in his scenario, because he believes that the other participants are discussing technology options that fall outside his scenario. It is not necessary for this type of interaction to occur with scenario presentation. In fact, it was not observed this clearly in all scenarios that were presented. However, this type of interaction process is absent during the issue selection workshops.

A third observation is a difference between the insider and mixed workshops. In the mixed workshops, when a discussion is held, there is, compared to the insider workshops, a larger variety of expertise sitting around the table. Participants can therefore request a wider base of expertise. The result is that different relations are discussed: "What does the health care insurer think of this issue?" or "Does the general practitioner really need the type of devices that we are talking about now?" Similar questions are raised in the insider workshop, but the difference is that in the mixed workshop there is a higher chance that actually somebody is present to answer the question directly. On the contrary, in the insider workshops (with mainly scientists and businesses present) the relation between scientists and businesses gets much attention. Exemplary in this respect is a discussion between a company and a scientist where the company tries to explain the role of scientists: "When you as a scientist investigate a module, you need to have in mind how it can be integrated in a system. You should therefore not make complex modules that are difficult to integrate for companies that want to use them. Actually, you should find a company to cooperate with. In this way you develop modules that are suitable for mass production." This explanation specifically points out the relation between scientists and businesses. In the mixed workshops various relations are addressed, but none as explicit as in the just mentioned quote. This observation indicates that the actor composition enables certain relations to be discussed; directly and face-to-face. In insider workshops this is limited to one relation: between scientists and businesses.

On the basis of the observations made above, the following findings can be reported:

- The design of a workshop can provoke a certain attitude towards a particular kind of interaction processes (e.g., challenging scenarios).
- The design of a workshop can provoke particular interaction processes (e.g., discussion centred on scenario presenter).
- The design of a workshop can enable certain interaction processes. For example, in mixed workshops participants can directly address various actors (and with that various expertises). In an insider workshop, only scientists and businesses can address each other directly.

Positioning analysis

By focusing specifically on positioning this part of the first evaluation phase presents a systematic analysis of interaction processes. In interactions, positioning happens all the time and is used to express the relation to other actors from the viewpoint of the participant that makes the positioning statement (see Section 3.5). Before presenting the observations that indicate differences in interaction processes, first it will be explained how the analysis of positioning on the workshop transcripts is performed. A fragment of edited and annotated transcript is presented in Box 6.3.

On the left side, Box 6.3 shows the type of positioning that is going on. Figure 3.9 gave examples of the different types of positioning that are distinguished in this analysis. Deliberate

Box 6.3 Annotated stylised text as example of the analysis performed on the transcripts of the workshops

There is a discussion going on about the costs of blood tests (with and without Lab-on-a-chip technology) and who could or should pay for the tests. A change in the discussion topic occurs towards the development of new tests and the necessary clinical studies. The latter topic was already debated earlier on during the workshop.

DOP/ DSP	HCP: I am glad that *we* have this discussion here. *I* cannot have that at home. It is difficult to reach the health care insurer with questions. You never get to talk to the one that you want to talk to.
↳	POI: They are assigned to do that.
↳	HCP: Yes indeed, you never reach the person you want.
↳	SME: And this holds when there already is a product, right?
earlier → DSP DOP	SC: … so we need clinical studies as well. At *the university* we have the knowledge to make products. The *health care insurer* is interested in the case. Where can we start? We should not go back to the lab and perform new tests. No, we should start with clinical studies to analyse the case.
DSP ↳	HCP: I agree
DSP ↳ DOP	HCI: Yes, *I* think we would be pleased to see the cost benefits. Especially when they are on the short term. The more vague this is, the less we have to talk about. But on the short term issue, *you* can calculate that together. So you can say, let's do that.
DOP ↳	LC: Does this mean that we will sit around the table together with the *health care insurer* and the *medical professional*?
FSP ↳	HCI: Yes. Look, *I* hear things here and I like it. I see money in these type of cases, so who am I to say you should not do this.

Legend

Actors	*Positioning*
HCP: health care professional	DSP: deliberate self positioning
POI: patient oriented institution	DOP: deliberate other positioning
SME: small and medium sized enterprise	FSP: forced self positioning
SC: scientist	↳ : reaction
HCI: health care insurer	
LC: large company	

self and other positioning are most common and occur in many of the statements that are made. Consequently, when analysing transcript data, most sentences are positioning statements and can often be typified as multiple types of positioning. For example, self and other positioning can occur in the same statement as in the first sentence of the text fragment. In this statement 'we' addresses the other participants in the workshop, which can trigger another participant to react. In the same statement 'I' starts an explanation of the situation that the health care professional is normally in. Forced self and other positioning occur much less frequent. The forced self positioning in the text fragment (Box 6.3) is actually not much more than giving an answer to a directed question.[3] Subsequently the health care insurer gives an explanation how he looks upon the issue under discussion.

The arrows on the left indicate the statement that is reacted on. Most of the time this is the previous statement. In the reaction of the scientist it can be seen that an issue discussed earlier is brought back into the discussion and consequently the discussion shifts. Counter reactions are made when people don't agree with each other. In Box 6.4 a text fragment is provided where counter reactions do occur.

In this fragment forced self positioning has another meaning compared to the forced self positioning that was shown in Box 6.4. Counter reactions are given out of disagreement on the issue. The patient oriented institution is forced to clarify his statement (opinion) again after a

Box 6.4 Another example of annotated stylised text

Somewhat later during the workshop, a discussion is started on using health care guidelines and the relation with innovation.

DOP/ SME: Yes, but guidelines go against the nature of innovation.
DSP ⤷ POI: *I* would like to make another statement: if *we* would apply all knowledge that we have on proven cost-effective guidelines, we would macro economically be much better of than with what we spend these days on innovation.
DSP/
DOP c⤷ SME: If we apply all knowledge? *Man*!, that is …
FSP c⤷ POI: Yes, if we would do that throughout health care, we would be much better of.

Then a discussion starts about the definition of innovation.

Legend

Actors
POI: patient oriented institution
SME: small and medium sized enterprise

Positioning
DSP: deliberate self positioning
DOP: deliberate other positioning
FSP: forced self positioning
⤷ : reaction
c⤷ : counter reaction

firm deliberate other positioning. This clarification is a self positioning statement, because an opinion is given.

Not only persons, but also artefacts are positioned. As an example, a health care professional during one of the workshops stated: "Point-of-care testing for certain viruses; that would be a very practical test for general practitioners." Other participants can agree or not in the remainder of the discussion.

Above, it was described how transcripts from the workshops were annotated line-by-line. Single positioning statements, however, do not say much about the interactions going on during a workshop. Interaction processes, as the word 'process' implies, should be analysed by following the discussion and by finding patterns that characterise the interaction processes. For example, periods where the same issue is discussed, periods where a certain type of positioning is used a lot, or periods where there is dispute about an issue. The annotations support the evaluator in finding these patterns. For example, when there are many counter positionings it is likely that an issue is heavily debated. Subsequently, questions will arise 'how' and 'why' these patterns occur and whether the same patterns are also visible in the other workshops. Further questions should then be asked whether the observed interaction processes can be linked to the particular design of that workshop (e.g., issue selection versus scenario presentation). Answering such questions then forms the basis of the results of the analysis. In doing so, interaction processes during the workshops can be analysed and differences between workshops can be found. Thus, to observe differences in interaction processes between the four workshops, the analysis has to be highly iterative. The results of this iterative analysis are presented below.

A first observation is a difference between the insider and the mixed workshops. During the insider workshop 'technology' is positioned as something that still needs to be worked on. Consequently, 'technology' is something that can constrain (but also enable) certain technology options. Throughout the insider workshops technology (and what it means for the possibilities of Lab-on-a-chip technology) remains contested. In contrast, during the mixed workshops technology is positioned as 'not being a problem'. Outsiders occasionally asked the insiders whether there are any technological limitations for certain technology options. Typical answers were "for the largest part it is technically realizable" or "technologically it is possible, that is not the question". The participants could then close the discussion on the technological issue and continue to discuss other issues. In the transcripts of the insider workshops it was observed that technological feasibility remains contested and is also a point of departure to come up with potential applications. These applications are then often discussed in detail.

Such detailed discussions about technological feasibility (can it be realised technologically?) do not occur in the mixed workshops where the discussion topics are generally more at a higher level (e.g., health care wide issues such as reimbursement). This difference can be illustrated by giving sequences of discussion topics, and the changes thereof, which are addressed throughout a workshop round. Table 6.3 provides such sequences.

In general, the content of the discussion topics in the insider workshops is about technology and markets. Markets in the business sense of the word; places where money can be earned. Technological feasibility is an issue and is addressed as something that makes certain options possible and constrains other options. In the mixed workshop in Table 6.3, technological feasibility is addressed at the start of the discussion, but immediately played down. Furthermore,

Table 6.3 Sequences of discussion topics

Insider workshop, Issue selection, Round 2	Outsider workshop, Issue selection, Round 2
Demands for successful LoC for self-diagnostics	Technologically there are no limitations
Cost of LoC coupled with production technology	Parties that might invest in the development of LoC applications
Other demands for successful LoC	Investments in the pharmaceutical market
Technical demands for LoC	Investments of diagnostic companies
Integration of modules	The role of SMEs
Market segmentation versus technology segmentation	To get innovation you need collaboration
Possible added value of LoC	The role of the government
Different technical demands	The role of the health care insurer
Segmentation by disease	Cost effectiveness studies are needed. This is difficult

the discussions deal more with general health care issues, the role of different actors, and the complexity of health care innovations. The questionnaire immediately after the workshops also contributes data to support this observation as a few participants from the insider workshops indicated that the discussions were rather technical.

In light of this issue, Garud and Ahlstrom (1997) indicate that insiders use narrow evaluation frames to assess a technology, which implies that mainly benefits are emphasized. Outsiders use broad evaluation frames that emphasise costs, benefits, and risks. These differences in assessment criteria to some extent explain the difference as discussed here; insiders focus on technology based reasoning, while a mixed group of insiders and outsiders focuses more on selecting technologies for specific purposes.

Another observation is about a particular type of positioning statement: forced self positioning (FSP). Forced self positioning does not happen a lot during the workshops. What does it mean when a participant asks another participant to position himself? Forced self positioning can have several meanings and in the transcripts three types can be distinguished. Firstly, forced self positioning can contain a straightforward question about explanation or clarification (How do you think about this subject?). In this case the positioned participant can just answer the question. Secondly, forced self positioning can induce a kind of lecturing. Lecturing in the sense that a person starts to explain how he thinks the world works. This person is, as it were, triggered to do this by comments of other participants. Thirdly, forced self positioning can be of an accusing kind, where people often raise their voice. The latter use of forced self positioning can put a discussion on edge, which can result in opposition and contestation.

Of the third type of forced self positioning, there is one prime example in workshop No. 1 (insider workshop with scenario presentation) where contestation was triggered by the presentation of a scenario.[4] This contestation lasted one full part (one third) of the workshop. What could be observed here is that during the contestation forced self positioning was triggered a lot and that standpoints are repeated many times.[5] A lot of time is spent without getting much further in the discussion and leaving other topics non-discussed. The efficiency of a discussion that turns into a long-lasting contestation is therefore not very high. In other instances a sequence of forced self positionings indicates fierce argumentation, but never really led to contestation.

Given that scenario presentation led to contestation once in an insider workshop, this indicates that with scenario presentation there is at least more occasion and a higher chance for opposition and contestation to occur. Why can this be the case? When a scenario is presented, a situation can develop where the presenter (maybe backed up by others) defends his view. This defensive position can continue for some period of time and subsequently turn into contestation. In the case of issue selection the participants decide where they want to talk about as a group, which can make the discussion topic more easily (although not necessarily) accepted by the whole group. The workshop transcripts indicate that such a start of the discussion is more distributed, which means that the discussion goes back and forth between various participants and is not centred on the scenario presenter (as was observed in the first part of this section).

It could further be observed that representation differs in insider and mixed workshops.[6] When during an insider workshop an actor is positioned that is not present in the workshop, often

Box 6.5 Other positioning is followed by more other positioning when the positioned actor is not present

A participant mentions health care insurance. Other participants react.

DOP ↪ LC1: Probably, groups of patients with the same diseases will get particular offers of *health care insurers*.
DOP ↪ Sc1: When other *health care insurers* don't offer that package, customers can start to switch.
DSP ↪ LC1: Yes, that's really part of the issue.
DOP c ↪ SME: But how far do we go in such an insurance system?
DSP ↪ LC1: But it is based on voluntariness.
DOP ↪ LC2: A *health care insurer* that focuses on particular groups of patients can be very efficient.
↪ F: Insurance policies exist for diabetes
↪ Sc2: What does that has to do with insurance?

This discussion continued for 13 more statements until:

Sc2: We are drifting away from discussing Lab-on-a-chip.

Legend

Actors
LC: large company
Sc: scientist
SME: small and medium sized enterprise
F: facilitator

Positioning
DSP: deliberate self positioning
DOP: deliberate other positioning
↪ : reaction
c ↪ : counter reaction

other participants make positioning statements about the non-present actor as well. The result is that the non-present actor is positioned by different participants. In an insider workshop, other positioning is thus often followed by more other positioning. Box 6.5 gives a text fragment that is exemplary in this respect. Further, when such a repetition of other positioning happens it is difficult to get closure on the discussion topic. Multiple participants give input to the discussion, but there is no conclusion. The result is often that, after different participants made their opinion heard, the discussion shifts to another topic.

In the mixed workshops the interaction can take another course. Here, a participant can use ‘real’ representation as the positioned actor is actually present. Although this does not always happen, a direct reaction of the actor that is positioned is possible. In a mixed workshop deliberate other positioning can thus be followed by forced self positioning. Box 6.6 gives a text fragment that is exemplary in this respect.

The result is that, when having a representative actor present, this allows the whole group to get direct feedback from the actor that is positioned and to continue the discussion based on that input. In an insider workshop a discussion can start about, for example, “what a general practitioner would do or think”, while in a mixed workshop, such a question can be answered by the general practitioner that is present. In this respect the discussions during the mixed workshops can -so to say- flow better, which stimulates the debate. Discussions do not get obstructed by multiple other positionings without closure of the issue. In insider workshops the result can be that other relevant discussion topics are under-exposed, because the group is busy discussing issues that would have been resolved quickly when the non-present actor would have

Box 6.6 Other positioning is followed by forced self positioning when the positioned actor is actually present

A participant addresses the health care insurer who can react directly.

DSP ↪ SME: That’s the idea. That efficiency becomes more important, through privatization and other measures.
DOP ↪ HCP: … but, what has the health care insurer to say about this issue, because …
Sc: *statement by scientist which is ignored.*
FSP ↪ HCI: Well look, when I talk from the point of view of the health care insurer. What I recently experience is that it seems like there is sand everywhere in the machine. On the other hand, what seems to work is when you collaborate with somewhat larger parties and dare to, together, sketch a dream.

Legend

Actors	*Positioning*
SME: small and medium sized enterprise	DSP: deliberate self positioning
HCP: health care professional	DOP: deliberate other positioning
HCI: health care insurer	FSP: forced self positioning
	↪ : reaction

been present. These interaction processes are, however, not absent in the mixed workshops. The same interaction processes can be observed here when an actor is not present, for example, 'the consumer', although the chances are much lower as many actors are present.

On the basis of the observations made above, the following findings can be reported:

- Technological feasibility is a relevant discussion topic in insider workshops and not in the mixed workshops. In mixed workshops higher level and more general issues get more priority.
- Scenario presentation leads more easily to opposition and contestation.
- Direct representation stimulates the flow of discussions.

6.2.2 Phase 2: broadening and enriching two months after the workshop

In this section the relative differences in the overall effect, broadening and enriching in the normal working environment, are analysed. For this analysis the six effect indicators are used. This section thus builds upon the results as presented in Section 6.1. By presenting the effect indicators for each workshop permutation in a table, an assessment of the relative differences in broadening and enriching can be made. The first two parts of this section each discuss one set of effect indicators. The third part assesses relative differences between the workshop permutations in terms of broadening and enriching.

Differences in knowledge uptake and use

On the effect indicator *enhancing knowledge* Section 6.1 reported that in total 85% of the participants indicated changes in their socio-technical scenario. However, for workshop No. 1

		Actor composition	
		Insiders	Mixed
Use of scenarios	Scenario presentation	1 Fewer changes compared to other workshops The value of the indicator 'enhancing knowledge' is lower compared to other workshops	2 All aspects are addressed Many areas of use are addressed compared to workshop No. 3
	Issue selection	3 All aspects are addressed, but fewer changes compared to workshop No. 2 and 4 More specific applications are addressed compared to workshop No. 2 and 4	4 Roughly the same amount of changes as workshop No. 3 The spread of changes is rather similar to workshop No. 2

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Figure 6.3 Observations from Figures A.1-A.4 on the effect indicator 'enhancing knowledge' this effect is less; approx. 75%. These changes in the participants' socio-technical scenarios can be further analysed by plotting them in a scenario map (see Figure 4.2 for an empty scenario map). Each time a participant indicates a change a mark is made in the scenario map. A participant can indicate multiple changes. In this way for each of the workshops an assessment can be made about the type of changes at the level of the group of participants. For each workshop separately, these scenario maps are shown in Appendix A (Figure A.1-A.4). When these maps are compared to Figure 4.3 (which indicates the approximate location of different topics in a scenario map) it can be analysed where the focus of the enhanced knowledge lies. Figure 6.3 indicates these observations per workshop.

What is remarkable of workshop No. 3 (Figure A.3) is that there are a considerable number of changes that relate to applications, which is not the case for the mixed workshops (No. 2 and 4). This is not observed for the other insider workshop (No. 1 – Figure A.1), but for this workshop there are also a limited number of changes reported. Therefore, on the basis of the changes indicated for workshop No. 3, compared to the mixed workshops, it is found that in insider workshops participants have a higher chance to enhance their technical knowledge. However, as can be seen in the scenario map of workshop No. 3 (Figure A.3) as well, this does not exclude the enhancement of knowledge on other aspects. Thus, the content of the changes in the socio-technical scenarios of participants in the insider workshops is more focussed on technological aspects and applications. For the mixed workshops the content is focused more on use and practices.

For the effect indicator *changing attitudes and opinions* an average effect of 75% was reported (see Section 6.1.1). However, for workshop No. 1 (insider workshop with scenario presentation) the percentage was considerably lower; approx. 40%. Participants were further questioned whether they changed their attitudes towards collaborations. On average 50% answered this question positively. The mixed workshops indicate a slightly higher effect of 60% compared to 40% (issue selection) and 25% (scenario presentation) in the insider workshops.

On *initialising action*, almost no effects were reported. No differences were found between the workshop permutations.

Differences in quality indicators for CTA activities

Anticipation was barely observed. No differences were found between the workshop permutations.

Reflection was observed as on average 75% of the participants now take into account more aspects doing their work. However, for workshop No. 1 (insider workshop with scenario presentation) a smaller effect has to be reported on this issue; approx. 40%. The mixed workshops demonstrate a larger effect on the issue whether participants now look differently towards collaborations.

For the effect indicator *learning*, for an average of 85% of the participants, factual learning could be observed (see Section 6.1.2). However, for Workshop No. 1 (insider workshop with scenario presentation) a slightly smaller effect can be reported on this issue; approx. 75%. Deeper learning can be indicated by changes in reactions to requests for collaboration, because this involves considerations about how participants work. For the mixed workshops a larger effect can be reported on this issue. On the question whether participants now tell different stories to their colleagues, on average 70% gave positive answers. For the mixed workshop with scenario presentation (No. 2) this percentage was higher; approx. 90%.

Relative differences in broadening and enriching

Just as in Section 6.1 a combination of the six effect indicators is seen as a proxy for broadening and enriching. Table 6.4 presents the results on the effect indicators as reported in the previous two parts of this section. In this table the relative differences between the workshop permutations are indicated by a plus/'+' (most effect), a null/'o' (medium effect), or a minus/'-' (least effect).

In the assessment of broadening and enriching it are not the individual pluses and minuses in Table 6.4 that count. It is the total effect that surfaces from these data upon which findings can be based. Analysing Table 6.4 in this way it is found that, compared to insider workshops, mixed workshops likely result in more broadening and enriching. The relative differences between the insider workshops indicate that, compared to issue selection, scenario presentation likely results in more broadening and enriching. This difference is not found between the mixed workshops.

By using values for the effect indicators by indicating most, mid, and least, the relative effects may appear more extreme in Table 6.4 then they actually are. A minus means, compared to the other workshops, a lower value on the effect indicator. In terms of broadening and enriching it is not that the insider workshop with scenario presentation (No. 1) is unproductive and the mixed workshops are very productive. Section 6.1 indicated that all workshops are productive and Table 6.4 indicates that there are differences in productivity. For example, in workshop No. 1 broadening and enriching occurs, although the effect is less compared to the effect of other workshop permutations.

From the evaluation above, the following findings can be reported:

- A mixed actor composition tends to facilitate a more productive intervention compared to an actor composition consisting of insiders.
- Based on the results of the insider workshops issue selection tends to be more productive than scenario presentation. This relative difference was not observed between the two mixed workshops.

Table 6.4 Effect indicators for broadening and enriching. Ordered under the workshop permutations. Relative effects: +=most, o=mid, and -=least

	Insider		**Mixed**	
Effect indicator	*Issue selection*	*Scenario presentation*	*Issue selection*	*Scenario presentation*
Enhancing knowledge	o	-	+	+
Changing attitudes and opinions	+	-	+	+
Initialised action	Limited results	Limited results	Limited results	Limited results
Anticipation	Limited results	Limited results	Limited results	Limited results
Reflection	o	-	+	+
Learning	o	-	+	+

6.2.3 Phase 3: attribution stories

In the third phase of the evaluation of the intervention in Lab-on-a-chip technology the results of the previous two phases are compared. This comparison is performed by attributing results of the second phase, differences in broadening and enriching, to observations in the first phase, interaction processes. This comparison takes the form of attribution stories in which possible causal links between results in the first two phases are explored. In Table 6.4 the relative differences in broadening and enriching are ordered according to the workshop permutations. To find the possible causal links, the observations made on differences in interaction processes will be ordered in the same way, which is presented in Table 6.5.

Attribution stories about scenario presentation versus issue selection

In Table 6.4, for the two insider workshops, a difference in productivity (broadening and enriching) is reported. Between the two mixed workshops no differences are found. What observations on differences in interaction processes could have contributed to these relative differences in productivity? The top half of Table 6.5 lists three differences between scenario presentation and issue selection. These observed differences will now be discussed to see whether they can be attributed to the differences found in broadening and enriching.

The analysis of positioning indicated that forced self positioning can take the shape of accusation, which can lead to opposition and contestation. A prime example of opposition was identified in Section 6.2.1 and occurred after someone presented his scenario. In the transcripts of the other workshops sometimes fierce argumentation was observed. These moments of fierce argumentation are short and do not hamper the flow of the discussion. During this prime example of opposition a participant explicitly expressed an attitude that scenarios needed to be challenged. Such expressions were not found after the three other scenario presentations. In issue selection workshops such an attitude is due to the design of the workshops not possible.

Furthermore, when a considerable amount of time is spent on one topic (the contestation) other potentially valuable and relevant discussion topics remain non-discussed. During opposition and contestation often the same arguments and statements are repeated. The nature of a contestation is such that both parties try to hold ground on the issue without giving in. This is inefficient as in the same time many other issues could have been discussed. As a result the value of the effect indicators can be lower compared to workshops without long-lasting contestation. Nonetheless, the follow-up interviews indicate that contestation can also have a positive effect. One of the participants directly involved in the lengthy contestation took with him that the dynamics for (technically) complex and simple applications are different. He indicated that there are other factors that are important for making one or the other type of applications work. It is not that contestation cannot have positive effects on the effect indicators; the point is that the atmosphere that is created during contestation likely results in less efficient interaction processes.

Another observation is that, with scenario presentation the discussion can stay focussed on the presenter ("Is this in line with your scenario?") or the discussion can easily come back to the presenter ("My scenario was more about …"). Thus, with scenario presentation there is a kind of selection-by-design where one actor is put central in the discussion. With issue selection this is not the case, which likely results in a more distributed discussion.

Table 6.5 Observed differences in interaction processes. Ordered under the workshop permutations

	Insider		**Mixed**	
Observed differences on …	*Issue selection*	*Scenario presentation*	*Issue selection*	*Scenario presentation*
		Scenario presentation versus issue selection		
Expected interaction processes	n/a	Challenging scenarios	n/a	No clear challenging of scenarios
Focus	More distributed start of the discussion	Centred on or coming back to scenario presenter	More distributed start of the discussion	Centred on or coming back to scenario presenter
Opposition	Short term fierce argumentation, but not hampering the continuation of the discussion	Opposition/ contestation triggered	Short term fierce argumentation, but not hampering the continuation of the discussion	Short term fierce argumentation, but not hampering the continuation of the discussion
		Insider versus mixed actor composition		
Elucidating relations	Dyadic relation (science versus industry) is discussed intensively in one part of the workshop	Dyadic relation (science versus industry) is sometimes discussed	Different relations discussed directly	Different relations discussed directly
Content focus	Technological feasibility is relevant discussion topic	Technological feasibility is relevant discussion topic	High lever and more general issues discussed	High lever and more general issues discussed
Representation	Repetitive addressing non-present actors	Repetitive addressing non-present actors	Direct reactions possible	Direct reactions possible

The question is now whether these three differences in interaction processes (top halve of Table 6.5) could have contributed to the relative differences in productivity (Table 6.4) between workshops with scenario presentation and issue selection? The different observations add up in the sense that for the insider workshop with scenario presentation the efficiency of the interactions was less compared to the other insider workshop. At a certain moment this led to a long-lasting contestation. Between the two mixed workshops no difference in productivity was found. It is therefore not purely the fact that scenario presentation led to less efficient interactions and by this to a lower productivity, otherwise there should also be a difference between the two mixed workshops.

What remains is that scenario presentation in the insider workshop focussed the discussion on a particular view of one participant, which was challenged and caused contestation. The same could have happened in the mixed workshops with scenario presentation. Chances for contestation in workshops with issue selection are lower, because one of the elements that triggered the lengthy contestation, namely discussion centred on the scenario presenter, is absent by design. It is therefore that scenario presentation is more likely to trigger contestation.

Attribution stories about insider versus mixed actor composition
Table 6.4 reports a difference in productivity between the insider and mixed workshops. Which observations of the differences in interaction processes could have contributed to these differences in productivity? The lower halve of Table 6.5 lists three observations, which will be discussed below.

In the insider workshop technological feasibility is taken as a serious topic for discussion, while in the mixed workshops it is brushed aside as unimportant. In the mixed workshops it is assumed that 'technology' is not a limiting factor. Discussions in the insider workshops elaborate on technological aspects and the participants continue discussing technological topics for long periods of time. The mixed workshops discuss higher level and more general topics at length (e.g., how health care innovations diffuse and what hampers diffusion), which reflects the broad evaluation frames held by outsiders (Garud and Ahlstrom, 1997). In terms of broadening and enriching technological feasibility is only one aspect out of many that are relevant to discuss. The topics discussed in the mixed workshop generally touch upon more aspects and also show more of the dynamics of innovation processes.

Furthermore, in the workshop transcripts it could be observed that in mixed workshops 'real' representation had an effect on the interactions during a workshop. When an actor was positioned a direct reaction could be expected, because the actor was actually represented by one of the participants. 'Direct reaction' speeds up the discussion and informs the participants from the source (the actor that is present). This stimulates to keep a certain flow in the discussion, which results in that many topics are discussed and different relations become clearer to the participants. In the insider workshops the only relation that can really become clearer is between science and industry. When other relations are discussed it often is not possible to reach closure as different participants have their own idea about the role of the actor that is discussed. Would this actor be present a direct contribution to the discussion could resolve the issue or the relation could actually be further discussed. In mixed workshops discussions can therefore be more efficiently held (in the light of broadening and enriching). Thus, a mixed actor composition is more likely to result in more efficient discussions.

To summarise, these observations hint that mixed workshops show more of the dynamics of innovation processes, because more relations between actors are addressed and discussions generally touch upon more aspect. Participants are therefore more likely to enrich their insights thereof. The more general level of discussions will make it easier for participants to broaden their perspectives compared to technology focussed discussions, because in these discussions a wide variety of aspects is discussed.

A combination of an insider workshop with scenario presentation gives the highest chance on a less productive workshop, not saying that this always has to be the case. Mixed workshops are found to be more productive (Table 6.4) and likely result in more efficient discussions. Issue selection gives less chance for opposition and contestation. For these reasons, even though between the two mixed workshops no differences in productivity was observed, a mixed workshop with issue selection should be the choice when organising workshops that strive for broadening and enriching.

From the analysis above, the following findings can be reported:

- Scenario presentation is more likely to trigger contestation.
- A mixed actor composition is more likely to result in more efficient discussions.
- A combination of an insider workshop with scenario presentation gives the highest chance on a less productive workshop.
- When organising workshops that strive for broadening and enriching, mixed workshops with issue selection (No. 4) are considered the preferred choice.

6.3 Additional observations about effects of the intervention

Up to now, the overall and relative effects of the intervention were evaluated and discussed. During this evaluation there were some observations that could not be discussed in the previous sections, but are nonetheless worthwhile to discuss further. This section will discuss three of such additional observations.

Firstly, there is a striking difference between the enthusiasm among the participants that was initiated by the intervention and the actual effects that turn up in terms of initialised action. The enthusiasm can be observed as 98% of the participants indicated in the questionnaire immediately after the workshop that they showed interest in follow-up activities to continue the discussions in one way or the other. The type of follow-up activities that were indicated ranged from developing business cases with a small heterogeneous group, to similar workshops, to a large congress on medical applications of Lab-on-a-chip technology.[7] Further, more than 70% of the participants expressed in the same questionnaire that the intervention would affect their work. More general enthusiasm that Lab-on-a-chip technology is something to take up more intensively can also be observed. For example, 90% of the invited people participated, participants express their enthusiasm during the workshops, and businesses that were not yet involved in Lab-on-a-chip technology were interested to participate. However, there are also expressions of the opposite, people that have their doubts about the successful future of Lab-on-a-chip technology. The overall enthusiasm is nevertheless rather high and a limited effect on initialised action is therefore remarkable. Section 6.4.1 will reflect on this issue by putting this result in the light of the three issues mentioned in Section 2.5, namely the intramural effect, different types of impact, and different dimensions of knowledge utilization.

Secondly, Section 2.3 explained that a position is considered as an accepted or established role, which means that different actors see the same role for an actor. Can positions change due to multilogue workshops? If positions can change this would mean that the intervention has a somewhat structural effect on the Lab-on-a-chip field. Section 6.4.2 will reflect on this issue.

Thirdly, it will be discussed in Section 6.4.3 whether the intervention was actually valuable for the participants. Not unimportant, because if participants believe the intervention was valuable for them, chances are that they actually do something with the results.

6.3.1 Reflections on limited initialised action

The introduction of this section argued that the intervention initiated quite some enthusiasm among the participants to take up Lab-on-a-chip technology more intensively. Puzzling is that, despite this enthusiasm, limited action is initialised. What can be the reason hereof? In Section 2.5 three issues were discussed that are relevant to consider in relation to this question, namely the intramural effect, different types of impact, and different dimension of knowledge utilization.

The intramural effect is actually a double-edged sword. On the one hand participants can speak more freely during the workshop, because they are bound less by the daily constraints that they are normally faced with.[8] This enables the group of participants to more easily explicate the relations between each other and/or come closer together. On the other hand, when returning back to work, the lessons learned are confronted with practical constraints. In addition, the 'normal' and ongoing issues are more important again which push new insights to the background. These effects moderate the initial enthusiasm of the participants directly after the workshops.

That the intramural effect indeed has this moderating effect can be seen in reactions of participants during the follow-up interviews. One of the scientists mentioned: "In the train home I was full of plans and I thought that I would change my research and write new proposals. Being back in the lab for some time now, I have to say this didn't happen." (stylized quote) Furthermore, during the workshop various ideas were proposed to get things going in the wider world and the participants were also queried at the end of the workshop whether the intervention would affect their work. The follow-up interviews returned to the answers to these questions and assessed whether they were still valid. Mostly, this was not the case, which exemplifies the intramural effect.

However, this is just one part of the puzzle. Section 2.5 explained that, some effects can only occur when the right circumstances for change are available. If the circumstances were not right at the time of the intervention or two months later, it does not mean that they will not be right at later stages. In light of this, Bhola mentions that for certain impacts to occur interaction with other interventions (impact by interaction) or wider cultural processes (impact by emergence) are needed. These *different types of impact* thus nuance the limited effect on initialised action, because actions that where not initialised after two months can still be initialised later on.

The limited effect on initialised action can be further nuanced when it is taken into account that there exist *different dimensions of knowledge utilization* (Section 2.5). Conceptual use of knowledge affects the frame of reference or mental model of the processes or problem at hand. When knowledge is used instrumentally, it is used practically in gathering information to solve everyday problems. Caplan (1979) argues that between different communities, especially conceptual knowledge transfer takes place, rather than instrumental knowledge. For instrumental knowledge people rely much more on their own community.

Initialising action is an effect measure that heavily relies on instrumental use of knowledge. Taking action in the normal working environment is usually connected with the problems at hand during normal working hours. It is therefore not surprising that initiated action receives a relatively low value compared to effect measures that rely more on conceptual use of knowledge.[9]

To summarise, this section started by pointing to a puzzle that a high initial enthusiasm of the participants did not lead to much initialised action. This puzzle was not completely solved, but was certainly enlightened by discussing the intramural effect, different types of impact, and different dimensions of knowledge utilization. It was indicated that the intramural effect indeed occurs. It is therefore understandable that the effect indicator initialised action, when assessed two months after the workshops, was not as high as was expected from the initial enthusiasm. Furthermore, actions can be postponed until better circumstances for change arise, which partly resolves the limited effect on initialised action. Last, initialised action was recognised as an instrumental kind of knowledge utilization. Literature on knowledge utilization indicates that for knowledge transfer between different communities (as is the case here) higher effects can be expected on conceptual forms of knowledge utilization. This makes the limited effect on initialised action compared to other effect indicators understandable.

6.3.2 Changed positions

Arguably, due to the multilogue workshops positions can change, because during the workshops relations between actors are discussed and explicated (e.g., Boxes 6.3, 6.5, and 6.5). Also, in emerging technological fields, positions are often not well established. In analysing patterns in prospective positioning this ambiguous situation was confirmed (see Section 5.3). What types of changes can be identified based on the available data? Two types of changes are discussed here of which the first type deals with other positioning (see Figure 3.9) or how other actors address the role of a particular actor. The second type deals with self positioning or more specifically, whether on the individual level actors agree with the position given to them.

Positions of others become clearer

There are a number of examples in the different data sources that indicate that a position can become clearer to the participants. Exemplary in this respect is the importance of the position of health care insurers, which is recognised by more participants after the intervention than before. This increased recognition can be seen 1) in the workshop transcripts (e.g., last two sentences in Box 6.3), 2) in the questionnaire immediately after the workshops (a few participants indicated the importance of health care insurers and expressed their interest in further discussions with this stakeholder), 3) in the follow-up interviews (nine participants from different workshops addressed the position of the health care insurer and indicated that they are now more aware of the position that the health care insurer has in the health care system in relation to innovation processes), and 4) in the opinion article that was written together with Prof. Albert van den Berg (Van Merkerk and Van den Berg, 2006). The article mentions on page 839: “What is needed are meetings between scientists, the medical community, industry, investors, *health care insurers* (italics added, ed.), patient organisations, and government.” and a little later “This implies initiatives that include ‘unconventional’ stakeholders such as *health care insurers* (italics added, ed.), business investors, or general practitioners.” The health care insurer was brought into the paper by Albert van den Berg.[10]

Another example of positions of others that become clearer relates to the importance of hospital logistics in creating incentives for Point-of-care applications. Point-of-care applications can save time (and thus money) for hospital personnel, because the time that is usually spent between blood tapping and laboratory analysis can be saved. In workshop No. 2 (mixed actor composition with scenario presentation) this issue was made clear by a health care professional and discussed further between different people. In the follow-up interviews this issue comes back. Two participants indicate that they learned about the importance of this issue around hospital logistics. One of these two participants was directly involved in this discussion during the workshop, while the other participant was not. Both participants now clearly see that hospital logistics can be an important driver for the adoption of Point-of-care devices.

For both examples it holds that, when the various pieces of data are combined, an effect of the intervention on positions can be indicated, i.e. positions can become clearer and/or change. Such changes might result in changes at the work floor and can therefore contribute to the overall effect of the intervention.

Comments about 'your own' position

There are a number of examples in the available data sources that indicate that participants obtained understanding about their own position in relation to others. For example, in workshop No. 3 (insider workshop with issue selection) a discussion was held about what scientists can do to link up better with industry demands in order to make their research more easily available for industrial partners. The proposition of a company representative was that scientists should develop simple technologies instead of complex, which is mostly what is actually under development. When the technology is simple it makes the transition to and integration with industrial designs much easier. The suggestion of the company representative was that this can be institutionalised by focusing earlier on collaborations between science and the industry. Box 6.7 provides the annotated stylized text for the closing part of this discussion.

The questionnaire immediately after the workshop offers more data on this issue. The company representative indicates in his answers that scientists do not realise the integration-challenge that lies ahead for Lab-on-a-chip applications. Three scientists come back to this issue as well. The scientist in Box 6.7 mentions that he intends to collaborate more with industrial partners in the near future. Another scientist can now also position himself better in relation to businesses: "Businesses need simple solutions, while we are working on complex highly integrated systems." In the follow-up interviews two months later, one of these scientists mentions the integration-challenge and the necessary collaboration with industrial partners again.

There are other instances that indicate that participants obtained understanding about their own position, for example, in those instances where insiders express that their position, in relation to other aspects and actors, should be marginalised. From the richness of the socio-technical scenarios and the discussions during the workshops, it becomes clear that a broad view is necessary to make applications successful. However, in the questionnaire immediately after the workshop this effect cannot yet be observed. Participants do make remarks about the need to get more parties around the table or express their intention that they want to talk more often with a broad(er) set of parties. Only in the follow-up interviews participants can tell their experiences on how the workshops affected their thinking and doing. A few participants express, for example, that they now tell different stories because they turned around their logic; first the need (e.g., social or economic), then the technical solution. Or, participants put more emphasis on non-technical aspects and pursue wider collaboration, because 'you cannot do it yourself'. Hence, a few insiders now see that technology is only one component of the puzzle, which they now assume to be less important then before the intervention.

The abovementioned examples indicate that the interactions during the workshops can have an effect on how actors perceive their own position in relation to how they are positioned by others.

Box 6.7 Annotated stylised text indicating that participant obtain understanding about their position in relation to others

A discussion is going on about what kind of technology scientists should develop to link up better with industrial players. Collaborations that potentially make the link easier are discussed as well.

FSP/DOP LC: […] I actually think that *you* should collaborate with companies early
DOP on to make the transition to the next phase more fluently. *You* have to work
DOP with mass fabrication techniques for example. Otherwise *you* just displaced
the bottleneck.
DOP/FSP ⤷ SC: So *you* say that, as a *research group* you should be in contact with an
FSP industrial partner in order to be able to bring the solution to the market?
FSP ⤷ LC: Yes. Or at least do the validation.
DSP ⤷ SC: Yes. ←

Gained understanding
The 'yes' indicates acknowledgement of the points made earlier.

Then a discussion starts about the definition of innovation.

Legend

Actors
LC: large company
SC: scientist

Positioning
DSP: deliberate self positioning
DOP: deliberate other positioning
FSP: forced self positioning
⤷ : reaction

These participants gained insights into how they relate to other actors. As a consequence, the position that these participants can or should take in innovation processes becomes clearer to them. Based on such new insights these participants can change their actions and interactions in the normal working environment, which contributes to the overall effect of the intervention.

6.3.3 The value of the intervention for participants

At different points during the intervention and the follow-up interview, participants indicated that the intervention was valuable to them. As a first indication, participants expressed that making a scenario helped them to structure their thoughts and to relate different aspects to each other. This does not indicate broadening and enriching per se, but it surely indicates that constructing a socio-technical scenario is a valuable exercise for actors dealing with emerging technologies. After the scenario interview (step 2 of the 3-step CTA approach) a few participants also expressed that they were surprised with the scenario they could come up with. They were surprised in the sense that they were able to construct a rich and consistent scenario that includes many aspects and the relations between these aspects. This indicates that, during the scenario interview, the first steps towards broadening and enriching are made. Participants came up with issues (broadening) or relations (enriching) that they did not think of before.

Box 6.8 On a Monday afternoon on the phone with Prof. Albert van den Berg

In the spring of 2007, more than a year after the intervention, a phone call was made with Albert van den Berg, professor on Lab-on-a-chip technology at the Twente University. During this phone call he talked about two issues that nicely show the effect of the workshops through the eyes of a participant.

Prof. Van den Berg suggested that, according to him, one of the most important results of the workshops is that a spin-off from his group is now active in involving various stakeholders. The most remarkable example thereof is their relation with a health care insurer. The realisation of this relation is however not a direct effect of the intervention.

Albert van den Berg further mentioned that, due to his participation in the intervention, he now knows better how and why innovations do or do not succeed. He always knew that it was something in the order of 1/3 technology, 1/3 money, and 1/3 something else. "Due to your workshops, I now know better what the 'something else' is." It has to do with other stakeholders and the interests of others. This is different from case to case, but the relation between the spin-off company and the health care insurer is definitely an example. "Also, in relation with the article in 'Lab on a chip' that we wrote together, I still hear from people that it opened their eyes, which exemplifies the same issue."[11]

Furthermore, 90% of the invited people attended the workshops. Box 6.2 explained that participants can have many reasons to attend the workshop, but this number also indicates that the participants thought that attending the workshop would be worth spending time on. Moreover, in the questionnaire immediately after the workshops participants expressed that the workshop was valuable to them. Two months later, during the follow-up interviews, without asking for it, participants expressed again that the intervention was valuable to them. Box 6.8 provides an example of such an expression.

From these three elaborated observations, the following findings can be reported:

- Initial enthusiasm is indeed moderated by the intramural effect. Further, action can be postponed until the right circumstances present themselves. Also, a limited effect on initialised action is understandable, because conceptual knowledge use is likely the prominent type of knowledge utilization.
- As a result of the intervention, positions of other actors and/or their own position can become clearer to participants. Participants gained insights into how they relate to other actors. Such insights can affect how actors think, act, and interact at the work floor.
- Throughout the course of the intervention participants expressed that the steps in the 3-step CTA approach were valuable to them.

6.4 Summary and reflection

In this chapter a detailed evaluation of a particular designed and applied intervention was presented. The level of detail in the evaluation was necessary to get from 'what happened exactly during the intervention' to 'what are the effects on the participants' thinking, actions, and interactions in their normal working environment.' In the first section the overall effects were evaluated. It was found that, as an effect of the intervention, broadening and enriching in the normal working environment indeed occurred. This finding is important as it indicates that the 3-step CTA approach is a feasible approach to improve the quality of innovation processes, and with that -at least partly- deal with the Collingridge dilemma through constructive intervention.

In the second section the relative effects of the workshop permutations were evaluated. A pre-developed evaluation scheme (Table 6.2) was used to guide this assessment. In three phases the following question was answered: can differences in productivity between the workshop permutations be attributed to differences in interaction processes? It was found that scenario presentation is more likely to trigger contestation and that a mixed actor composition is more likely to result in more efficient discussions. A combination of an insider workshop with scenario presentation thus gives the highest chance on a less productive workshop. When organising workshops that strive for broadening and enriching, mixed workshops with issue selection (No. 4) are considered the preferred choice.

The third section provided further observations that are additional to the evaluation. The first observation noted a striking difference in the enthusiasm among the participants that was initiated by the intervention and the actual effects that turn up in terms of initialised action. It was found that this initial enthusiasm is indeed moderated by the intramural effect, but furthermore, that action can be postponed until the right circumstances present themselves. Further, a limited effect on initialised action can be understood, because conceptual knowledge use is likely the prominent type of knowledge utilization. Secondly, as a result of the intervention positions of other actors and/or their own position can become clearer to participants. This implies that participants gained insights into how they relate to other actors. Such insights can affect how actors think, act, and interact at the work floor. Third, it was observed that participants, throughout the course of the intervention, expressed that each of the different steps in the 3-step CTA approach were valuable to them.

In this chapter the *evaluation scheme* that was developed in Section 3.5 was used. What are the experiences with this evaluation scheme? In line of this question there are two issues to reflect upon. As a first issue, in assessing broadening and enriching, the six effect indicators to some extent overlap with each other. For example, enhancing knowledge was assessed in Section 6.1 by asking participants whether they wanted to adapt their socio-technical scenario as a result of the workshop. Participants added new items to their scenario that were picked up during the workshop. Such changes also indicate a factual kind of learning, which indicates that enhancing knowledge can be seen as part of learning effects. Further, learning effects can be deeper as well, which could be indicated as participants changed their attitude towards future collaborations. This kind of learning does not just consist of a new thing that is picked up during the workshop, but actually involves considerations on how to organise work. Another overlap in the effect indicators can be seen between changing attitudes and opinions, and reflection. For attitudes and opinions to change, participants have to rethink aspects of their work. In other words, participants have to reflect.

This overlap in the two sets of effect indicators can be confusing: both for the evaluator as well as for the reader of this thesis. For future evaluating activities of constructive intervention, it would therefore be helpful to develop a set of more distinctive effect indicators.

Another issue relates to the evaluation of relevant effects and considers the analysis of positioning in part two of the first phase. Is analysing positioning a valuable approach to study interaction processes? The answer is both Yes and No. Yes, because it forces the evaluator to go through the transcripts line by line, which supports a detailed analysis of the workshop transcripts. Furthermore, as was demonstrated in Section 6.2.1, it enables to find patterns in interaction processes that were left unobserved by observing workshop dynamics (first part of the first phase).

The answer is also No, because the four types of positioning (DSP, FSP, DOP, and FOP; see Figure 3.9) that are used to annotate the transcripts are not distinctive enough. What is meant by this is that the evaluator often wants to use more types of positioning for the annotations, because different positioning statements have to be annotated with the same type. Using more distinctive types of positioning statements would not be difficult to do; Harré and Van Langenhove (1999) offer more types that can be used. However, more experimentation with this type of positioning analysis is needed before the real value of this aspect of the evaluation approach can be determined.

In *applying the intervention* and using the 3-step CTA approach there are further issues to reflect upon. The first issue has to do with the distinction between insiders and outsiders. Insiders and outsiders play different roles in innovation processes (enacting versus selecting) and have different ways to assess emerging technologies (in short: insiders work towards the realisation of technology options and are committed to its success, while for outsiders the technology options are just one of many from which they can select the most suitable). Is this distinction really this black and white? Yes and No. The answer is Yes, because on both sides of the spectrum the distinction is clear and valuable when organising an intervention. Scientists and businesses try to translate technology options into successful innovations, while, for example, a general practitioner or a health care insurer will have a critical selective role. In applying interventions the organiser can therefore simply invite people on the basis of their affiliation in putting together certain actor compositions.

The answer is also No, because the distinction is not always clear. For instance, insiders can become outsiders (and vice versa). When a venture capitalist decides to invest in a start-up its focus shifts from selecting among companies to invest in (outsider) to try and make the start-up, and the commercialised technology option, a success (insider). In addition, in group discussions an insider can fulfil the role of an outsider when he proposes to know how the outsider will react. This was observed in the workshops when participants talked about applications for patients. Given that patients were not present, participants put themselves forward as knowing what the patient would and would not want. Something similar happens when applications for consumers were discussed. Consumers were not present at the workshops, but in a way everybody is a potential consumer. Therefore, when consumer applications were discussed insiders easily become outsiders.

Another issue deals with the heterogeneity of actor compositions. In inviting heterogeneous group of actors to partake in workshops there is a constraint on how far the organiser can go. The reason for this is that there exists a tension between group size and heterogeneity on one side and enabling a constructive multilogue on the other. For larger groups, simply due to the size of the group, it is more difficult to facilitate and secure a constructive discussion. For heterogeneous groups the difference in background of the participants can become too large and diverse as well. In one of the follow-up interviews a participant that did not directly originate from the medical or the technology field experienced this tension. This person indicated that he found the workshop useful. It was however difficult for this person to get involved in the discussion, because the topics were too distinct from his daily pursuits. Participants can experience something similar when the topic of the project is taken too broad. If the topic gets broader, the number of participants experiencing difficulties in contributing to the discussion will likely increase. This consideration was one of the reasons to limit the field of application to medical applications of Lab-on-a-chip technology.

Furthermore, when the heterogeneity of the actors increases and the group size is limited, the organiser ends up with a group of participants where only one or two representatives of every actor are present. This makes applying the intervention vulnerable. When, for instance, only a few participants send their excuses for the meeting certain actors are not represented anymore. Consequently, when certain actors are not present this alters the interaction processes during (and thus the effects of) the workshop. The mixed workshops were vulnerable in this sense (see Figure 3.7), although the effect just described was minimal, because 90% of the invited people attended the workshop. Furthermore, although one can never exclude it, in small scale meetings the representative participant for a certain actor becomes almost an individual (or a few people). Individual standpoints therefore become more prominent in relation to a more shared representation of that actor.

A last issue concerns the timing of interventions. During field interviews with scientists, the interviewees mentioned that scientists working on Lab-on-a-chip technology were actively looking for opportunities to bridge the gap between science and industry. The reason was that these scientists thought it was about time for Lab-on-a-chip technology to become integrated in applications that are part of common practices such as health care. These scientists sensed it was time for the technology to show its real value in products that are actually used. This observation points to a 'sense of urgency' (De Bruin *et al.*, 1998; see Section 2.5) that was already present in the field when the intervention just started in the summer of 2005. The advantage of such a 'sense of urgency' makes a part of the participants directly committed, because the intervention responds directly to their needs. When there is a 'sense of urgency' present in the field, this will likely increase the potential effect of any intervention.

Notes

1 Of course the facilitator asks permission to tape the session at the beginning of the workshop.

2 This further implies that the facilitator of the workshops should not steer the discussions too much, because this would influence the interaction processes. Instead, the facilitator focuses on keeping the discussion, and with that the interaction processes, going.

3 Other possibilities for forced other positioning will be discussed later.

4 This example of contestation was also observed in the first part of this section.

5 Contestation shows part of the dynamics that is present in the wider world, which are now discussed in a closed-of setting. In this example from Workshop No.1, one side of the argument was that complex technology would bring a revolution to health care practices, while the other side argued that there was no need for such technology driven solutions and that with present day technology it was already possible to do what was proposed with the complex technological solution.

6 There can be differences in the representation of participants. They can for example make statements on personal account or represent a particular actor (e.g. health care insurers). At least, in the invitation for the intervention the participants were invited as a representative of a certain actor.

7 In these kinds of reactions it can also be seen that actors already take into account different actors.

8 That the participants indeed talk freer during the workshops can be seen in the following example form the mixed workshops. Scientists claim in mixed workshops that technologically everything is possible in a few years. Back in the lab they probably would have problems with such statements or have to nuance it much more.

9 For example, an effect measure such as changing attitudes and opinions received a much higher value (on average 75%). When participants now take into account more actors and more aspects in their work (which was data attributed to changed attitudes and opinions), this refers to an increase in conceptual understanding that considering more aspects and actors improves the decisions and actions taken at the work floor.

10 More recently, close contacts were formed between a health care insurer, the research group of Prof. Albert van den Berg, and a start-up company at the University of Twente. This result was not presented in the main text, because the shaping of this bond was not completely free of later actions from my side, and is therefore not a direct result of the intervention. The result that can be attributed to the workshops is that actors became more aware of each other, which made the connections easier later on.

11 The reference of this article is Van Merkerk and Van den Berg (2006).

7 Conclusions and discussion

The prime interest of this thesis is to improve the shaping of emerging technologies (such as nanotechnology) by society in the early stage of technological developments. This interest is reflected in two research topics; 1) understanding the dynamics of emerging technologies, and 2) constructive intervention in emerging technologies. There are ongoing technological developments and innovation processes, which implies that the two research topics have to take into account the fluidity and open-endedness of emerging technologies on the one hand, and the complexity of innovation processes on the other. Furthermore, emerging technologies and society are interrelated in a complex manner, while the potential societal and economic benefits of emerging technologies can be significant. These issues provide opportunities and inspiration for the analyst, and stimulate questions to be asked in terms of understanding the dynamics and how to help deal better with emerging technologies in society.

The first two sections of this chapter will present and discuss conclusions for both research topics separately. To support the investigations in emerging technological fields, two mapping tools and an interview instrument were developed in Chapter 4. The development and testing of these tools was part of the research with the goal to enrich the toolkit for the constructivist and CTA analyst. The usefulness and limitations of the tools were discussed in Section 5.5. The third section will address whether there is a synergy between the insights gained in the two research topics. The fourth and last section will offer broader considerations. Attention is devoted to reflection on CTA of emerging technologies, the Collingridge dilemma, and conclusions will be drawn regarding innovation policies.

7.1 The first research topic: understanding the dynamics of emerging technologies

To recapitulate, the early phases of technology development show a great deal of fluidity and open ends. Furthermore, emerging technologies have complex dynamics. Actors, visions, and artefacts all influence each other. Different bodies of literature deal with the early phases of technology development. These studies indicate, for example, the importance of expectation dynamics in emerging technologies (Brown *et al.*, 2005) and the importance of understanding processes of stabilisation (Callon, 1995). The same studies indicate that there is still room for an improved theoretical understanding of emerging technologies and for methods to analyse emerging technological fields. These challenges are taken up in the first research topic and are reflected in the main research question (RQ 1): *How to understand the dynamics of emerging technologies?*

This research question can be answered from different perspectives. From a constructivist point of view (see Section 2.1), the dynamics of emerging technologies should be understood mainly in terms of the behaviour of actors that mutually interact, and interact with technology.

This thesis also addresses the question how technology options are successfully exploited commercially and can benefit society through innovation. Three elements of the dynamics of emerging technologies were identified as focal points, namely 1) how over time early entrenchment sets in, 2) how actors relate to each other and how this influences interactions, and 3) how interaction between actors is organised. A theoretical concept has been linked to each of these elements, emerging irreversibilities, positioning, and spaces respectively. These concepts, however, are not clear cut or fully developed. Hence there is a dual interest in the first research topic: to study elements of the dynamics of emerging technologies and to contribute to the conceptualisation of these elements. The following sections (7.1.1 - 7.1.3) provide conclusions and discussion based on the research into these elements separately.

7.1.1 Dynamics: early entrenchment

Already in the early stages of technological development does entrenchment set in. To obtain an understanding of early entrenchment, Section 2.3 presented the concept of emerging irreversibilities. This interest is also reflected in research question 1.1: *How can early entrenchment be understood by studying emerging irreversibilities?*

To recapitulate from Chapter 2, emerging irreversibilities denote a decrease of fluidity and openness, and in doing so enable and constrain the future activities of actors. Such a decrease can be seen as an ordering or pattern of how actors interact, arrange themselves in networks, search for solutions, take decisions, and in the institutions they create. Patterns can also be found in the organisation of financial support, expectations and visions that become shared among various actors, and solutions to certain problems that become the standard. Emerging irreversibilities can result in a certain degree of black boxing. Given that certain decisions, interaction, or solutions become standard, there is no longer a need for explanation or justification.

With these insights into emerging irreversibilities, Section 5.2 investigated and discussed two cases of possible emerging irreversibilities in the emerging Lab-on-a-chip field. The case of polymer chips indicated that the existence of polymers as an alternative material to make fluidic chips certainly influences the decisions of -at least some- actors in the field of Lab-on-a-chip technology. A pattern was found in the build-up and use of polymers for a particular purpose, namely biologists experimenting with living cells. In the case of synthetic chemists and microreactors, microreactors are now seen as part of the emerging Lab-on-a-chip field. This indicates a bond between what was previously two separate technological fields. The formation of this bond is influential in the interactions between actors of the two fields.

Trialling the strength of the influential patterns that were found in the cases could provide insights into the aspect of irreversibility. For example, are certain solutions being black-boxed by actors? In the case of polymers there exist scientists that experiment with living biological samples and do not use polymers. In the case of synthetic chemists and microreactors, negative research results or disappointing commercial activities can decrease the strength of the bond. In both cases there was no hard evidence to prove irreversibility in the field of Lab-on-a-chip technology. What could be demonstrated, however, is that there are particular influential patterns which, if they are continued to be reinforced, are likely to become irreversible. Even in the present state these influential patterns cannot easily be reversed as previous actions, interactions, and decisions have been taken that have built up resistance to change. On the basis of these findings, it can be concluded that the patterns found in the two cases indicate that early entrenchment has set in; however, this is not (yet) fully irreversible.

In other words, despite the commercial interest and activity, and the more than 15 years of technological development in the field of Lab-on-a-chip technology, many directions are still feasible. A few directions are indeed carefully being taken, but -figuratively speaking- firmly paved roads cannot be observed as yet. A similar picture could be distilled from the historical narrative of the field of Lab-on-a-chip technology (Section 5.1). It was found that the number of entities (e.g., actors, artefacts, visions, and expectations) that have built up the technological field are still growing and that no shake-out has occurred. The complexity of the field still increases, while no indications were seen of technological options that had been discarded. In other technological fields with similar characteristics, such as mainly scientific, limited commercialisation, and growing industrial interest, it is likely that the same dynamics can be found. In other words, the interests of actors are expressed in expectations and tentative agendas, although high uncertainties about outcomes (innovations), yields, and the strategies to take, also make actors wary of investing heavily before a few technology options have proven the feasibility of commercialisation. In this way the open-ended and fluidic situation can easily be maintained, as was found to be the case for the field of Lab-on-a-chip technology.

Methodologically, the investigation of the cases was supported by a tool that was developed in Chapter 4, namely the three-level framework. By working with three-level frameworks, it is emphasised that technological developments take place at different interrelated levels. With the help of three-level frameworks, a further interesting dynamic was found; actors at different levels become influenced over time. This suggests that the strength of (possible) emerging irreversibilities depends on the extent of the influence on different (types of) actors and on different levels. In the polymer case, while polymers were initially used in laboratory experiments, later companies started to produce fluidic chips from polymers as well. Also, in a 'white paper' produced by a consultancy company (Yole Développement, 2003), Lab-on-a-chip companies were arranged by the material they used for their chips: "Regarding the processed material, it is mainly Si/glass and polymer which are equally used." (page 4) In the case of synthetic chemists and microreactors, the influence also spreads from individual research groups making microreactors with Lab-on-a-chip technology to the scientific community, businesses, and industry (see Figure 5.2). This increasing influence of potential emerging irreversibilities can be visualised with a three-level framework, although the processes and mechanisms behind multi-level interactions cannot be identified in this way.

In addition, the case of polymer indicates that biologists often choose polymer when experimenting with living biological samples. When such a choice is made repeatedly in the same way it can become black-boxed. These dynamics suggest that the strength of (possible) emerging irreversibilities depends on the period and the persistence of the patterns to stay influential. Thus, reinforcement of a particular search heuristic makes the emerging irreversibility last. Due to these reinforcements the emerging irreversibility becomes stronger. Furthermore, the focus was on what contributes to the strength of emerging irreversibilities and paid less attention to the possibility to measure such strengths. In general, the strength of emerging irreversibilities will only surface when actors try to go against it. Such action by definition requires a certain amount of effort proportional to the strength of the emerging irreversibilities. This was recognised in Section 5.2, but the available data was not sufficient to study emerging irreversibilities from this angle.

Early entrenchment stresses the phenomenon that some technological options become more probable while others loose attention and interest. The same phenomenon has been studied in path dependency literature (see Section 2.3.1). The concept of emerging irreversibilities has the potential to contribute to this existing literature by providing insights into the processes that facilitate path emergence (Van Merkerk and Robinson, 2006). It is difficult to relate individual emerging irreversibilities to the more general phenomenon of path creation (Garud and Karnøe, 2001). Arguably, as emerging irreversibilities provide some direction in the actions and interactions of actors, more and stronger emerging irreversibilities contribute to path creation. Also, the intertwining of emerging irreversibilities will contribute to the creation of socio-technical paths. However, the results and conclusions in this section do not provide many points of departure to contribute to the further understanding of path emergence. What can be contributed are the insights in the strength of emerging irreversibilities and the three-level framework (with its limitations) to study emerging irreversibilities.

Summing up, by studying cases of (possible) emerging irreversibilities, the analyst looks for patterns that influence actors. Examples are patterns in the way actors interact or solve certain problems. In the cases of polymer and microreactors, such patterns were found and early entrenchment was demonstrated. If biologists continue to use polymers for experimenting with living biological samples, the choice for polymers can become black-boxed, and this would make it irreversible. When the two fields of (traditional) microreactors and Lab-on-a-chip technology continue to meet and work together, the physical combination between analysis and synthesis on chips can become inseparable.

7.1.2 Dynamics: relations between actors

How actors relate to each other affects how they interact and is therefore an important element in our understanding of the dynamics of emerging technologies. When making positioning statements, actors take into account how they relate to other actors and the role that others expect them to fulfil. Actors are not at liberty to assume the role they want, but depend on their positioning by others. To address this, the following research question was put forward in Section 2.6: *How can relations between actors be understood by studying envisioned future positions?* Section 5.3 concentrated on a systematic analysis of how different actors envisage the roles of other actors in the light of a particular vision in the field of Lab-on-a-chip technology: Point-of-care testing.

By the research presented in Section 5.3 it was found that the relations between actors are often undetermined and appear as one-way, rather than mutual. Illustrative is that although health care insurers can have an important role in health care innovations, this was hardly recognised by other actors in relation with Point-of-care testing. Furthermore, while the two main application areas (first and second line care) are generally recognised, the role of health care professionals is interpreted differently by the various actors. The result is a very open situation in which many relations still must and can be formed and (re-)shaped. It can therefore be concluded that one of the reasons for the field of Lab-on-a-chip technology in particular and emerging technologies in general to be fluidic and open-ended, is that relations between actors are undetermined. This conclusion resonates with earlier findings reported in literature. Callon (1995), for example, notes that in the early stages disagreement is likely among the actors and techniques that make up the socio-technical network. He calls such a situation 'divergent'. The results presented here -to some extent- add to these types of analysis by indicating that an element of disagreement has to be sought in the relations between actors, which in emerging technologies are more likely to be tentative and one-way, rather than mutual and stable.

These findings form the basis of a more general observation, i.e. while a vision might be clear and generally recognised by some actors in emerging technologies; it is certainly not self-evident how the vision is interpreted by different actors. Actors hold different ideas about which technology options will become innovations, and which positions and roles different actors should have and fulfil over time in shaping the innovation processes. This research is related to studies of expectation dynamics, which stresses the importance of studying expectations and how expectations play a role in present day technology developments (Van Lente, 1993; Brown *et al.*, 2005). The research in this thesis contributes to these studies by explicitly addressing roles and positions as they appear in expectations and visions.

There is one remark that must be made about the generalisability of these results. With the method that was used in studying prospective positioning, only those roles that are related to a particular topic (in this case: Point-of-care testing) are taken into account. The results are therefore not fully representative for the whole field of Lab-on-a-chip technology. However, studying other topics in the field of Lab-on-a-chip technology or in other emerging technological fields will likely find similar results. The abundance of one-way instead of mutual articulation of roles is seen as a typical characteristic of emerging technological fields.

To conclude, expressions of envisioned roles can be used to indicate how actors relate to each other. It was found that relations are often tentative, one-way, and undetermined. Due to the open-endedness of the situation, the course of Point-of-care developments and the implementation thereof by using Lab-on-a-chip technology is unpredictable and malleable.

7.1.3 Dynamics: organised interaction

The concept of space was introduced in Chapter 2 in order to study how interactions are and become organised in emerging technological fields. This interest is also reflected in research question 1.3: *How can organised interaction be understood by studying spaces?* Spaces allow actors to assemble for negotiation, deliberation, and aggregation. New spaces can emerge (seemingly) spontaneously or can be actively created. In emerging technologies, actors are confronted with the lack of appropriate structures for organised interaction. While (old) structures do exist, they can be insufficient as new actor arrangements are needed to explore different technology options. Hence the use and creation of new spaces are of special interest in studying the dynamics of emerging technologies. These effects of organised interactions can take on different forms and shapes, for example, network building, learning about each others interests and developments, or exploration into novel research topics.

In Section 5.4 two spaces (one created and one emerging) were investigated with a simple analysis scheme that was developed in Section 3.3.3. One of the items addressed was the effect of the space on the actors involved. The case of the '1st Lab-in-a-Cell workshop' indicated that after the temporary space had been closed, the interactions between the workshop participants had changed. A few of the participants started to collaborate more intensively. In a space that exists for a longer period of time, as is the case in Lab-on-a-chip technology, interactions also change. New configurations of actors that work together emerged and stabilised. These findings indicate that new spaces have the potential to bind actors for shorter or longer periods. Furthermore, as spaces can (re-)shape interactions, in addition to entities such as actors, artefacts, and visions, spaces influence the dynamics of emerging technologies.

The concept of spaces was operationalised in a simple manner. This operationalisation should be seen as a first attempt. The concept of spaces allows the analyst to study the occasion and possibilities for (new) actor arrangements to occur. Furthermore, once opened up spaces obtain certain characteristics. The cases in Section 5.4 indicated that with a short-list of characteristics (involved actors, infrastructure, boundary, and temporality) a basic understanding of spaces can be obtained. However, with the limited number of characteristics used in the elaborated cases in Section 5.4, not all effects could be accounted for.

To conclude, by studying spaces, organised interaction can be understood as being determined by the characteristics of spaces. Especially for emerging technologies, new spaces provide occasion and possibilities for new interactions to become organised, which is often necessary as old structures are not always sufficient and adequate. Finally, given that actors can become bound in and through spaces, this binding can have shorter or longer term effects on the dynamics of emerging technologies.

7.2 The second research topic: intervening in emerging technologies

New science and technology confronts societies with (potential) societal and economic benefits (innovation), but also raises questions of how to maximise social benefits and to minimise unwanted impacts. Historical cases such as the GMO impasse indicate that the evolution of emerging technologies does not always go smoothly and without controversy.

While in the early stages opportunities to develop and apply new science and technology seem limitless, no one knows which technology options will eventually become successful. At later stages the outcomes can be better estimated, but changes are difficult to make due to earlier decisions and investments. Collingridge's (1980) solution to (t)his dilemma is to keep technological developments flexible in order to make changes possible when technology options turn out to be less fruitful or even harmful. This thesis puts forward the stimulation of broadening and enriching by means of constructive intervention as an alternative route. The advantage of such an approach is that at an early stage more directed influence can be exercised at innovation processes in order to improve the quality thereof and increase the societal embedment of technology options. This approach is reflected in the main research question (RQ 2); h*ow to design constructive intervention in order to improve the quality of innovation processes in emerging technologies?* The 'loci of alignment' variant of CTA was chosen as a basic approach for its focus on early-stage broadening of design and development of technologies, the recognition of a broad range of actors, and the emphasis on feedback in ongoing technological developments.

In developing the research design for the second research topic the focus was on supporting actors in emerging technologies by providing a platform where actors can broaden their perspectives on and enrich their insights into the dynamics of innovation processes. Will broadening and enriching does indeed influence thinking, actions, and interactions in the normal working environment? This emphasis on broadening and enriching was highlighted in research question 2.1; *how to develop, apply, and evaluate a CTA approach for emerging technologies* *that is productive in terms of broadening and enriching?* The 3-step CTA approach was developed in Section 3.4, which is applicable into emerging technologies and stimulates broadening and enriching. Also, to be able to learn lessons on how to design constructive intervention in emerging technologies, the design of the CTA approach was permutated. To reflect this interest in design the following research question was formulated; *what permutations in constructive intervention are insightful for CTA method development and what is the relation between these permutations and the productivity?*

In evaluating the intervention using the 3-step CTA approach, the first question was whether an overall effect in terms of broadening and enriching occurred at all. Second, differences in the overall effect that are visible in the different workshop designs were evaluated.

7.2.1 Intervention: overall effects of constructive intervention

When in Chapter 3 choices were made in the design of the intervention, it was argued that for broadening and enriching to occur, the interactions also needed to be broad. Broad in terms of actors participating in the intervention as well as in terms of the topics addressed during the intervention. The topics addressed during the intervention touched upon technological, economic, political, and socio-cultural aspects. Each participant had to formulate an individual socio-technical scenario to take the first steps in broadening and enriching. Because expectations and visions are important for the dynamics of emerging technologies (Van Lente, 1993; Brown *et al.*, 2005) and scenario development stimulates structured thinking about the future, formulating socio-technical scenarios is a good way to proceed. The expectations, visions, and expertise of participants can be captured into individual socio-technical scenarios. This can help the participants to develop and/or become more aware of their own visions and expectations and develop them further. The workshops gave the participants the opportunity to compare their scenarios with those of other participants. The data to evaluate the overall effect consisted of follow-up interviews with the fifty participants.

These follow-up interviews indicated that for 85% of the participants the workshops resulted in adjustments of their scenarios and 75% of the participants indicated that they now take into account more actors and more aspects in their work. Based upon these and other results it was found that, as an effect of the intervention, broadening and enriching occurred for all four workshops in the normal working environment (Section 6.1). This means that actors that participated in the intervention broadened their perspectives and enriched their understanding of the dynamics of innovation processes already at an early stage. This finding indicates that the approach taken in this thesis to improve the quality of innovation processes by way of constructive intervention is feasible. Given that broadening and enriching is achieved at an early stage, it -to some extent- supports actors to deal with the Collingridge dilemma. Actors are now able to base their actions and interactions on their new insights as well. Evidence that participants now actually do this was limited. More prominent in the data from the follow-up interviews was that most participants express intentions such as to incorporate new insights from the intervention in how they approach collaboration. In order to have a further influence on innovation processes, the actors have to change their actions and interactions. To this end changes are also often required in the organisation.

These findings indicate that in CTA activities, enriching is important to strive for as well, because when actors improve their insights in the dynamics of innovation processes, they can make more well-considered decisions. This point is specifically mentioned here given that to date CTA literature has almost exclusively focused on broadening; however, broadening and enriching are two distinct effects. However, with the effect indicators that were used, it was difficult to assess the two effects separately in the evaluation. A combination of these six effect indicators was used as a proxy to determine whether broadening and enriching changed the thinking, acting, and interacting of actors in the normal working environment. This proxy allowed for the testing of the feasibility of the 3-step CTA approach. Nonetheless, some effect indicators overlap, which can be confusing; both for the evaluator as well as for the reader of this thesis.

To set up an approach that strives for broadening and enriching, the combination of socio-technical scenarios and multilogue workshops turned out to be promising. In evaluating interventions, the reflection provided in Section 6.3.1 is relevant. In that section it was argued that a conceptual use of knowledge is likely to be more frequent and more important compared with the instrumental use of knowledge. The instrumental use of knowledge, for instance in new actions and interactions, can be postponed by actors until the right circumstances come along. Also, it often takes time for participants to incorporate new insights into their work (Smits, 1994). It is useful to assess the effects at different times, for example, immediately after the workshops, after 2-3 months, and after 6-12 months. Furthermore, due to the intramural effect, the constraints during normal working hours will filter out the initial enthusiasm directly after the intervention. Two months after the intervention the participants could be interviewed to see what happened as a result of the intervention in terms of different thinking, acting, and interacting in their everyday activities.

7.2.2 Intervention: relative effects between different workshop designs

Given that scenarios were used to prepare the participants for the group meetings they could be used as explicit input in the workshops (step 3 of the approach) or to prepare issue selection. The other permutation was a highly heterogeneous workshop versus a narrow actor composition. The actor composition in the insider workshop consists of enactors (mainly scientists and businesses) and the mixed workshops incorporates a much broader set of actors (from scientists to end-users).

Based on differences in *interaction processes* observed during the workshops it can be concluded that scenario presentation is more likely to trigger contestation than issue selection. When contestation leads to a locked-in discussion the productivity (broadening and enriching) is influenced negatively. When compared to an actor composition consisting of insiders, a mixed actor composition is more likely to result in efficient discussions. In mixed workshops, the participants can directly address a wider variety of actors and more aspects are brought in. This improves the flow of the discussions and stimulates the debate. In terms of *productivity* (broadening and enriching), a higher effect was observed for the mixed workshops. More generally it can be argued that, a greater diversity in the actor composition encourages participants to broaden and enrich. Furthermore, when comparing both insider workshops, a lower productivity was observed for the scenario workshop.

These results are based on four cases. The generalisability of these findings is therefore limited. In Section 6.2.3 the relative differences were attributed to interaction processes that are a direct result of the workshop design. For example, scenario presentation (workshop design) was found to increase the chance of long-lasting contestation to occur, which in turn decreases the efficiency of the discussion. This then provides the participants with more opportunities to broaden and enrich, which is reflected in the effect indicators. Such attribution stories link workshop design with the eventual effects of the intervention. The attribution stories therefore make the following conclusion plausible: a workshop with scenario presentation and an actor composition consisting of insiders (No. 1) is the least productive workshop constellation. Or, when organising workshops that strive after broadening and enriching, a mixed workshop with issue selection (No. 4) has to be the preferred choice.

To conclude, when applying constructive intervention that uses the 3-step CTA approach for emerging technologies the results indicate that broadening and enriching can be reached in the normal working environment of participants. This is seen as an improvement in the quality of innovation processes in the field of Lab-on-a-chip technology. It also increases an actor's ability to deal with the Collingridge dilemma. Arguably, the approach can be improved upon. A few suggestions for improvement will be discussed in Section 7.3.2.

7.3 Synergy between investigation and intervention

Up to now, in this chapter the two research topics, 'understanding of' and 'intervening in', have been discussed separately. However, there are clear links between these research topics. Insights gained in studying one research topic can also be relevant to the other. The two sections below will address the potential synergy in these links.

7.3.1 The intervention as a temporary created space

The intervention that was designed in Section 3.4 (or the workshops more in particular) can be seen as a temporary created space. The aim of this space is to stimulate broadening and enriching through constructive intervention in order to improve the quality of innovation processes. The effects (or productivity) of the space are defined in terms of broadening and enriching (see Section 2.5). The workshop design determines the characteristics of the space. In this way, the workshop permutations actually created four different spaces that, as was found in Section 6.2, lead to differences in the overall effect. It was concluded in Section 7.1 that spaces can also affect interactions outside the space (e.g., intensified collaboration in the case of the '1st Lab-in-a-cell workshop'). The scheme to study spaces will now be used to reflect on the intervention under scrutiny in this thesis.

The *occasion* of the intervention is that new science and technology raise societal questions of how to deal with advances and potential outcomes. If no action is undertaken to address these questions, the eventual societal embedment is not always satisfactory; not satisfactory from the societal as well as the economic point of view. By designing constructive intervention, an attempt is made to contribute to the societal embedment of new science and technology. In its turn, the TA NanoNed programme created the opportunity to organise the specific intervention for the field of Lab-on-a-chip technology in the Netherlands.

The scheme to study spaces emphasises four *characteristics* that can be recognised for each space: involved actors, boundary, infrastructure, and temporality. The following characteristics can be recognised for the 3-step CTA approach (see Section 3.4 for details).

- The workshops were permutated by *involving* different *actor* compositions. This permutation of actor composition therefore defines two different spaces, namely spaces with insiders and spaces with a mixed actor composition comprising insiders and outsiders.
- The workshops were *bound* to a specific location at Utrecht University. Also, the number of actors that could participate in a workshop was limited to fourteen.
- The workshop *infrastructure* was supported by pre-formulated socio-technical scenarios that were drawn up by the participants beforehand. How the scenarios are used as input was permutated (scenario presentation and issue selection), which also led to two different spaces. Also, as the emphasis in the workshops is on broadening the actors' perspectives and enriching their insights into the dynamics of innovation processes, during the workshops ample time is reserved to exchange views and discuss opinions. Furthermore, a Group Decision Support System (GDSS) is used to support the workshops.
- Regarding *temporality*, the workshops were held for a limited amount of time: one afternoon. This places significant time constraints on the design of the space, but also has advantages because more people are willing to spend time at a workshop that only takes up a single afternoon than one taking much longer.

Given these characteristics, the question is how they affect the *effects* of the space. Differences in effect between the four spaces could be expected as the workshop permutations imply different characteristics. In Section 7.2, for instance, it was concluded that while all four workshops lead to broadening and enriching in the participants' normal working environment, the mixed workshop with issue selection (No. 4) is the most likely one to result in an effective workshop. Figure 7.1 summarises the aspects of the workshops in the lights of the concept of spaces.

Does this description of the intervention using the concept of spaces provide new insights? Interesting here is that the effects on the participants are still present after the space has been closed and the intervention ended. This is an effect similar to the one observed in the case of the '1st Lab-in-a-Cell Workshop' (see Section 5.4.2). With regard to the '1st Lab-in-a-Cell Workshop', the participants gained insight into what to expect from one another and some of them started to collaborate more intensively. In the intervention with the 3-step CTA approach, the participants broadened their perspective and enriched their insights into the dynamics of innovation processes. These effects can be further interpreted into what Garud and Ahlstrom (1997) call 'bridging events'. Bridging events are occasions when insiders and outsiders can probe each others' realities. Spaces -so to speak- create opportunities for such bridging events to occur,

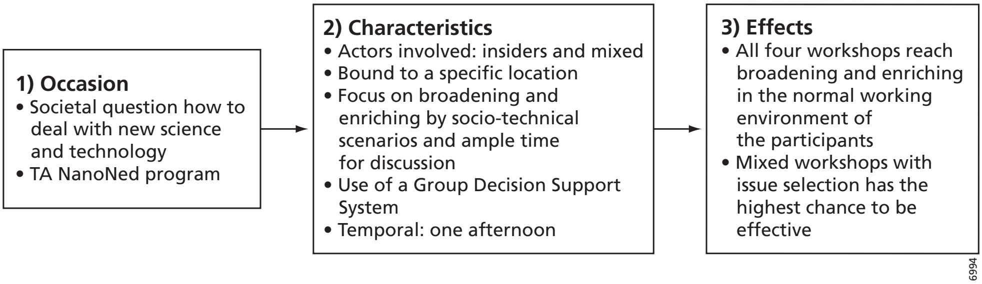

Figure 7.1 Visualisation of the temporary created space: multilogue workshops

and subsequently might contribute to further and lasting effects. This study of space, thus, will help to design 'bridging events'.

Temporary spaces such as workshops create opportunities for different actors to interact. The infrastructure of the space mediates these interactions. In the workshops individual sociotechnical scenarios were used and ample time was reserved for discussion, which is assumed to facilitate broad interaction that stimulates broadening and enriching. The eventual effects (presented in Section 6.1) suggest that on the basis of these broad interactions participants can, for instance, indeed change their attitudes and opinions. Section 6.3.2 further indicated that participants can also change their opinion about the roles of other actors. Outside the space, such changed opinions last and can affect the thinking, acting, and interacting of participants for a shorter or longer period of time.

7.3.2 Studies of emerging technologies can support the design and application of interventions

By using the results from dedicated studies in the design of interventions, the research topics 'understanding' and 'intervening' are linked more closely. Whether and how the different analysis presented in Chapter 5 can be useful and supportive in designing and applying interventions is discussed below.

As a first option, case studies that provide insights into the emerging irreversibilities (Section 5.2) can be used as direct input for workshops. There are many options available for how this can be done. One option is explored by another researcher in the TA NanoNed programme, Douglas Robinson. At his workshops, road maps and scenarios (as constructed by the CTA analyst) are presented and discussed with a group of insiders (Robinson and Propp, 2006). Early entrenchment, and the effects thereof, can be explicitly discussed. Another option is to discuss the effects of (possible) emerging irreversibilities and how they affect actors operating in the emerging technological field. The latter can be particularly helpful in enriching insights into innovation processes since the effect of emerging irreversibilities on the developments and actors are explicitly discussed.

Another possibility to support constructive intervention is to use insights into how different actors relate to each other. Section 5.3 indicated that such insights can be gained by studying patterns of prospective positioning. One way to use such insights in interventions is to have the participants explicitly discuss the convergence/divergence and match/mismatch about the envisioned future positions, which are analysed by the CTA analyst beforehand. Clarifying the positions of various actors by means of discussion is likely to be productive for the participants as it will inform them about the relationships between the actors and about what actors expect of one another. Depending on the goal of the intervention such an intervention design is feasible for mixed and insider actor compositions. This indeed is a potential improvement of the issue selection workshops, where disagreement in issues from the scenarios was put central rather than the envisioned future positions.

Yet another possibility for designing workshops builds on the argument that spaces are created by actors in the emerging technologies and sometimes also by third parties (Section 2.3). More detailed research on the effects of new spaces created by actors in emerging technologies can lead to insights into how to improve interventions organised by third parties. More generally, when there is more understanding about spaces, the concept can also be used to recognise the need for space, rather than use it descriptively. In this way, CTA practitioners can focus more on promoting and recognising opportunities for 'productive space(s)'. Rip and Joly (2004) refer to this as the normative use of spaces.

To summarise, there is synergy between the two research topics, which means that investigations can be used to improve interventions. Suggestions were made as to how the design and application of interventions can be supported.

7.4 To conclude: the role of CTA and emerging technologies

When a new technology emerges questions will be raised about the new potentials, about the directions of the development, and about possibilities for intervention. Another question is to what extent can the developments be steered or are they more or less autonomous. This thesis studied the dynamics of Lab-on-a-chip technology and the ability to steer its developments. Questions were asked about to what extent has entrenchment set in and about the relations between the different actors. How can decisions in innovation processes be made in a more socially robust manner? Much has already been said about these and related questions, but what do the findings teach us about the ability to steer and control technological developments?

Science and technology, Innovation, and Collingridge

In studies of *technology dynamics*, the aspect of determinism (technological as well as social) is seen as an extreme view and is questioned (Smith and Marx, 1994). Occasionally it may seem that new science and technology finds its way into society, making it appear that the developments are indeed autonomous. In this study it was found that, Lab-on-a-chip technology will have some impact, but it was also found that it is certainly not the case that Lab-on-a-chip technology will automatically have the full impact as is envisioned by actors. Even the areas in which products will or can enter the market have not yet crystallised. In the research into the dynamics of the field of Lab-on-a-chip technology it was observed that the present situation is still open. This means that many directions are still feasible.

In discussions about the *ability to control and steer* technological developments, the Collingridge dilemma seems to accept the autonomous character of technological developments, at least in the early phases. The underlying assumption of this dilemma is that in the early stages of technological development, although steering is easy, the directions in which to steer cannot be determined. However, this thesis has demonstrated that small changes can indeed be made in how actors think, act, and interact by specifically designed interventions. Consequently, through the actors, a certain ability to control and steer in more socially robust directions can be embedded in technological developments and innovation processes already in an early stage. Actors can be given support in making more well-considered, balances, and socially robust decisions.

Having said that, the question can still be raised to what *extent* constructive intervention that uses the 3-step CTA approach is capable of circumventing the Collingridge dilemma. Of course one should be realistic and not expect miracles. The intrinsic characteristics of emerging technologies will always complicate the aspects of steering and control. This implies that 'full control' of the directions in which emerging technologies develop cannot be achieved. This thesis has, however, demonstrated that there is certainly no reason to capitulate for the Collingridge dilemma and simply wait for the outcomes before any action can be taken. It was found here that actors indeed can be supported in broadening and enriching in the normal working environment (Section 7.2). This support helps actors to better play their part in ongoing innovation processes, also in the emerging, highly uncertain, stages of technological development and to increase the embedment of new science and technology in society.

On the other hand, some modesty is appropriate as the intervention described in this thesis did not show major changes in how actors operate in innovation processes. One of the reasons for this limited effect is that the intervention was of a small scale. For the participants involved in the intervention, the time spent was about one day in total. Another reason is that effects are not always visible at the time the evaluation is performed, for instance because action is postponed until better circumstances arise. Bhola (2000) argues that more interactions are often needed, learning has to be digested, and/or situations have to change before new actions can be taken. As a last reason, the degree to which actors take these kinds of activities seriously and are willing to draw the consequences of new insights to make changes at the work floor (Smits, 1994) influences the effects.

The above leads to the broader question how CTA has to be embedded in innovation processes, innovation systems, and innovation policies in order to increase its effectiveness and positive impact on technology developments and innovation processes. In the following, three important aspects of this question will be discussed. Firstly, it is argued that CTA should be organised as a process. Secondly, the institutionalisation of CTA in innovation process, innovation systems, and innovation policies is discussed. Thirdly, the role of various actors in facilitating and executing CTA and the implementation of the results of CTA activities will be discussed.

CTA as a learning process

The duration of the intervention described in this thesis was relatively short, especially in comparison with the time frame of ongoing technological development and innovation processes. CTA practitioners have commented on this issue as well. When looking back at the intentions of CTA, Schot (2001:40) states: "*[…] in CTA, technology is assessed […] throughout the entire process of design and redesign […]*". This quote says that CTA is intended to be a longer term process that links up with innovation processes from start to finish. Others also address this issue by stating that TA (i.e. not just CTA) should be seen more as a process closely linked and tuned to decision-making processes and not so much as a project producing a product as an incidental input in these decision-making processes (Smits and Leyten, 1991; Smits, 1994; Van Eijndhoven, 1997).

Not only that CTA should be organised as a process, also the kind of process is relevant. From the viewpoint of companies, Deuten *et al.* (1997) emphasise that increasing societal embedment is a continuous learning process. This point can be taken up for CTA by indicating that the kind of process that CTA should be is a learning process. Deuten *et al.* add that societal actors should be given a constructive role, which assumes that these actors should not be involved too late, when contributions to the product creation process cannot be made anymore. Furthermore, CTA can only be effective when actors are willing to take up CTA and its results. Actors may not want to or need to, because CTA interferes with how things are done now (in the organisation and between actors), which makes actors not always receptive to activities that interfere with their 'normal' pursuits.

Organising CTA as a process assumes that a series of activities can improve on -so-called- single-shot approaches such as the 3-step CTA approach. The timing of such a series of activities can best be left to the participants themselves who decide in dialogue with the CTA analyst on the planning of workshops and other possibly relevant activities. In this way, the process itself becomes a point for discussion, a possibility which is also discussed by Reuzel *et al.* (2006) in their work on interactive evaluation and by De Bruijn *et al.* (1998) in their work on process management.

TA activities such as the intervention described in this thesis contribute to the formulation of visions, the broadening and enriching of decision-making, and to the strengthening and/or elucidating of relations between actors at an early stage. All of this is important for the broader ambition of managing technology in society towards more socially embedded technology (Rip *et al.*, 1995). The extent to which such effects indeed have an impact depends -at least- on the following three issues. It first depends on whether actors perceive the contributions of CTA activities (vision development, support of decision-making, and relation building) as important in early-stage developments. Secondly, the question is whether actors are willing to reconsider their management processes and innovation processes and incorporate CTA activities. Thirdly, the question is important whether actors take the results from CTA activities seriously and take the consequences of the insights of CTA activities influences the impact.

Regarding the first two issues, the following can be said about the receptiveness of actors in the intervention presented in this thesis. Chapter 6 noted that (for the field of Lab-on-a-chip in particular) 90% of the participants attended the workshops and afterwards 98% of the participants showed interest in -in some form- follow-up activities. These numbers stress that the Lab-on-a-chip field was receptive towards the CTA activities described in this thesis. There might even be a need for more constructive intervention in the field of Lab-on-a-chip technology. According to De Bruijn *et al.* (1998) there has to be a 'sense of urgency' in the form of a problem that demands a solution. In addition to De Bruijn *et al.* (1998), the problem does not have to be the same for every actor. For example, technology developers of Lab-on-a-chip technology can have a problem with the delay in the forthcoming of commercialisation, while end-users can have a problem as they struggle to make health care practices more efficient. For both actors, deliberation about (new) technology options can be both fruitful and productive. On the third issue, when actors are willing to take the consequences of the insights of CTA activities, this sometimes implies that the involved organisations have to adapt (Smits, 1994), although some organisations will be better equipped to adapt than others.

The emphasis on CTA as a learning process does not imply that the 3-step CTA approach is always more suitable than other CTA-inspired approaches. Other approaches are often complementary and it is helpful to learn from each others' activities. After all, the interests and goals are similar: improving 'managing technology in society'. Interactive TA, Real-Time TA, and the ILA approach were discussed in Section 2.4. Each of these approaches emphasise a different aspect in the relevant activities. When consensus is sought in the intervention, Interactive TA (Grin *et al.*, 1997) provides feasible approaches. Real-Time TA (Guston and Sarewitz, 2002) is more focused on supporting the natural science and engineering research to become more reflexive about the embedment of social values in research-based innovations. Real-Time TA is therefore more directed towards the science system rather than the broad set of actors addressed in this thesis. The ILA approach (Broerse and Bunders, 2000) provides particular approaches to support users. Therefore, when an intervention is specifically directed towards scientists and engineers or users, Real-Time TA and the ILA approach can provide methods and tools. Hence, depending on the specific context in which the CTA activities are organised, bits and pieces of different approaches can be combined to create the right approach for the right circumstances. Given the overlap between the different forms of TA and CTA, the remainder of this section will discuss TA in the broader sense, indicated by (C)TA.

Roles in institutionalising (C)TA

How should (C)TA as a learning process be institutionalised, and who has to do what to facilitate, organise, and implement these processes? Who is responsible for the societal embedment of new science and technology? In a democratic system, the party most likely to be held responsible for the societal embedment of new science and technology are the bodies that represent society, parliament and government. (C)TA activities partially put this responsibility into the hands of the actors that are involved in and benefit from the new advances. This creates a tension between democracy and (C)TA. Instead of delegated responsibility in democracy as we know it, it is probably more appropriate to speak of shared responsibilities. Research institutes, businesses, end-users, governmental agencies, and financial institutions together share the responsibility for securing an appropriate level of societal embedment of the emerging technology they are involved with. Managing technology in society indeed is a joint task, rather than a governmental undertaking. In this joint task, the various individual private and public parties still have their own responsibility. (C)TA activities can be of help to (re-)shape the individual and shared responsibilities.

For governments, there are at least three roles to fulfil with respect to new and emerging science and technology. These roles are derived from the different types of responsibility of governments. Firstly, governments are responsible for a well-functioning innovation system in which the various actors can play their part (Smits and Weijers, 1990). For emerging technologies this implies that the government should also provide the right conditions in which actors can work on the articulation of visions and build up relations and networks. Innovation policies can therefore include (C)TA in supporting these activities and embed (C)TA activities in innovation systems (Freeman and Soete, 1997). In addition, when innovation policies link up better with the needs of actors, it is more likely that the actors will use the insights gained though (C)TA activities. Secondly, various governmental departments are responsible for domains such as health care, safety, and environment. Policies are created that should serve society in the best way possible. (C)TA activities can be organised and can play a supportive role in formulating these policies, including innovation policy. Thirdly, governments are responsible for achieving a democratic balance of interests and power. Here, (C)TA can be used as an instrument to create spaces that give a say to those actors that tend to be excluded and have no voice. There, (C)TA and democratic ideals coincide.

That governments take up these tasks can be seen, for instance in the establishment of TA bodies. The Rathenau institute, the Dutch national TA body, has a mandate from the government to conduct (C)TA activities. In this way, the government facilitates vision forming and debate about the social embedment of new science and technology, but also delegates a part of its task to an outside institution. Furthermore, these activities are rather small scale, often concentrate on ELSA activities, and are no integral aspect of innovation policies and innovation systems.

The Bsik (formerly ICES/KIS) stimulation programme in the Netherlands provides an example of governmental attention to support and reinforce the Dutch innovation system. The goal of this stimulation programme is to support the interfaces and interactions between knowledge production, and public and private users of this knowledge. This goal is taken up by funding consortia that not only produce new and relevant knowledge, but also by connecting the 'supply side' of knowledge creation to the 'demand side'. The Bsik programme in this respect refers to "consortia that have a private-public character and are capable of combining knowledge, expertise, and innovative capacity."[1] (C)TA can contribute to this mission to support these consortia in creating interfaces between various actors. How this can take shape can be illustrated by the NanoNed consortium (financed through the Bsik stimulation programme), which includes (C)TA activities in its programme. The (C)TA activities presented in this thesis are carried out within the framework of the TA programme in NanoNed. Government funding is used to work on advances in science and technology, and some 1% of the budget is devoted to improve its societal embedment. When NanoNed ends however, the continuation of the (C)TA activities is at risk, while Bsik intends to have a structural and more permanent strengthening effect on the Dutch innovation system.

Regarding the future in terms of the institutionalisation of (C)TA, if (C)TA could be adopted as a 'normal element' of innovation policy and systems, other parties that were previously not involved could also start to contribute to this process. For instance, consultancy firms could step in and play a facilitating role. This would require some modifications, because the time spent by the (C)TA analyst in this thesis to carry out and evaluate the intervention was substantially more than the time a consultant could spend. This study was set up as an experiment in an academic setting, with different workshops to draw methodological conclusions and make intensive evaluations by analysing workshop transcripts. Consequently, the academic character made the intervention time consuming. The time required can be reduced significantly if the lessons learned from the academic work are translated into -what could be referred to as- standard (C)TA packages. In this way, consultancy firms could start to organise (C)TA activities, for example by using the 3-step CTA approach with workshop No. 4 (mixed workshops with issue selection).

To summarise, the government, in its role as 'guardian' of the innovation system, can strengthen innovation processes by facilitating (C)TA activities. In its role as the problem-owner for domains such as health care, safety, and environment, the various governmental agencies can make use of (C)TA activities and incorporate the results in policy-making. The same also applies with regard to various other private and public organisations. In the Bsik funded NanoNed programme, (C)TA contributes to facilitate the interface between knowledge production and use. Overall, there is room for improvement in the embedding of (C)TA in ongoing technological developments and innovation processes.

To conclude, if (C)TA is adopted as an integral part of innovation processes, innovation policies, and innovation systems at an early stage, a variety of relevant actors would become involved (or at least consulted) in decision-making about societal and economically successful directions of emerging technologies at an early stage. This will enhance the capability of various involved parties to improve the societal embedment of technology options at an early stage. So this is what can be added to the Collingridge dilemma: the dilemma does not disappear, but the capabilities of various actors to handle it productively are enhanced.

Notes

1 Translated from: http://www.senternovem.nl/bsik (last visited: September 1, 2007).

References

Abernathy, W.J. and K.B. Clark. (1985). "Innovation: mapping the winds of creative destruction." Research Policy. 14:3-22.

ARDA (2004). "A quantum information science and technology roadmap." April 2. Version 2. Found at: http://qist.lanl.gov/pdfs/qc_roadmap.pdf (Last visited: 3rd August 2007).

Arendt, H. (1958). "The human condition." Chicago, University of Chicago Press.

Arthur, W.B. (1989). "Competing technologies, increasing returns, and lock-in by historical events." The Economic Journal, 99:116-131.

Austin, R. (2003). "The art of sucking spaghetti." Nature Materials. 2:567-568.

Barker, J., N. Schulte Noordholt and A. Rip. (2001). "The societal construction of technology in Indonesia." Enschede. University of Twente. Final Report to the Royal Netherlands Academy of Sciences.

Bayer, T., J. Jenck and M. Matlosz. (2005). "IMPULSE- a new approach to design." Chemical Engineering Technology. 28(4):431-438.

Becker H. and C. Gärtner. (2000). "Polymer microfabrication methods for microfluidic analytical applications." Electrophoresis. 21:12-26.

Bhola, H.S. (2000). "A discourse on impact evaluation." Evaluation. 5(2):161-178.

Bijker, W. E. (2001). "Social construction of technology." In Smelser, N.J. and P.B. Baltes (ed.). International Encyclopedia of the Social and Behavioral Sciences. Oxfort, Amsterdam, Elsevier Science Ltd. 15522-15527.

Bijker, W.E. (1995). "Democratisering van de technologische cultuur." Inaugural speech. University of Maastricht.

Bijker, W.E., T.P. Hughes and T.J. Pinch. (ed.). (1987). "The social construction of technological systems. New directions in the sociology and history of technology." Cambridge, The MIT Press.

Boon, W.P.C., E.H.M. Moors, S. Kuhlmann and R.E.H.M. Smits. (forthcoming 2007). "Demand articulation in intermediary organisations: The case of orphan drugs in the Netherlands." Technological Forecasting and Social Change. Accepted proof.

Boon, W. and R.O. van Merkerk. (forthcoming 2008). "Prospective Positioning of Industrial Players: the case of theranostics." Technology Analysis and Strategic Management. 20(6).

Borgatti, S.P. (2002). NetDraw. Graph Visualisation Software. Natick. Analytic Technologies.

Broerse, J.E.W. and J.F.G. Bunders. (2000). "Requirements for biotechnology development: The necessity of an interactive and participatory innovation process." International Journal of Biotechnology. 2(4):275-296.

Brown, N., C. Douglas, L. Eriksson, E. Rodrigues, S. Yearley and A. Webster. (2003). "Researching expectations in medicine, technology and science: theory and method." Positioning paper for the York Workshop of the 'Expectations Network'. 23 June.

Callon, M. (1991). "Techno-economic networks and irreversibility." In Law, J. (ed.). A sociology of monsters: Essays on power, technology and domination. London, Routledge.

Callon, M. (1995). "Technological conception and adoption network: Lesson for the CTA practitioner." In Rip, A., T.J. Misa and J. Schot. Managing technology in society. London, Pinter. 307-330.

Callon, M., P. Laredo, V. Rabeharisoa, T. Gonard and T. Leray. (1992). "The management and evaluation of technological programs and the dynamics of techno economic networks: The case of the AFME." Research Policy. 21:215-236.

Campbell, L.C., M.J. Wilkinson, A. Manz, P. Camilleri and C.J. Humphreys. (2004). "Electrophoretic manipulation of single DNA molecules in nanofabricated capillaries." Lab on a Chip. 4:225-229.

Caplan, N. (1979). "The two-communities theory and knowledge utilization." American Behavioral Scientist. 22(3):459-470.

Checkland, P. and J. Scholes. (1999). "Soft Systems Methodology in Action." Chichester, John Wiley & Sons.

Clausen, C. and C. Koch. (2002). "Spaces and occasions in the social shaping of information technologies: the transformation of IT systems for manufacturing in a Danish context." In: Sørensen, K.H. and R. Williams. (ed.). Shaping technology, guiding policy: concepts, spaces, and tools. Cheltenham, Edward Elgar Publishing Ltd. 223-248.

Collingridge, D. (1980). "The social control of technology." London, Pinter.

Collins, S., E.D. Green, A.E. Guttmacher and M.S. Guyer. (2003). "A vision for the future of genomics research." Nature. 422:835-847.

Cruz-Castro, L. and Sanz-Menéndez, L., 2005, Politics and institutions; European parliamentary technology assessment. Technological Forecasting and Social Change, Vol. 72, pp. 429-448.

Dale, A. and D. Loveridge. (1996). "Technology assessment – where is it going?" International. Journal of Technology Management. Special Issue on Technology Assessment. 11(5/6):715-723.

David, P.A. (1985). "Clio and the economics of QUERTY." Economic history. 75: 332-337.

De Bruijn, T.A., E.F. ten Heuvelhof and R.J. in't Veld. (1998). "Procesmanagement: over procesontwerp en besluitvorming." [Process management: about process design and decision making.] Schoonhoven, Academic Service.

De Jouvenel, H. (2000). "A brief methodological guide to scenario building." Technological Forecasting and Social Change. 65:37-48.

Decker, M. and M. Ladikas. (2004). "Bridges between science, society and policy." Berlin, Springer-Verlag.

Deuten, J., A. Rip and J. Jelsma. (1997). "Societal embedding and product creation management." Technology Analysis and Strategic Management. 9(2):131-148.

Dosi, G., C. Freeman, R. Nelson, G. Silverberg and L. Soete. (1988). "Technical Change and Economic Theory." London/New York, Pinter Publishers.

Ducrée, J. and R. Zengerle. (2004). "Flowmap – Microfluidics roadmap for the life sciences." Norderstedt, Books on Demand GmbH.

Duke, R.D. (1974). "Gaming: the future's language." New York, Halsted Press.

Dunn, W.N. (1980). "The two communities metaphor and models of knowledge use." Knowledge: creation, Diffusion, Utilization. 1(4):515-536.

Dürrenberger, G., H. Kastenholz and J. Behringer. (1996). "Integrated assessment focus groups: bridging the gap between science and policy?" Science and Public Policy. 26(5):341-349.

Effenhauser, C.S., G.J.M. Bruin, A. Paulus and M. Ehrat. (1997). "Integrated capillary electrophoresison flexible silicone microdevices: Analysis of DNA restriction fragments and detection of single DNA molecules on microchips." Analytical Chemistry. 69:3451-3457.

Ekström, B., G. Jacobsen, O. Öhman and H. Sjödin. (1990). International Patent: WO 91/16966.

Erickson, K.E. and P. Wilding. (1993). "Evaluation of a novel Point-of-care system, the i-STAT portable clinical analyser." Clinical Chemistry. 39(2):283-297.

ETC Group. (2003). "The big down." January Found at: http://www.etcgroup.org. (Last visited: 6th August 2007).

Freeman, C. and L. Soete. (1997). "The economics of industrial innovation." Cambridge, The MIT Press.

Garud, R. and Ahlstrom, D. (1997). "Technology assessment: a socio-cognitive perspective." Journal of Engineering and Technology Management. 14:25-48.

Garud, R. and P. Karnøe. (2001). "Path creation as a process of mindful deviation." In Garud, R. and P. Karnøe (ed.): Path Dependence and Creation. Mahwah, Lawrence Earlbaum Associates. 1-38.

Geels, F., en R. Kemp. (2000). "Transities vanuit sociotechnisch perspectief." [Transitions from an socio-technical perspective.] Report for the studiy 'Transities en Transitiemanagement' from ICIS and MERIT for VROM. Twente University, Enschede and MERIT, Maastricht.

Geels, F.W. (2002a). "Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study." Research Policy. 31:1257-1274.

Geels, F.W. (2002b). "Towards sociotechnical scenarios and reflexive anticipation: Using patterns and regularities in technology dynamics." In Sørensen, K.H. and R. Williams. (ed.). Shaping Technology, Guiding Policy: concepts, spaces and tools. Cheltenham, Edward Elgar Publishing. 359-385.

Geels, F.W. and J. Schot. (2007). "Typology of sociotechnical transition pathways." Research Policy. 36:399-417.

Genus, A. and A.-M. Coles. (2005). "On constructive technology assessment and limitations on public participation in technology assessment." Technology Analysis and Strategic Management. 17(4):433-443.

Geurts, J. (1993). "Omkijken naar de toekomst – Lange termijn verkenningen in beleidsexercities." [Looking back to the future – Long-term explorations in policy activities] Inaugural speech. University of Tilburg

Godin, B. (2006). "The linear model of innovation: the historical construction of an analytical framework." Science, Technology, and Human Values. 31(6):639-667.

Gow, G.A. (2003). "Canadian telecommunications policy and the national disaster mitigation strategy: observing wireless enhanced 9-1-1." Dissertation. Simon Fraser University.

Grin, J. and Grunwald, A. (2000). "Vision assessment: shaping technology in 21st century society; towards a repertoire for technology assessment." Berlin, Springer-Verlag.

Grin, J., H. van de Graaf and R. Hoppe. (1997) "Interactieve Technology Assessment. Een eerste gids voor wie het wagen wil." [Interactive Technology Assessment: A guide for people that want to try.] The Hague, Rathenau Institute.

Gustafsson, M., D. Hirschberg, C. Palmberg, H. Jörnvall and T. Bergman. (2004). "Integrated sample preparation and MALDI mass spectrometry on a microfluidic compact disk." Analytical Chemistry. 67:345-350.

Guston, D.H. and D. Sarewitz. (2002). "Real-time technology assessment." Technology in Society. 24:93-109.

Harré, R. and L. van Langenhove. (1999). "Positioning theory." Oxford, Blackwell Publishers.

Harrison, D. J., A. Manz, Z. Fan, H. Lüdi and M. Widmer. (1992). "Capillary electrophoresis and sample injection systems integrated on a planar glass chip." Analytical Chemistry. 64:1926-1932.

Harrison, D.J., K. Fluri, K. Seiler, Z. Fan, C.S. Effenhauser and A. Manz. (1993). "Micromachining a miniaturized capillary electrophoresis-based chemical analysis system on chip." Science. 261(5123):895-897.

Haswell, S.J. (1997). "Development and operating characteristics of micro flow injection analysis systems based on electroosmotic flow: a review." Analyst. 122:1R-10R.

Haswell, S.J. and V. Skelton. (2000). "Chemical and biochemical microreactors." Trends in analytical chemistry. 19(6):389-395.

Haswell, S.J., R.J. Middleton, B. O'Sullivan, V. Skelton, P. Watts and P. Styring. (2001). "The application of microreactors to synthetic chemistry." Chemical Communication. 5:391-398.

Heiskanen, E. (2005). "Taking the Golem – an experiment in participatory and constructive technology assessment." Science Studies. 18(1): 52-74.

Hollister, P., C.R. Vas and T. Harper. (2003). "NEMS." Cientifica. Technology White Papers No. 12. October.

Hong J.W. and S.R. Quake. (2003). "Integrated nanoliter systems." Nature Biotechnology, 21:1179-1183.

Hoogma, R., R. Kemp, J. Schot and B. Truffer. (2002). "Strategic Niche Management." In Hoogma, R., R. Kemp, J. Schot and B. Truffer. (ed.). Experimenting for sustainable transport. The approach of strategic niche management. Londen, EF&N Spon. 180-205.

Hooley, G.J. and J. Saunders. (1993). "Competitive positioning: the key to market strategy." London, Prentice Hall.

Hughes, T.P. (1986). "The seamless web: technology, science, etcetera, etcetera." Social Studies of Science. 16:281-92.

Jelsma, J. A. Rip and J.L. van Os. (1995). "Biotechnologie in bedrijf: een bijdrage van Constructief aan biotechnologisch innoveren." [Biotechnologie in companies: a contribution of Constructive Technology Assessment to biotechnological innovation.] The Hague, Rathenau Institute.

Jensen, K.F. (2001). "Microreaction engineering – is small better?" Chemical Engineering Science. 56:293-303.

Kalmholz, A.E. (2004). "Proliferation of microfluidics in literature and intellectual property." Lab on a Chip. 4:16N-20N.

Kan, C.-W., C.P. Fredlake, E.A.S. Doherty and A.E. Barron. (2004). "DNA sequencing and genotyping in miniaturized electrophoresis systems." Electrophoresis. 25:3564-3588.

Kenis, P.J., R.F. Ismagilov and G.M. Whitesides. (1999). "Microfabrication inside capillaries using multiphase laminar flow patterning." Science. 285:83-85.

Klank, H., J.P. Kutter and O. Geschke. (2002). "CO_2-laser micromachining and back-end processing for rapid production of PMMA-based microfluidic systems" Lab on a Chip. 2:242-246.

Latour, B. (1987). "Science in action: how to follow scientists and engineers through society." Cambridge, Harvard University Press.

Lee, J.N., C. Park and G. Whitesides. (2003). "Solvent compatibility of poly(dimethylsiloxane)-based microfluidic devices." Analytical Chemistry. 75(23):6544-6554.

Lefebvre, L.A. and E. Lefebvre. (1993). "Competitive positioning and innovative efforts in SMEs." Small Business Economics. 5:297-305.

Leonard-Barton, D. (1992). "Core capabilities and core rigidities: a paradox in managing new product development." Strategic Management Journal. 13:111-125.

Manz, A., N. Grabber and H.M. Widmer. (1990). "Miniaturized total chemical analysis systems: a novel concept for chemical sensing." Sensors and Actuators B1. 244-248

McDonald, J.C., D.C. Duffy, J.R. Anderson, D.T. Chiu, H. Wu, O.L.A. Schueller and G. Whitesides. (2000) "Fabrication of microfluidic systems in poly(dimethylsiloxane)." Electrophoresis. 21:27-50.

Nahuis, R. (2007). The Politics of Innovation in Public Transport. Dissertation. Utrecht University.

Nanomarkets. (2005). "The impact of nanotechnology in drug discovery: global developments, market analysis and future prospects." Market report.

Nature editorial. (2007). "Enough talk already." 448:1-2.

Negro, S. (2007). "Dynamics of technological innovation systems: the case of biomass energy." Dissertation. Utrecht University.

Nelson, R. R. and S. G. Winter. (1982). "An evolutionary theory of economic change." Cambridge, Belknap Press.

Norton, M., 1996, Parliamentary technology assessment in the UK. Int. J. Technology Management, Special Issue on Technology Assessment, Vol. 11, Nos. 5/6., pp. 581-588

Ornetzeder, M. and H. Rohracher. (2006). "Using Constructive Technology Assessment and lead user approaches in search for sustainable technology: theoretical considerations and practical implications." Paper presented at the SPRU 40th anniversary conference. September 11-13, Brighton.

Paegel, B.M., C.A. Emrich, G.J. Wedemayer, J.R. Scherer and R.A. Mathies. (2002). 'High throughput DNA sequencing with a microfabricated 96-lane capillary arra electrophoresis bioprocessor." Proceedings of the National Academy of Sciences of the United States of Amerika. 99(2):574-579.

Postma, T.J.B.M. and F. Liebl. (2005). "How to improve scenario analysis as a strategic management tool?" Technological Forecasting and Social Change. 72:161-173.

Price, C.P. and A. St John. (2006). "Point of care testing for managers and policymakers." Washington, AACC Press.

Price, C.P., A. St John and J.M. Hicks. (2004). “Point of care testing.” Washington, AACC Press. 2nd edition.

Raad voor de Volksgezondheid en Zorg. (2003). “Marktconcentraties in de ziekenhuiszorg.” Zoetermeer.

Raven, R.P.J.M. (2005). “Strategic Niche Management for biomass. A comparative study on the experimental introduction of bioenergy technologies in the Netherlands and Denmark.” Dissertation. Technical University of Eindhoven.

Reuzel, R., Grin, J. and Akkerman, T. (2006). “The role of the evaluator in an interactive evaluation of cochlear implantation: shaping power, trust, and deliberation.” International Journal of Forecasting and Innovation Policy. 3(1):76-94.

Rip, A. (2001). “Technology Assessment.” In Smelser, N.J. and P.B. Baltes (ed.): International Encyclopedia of the Social and Behavioral Sciences. Vol. 23. Oxford: Pergamon, Elsevier Science: 15512-15515.

Rip, A. (2007). “Die Verzahnung von technologischen und sozialen Determinismen und die Ambivalenzen von Handlungsträgerschaft im “Constructive Technology Assessment” [The entanglement of technological and social determinism, and ambivalencies of agency in Constructive Technology Assessment.] In Dolata, U. and R. Werle (ed.). Gesellschaft und die Macht der Technik. Frankfurt a.M, Campus.

Rip, A. and J. Schot. (2002). “Identifying loci for influencing the dynamics of technological development.” In Sørensen, K.H. and R. Williams (ed.). Shaping technology, guiding policy: concepts, spaces, and tools. Cheltenham, Edward Elgar Publishing Limited. 155-172.

Rip, A. and P.-B. Joly. (2004) “Multi-actor spaces and the governance of science and innovation in the ERA.” Workpackage 2. 3rd version.

Rip, A. and R. Kemp: (1998). “Technological change.” In Rayner, S. and E.L. Malone (ed.) Human choice and climate change. Columbus, Batelle Press. Volume 2. 327-399.

Rip, A., T.J. Misa and J. Schot. (ed.). (1995). “Managing technology in society. the approach of Constructive Technology Assessment.” London, Pinter Publishers.

RNCOS. (2006). “The World Nanotechnology Market (2006).” Executive summary.

Robinson, D.K.R. and T. Propp. (2006). “Multi-path roadmapping as a tool for reflexive alignment in emerging S&T.” Second International Seville Seminar on Future-Oriented Technology Analysis (FTA). 28th- 29th September.

Robinson, D.K.R., M. Ruivenkamp and A. Rip. (2007). “Tracking the evolution of new and emerging S&T via statement-linkages: Vision assessment in molecular machines.” Scientometrics. 70(3):831-858.

Roco, M.C. (1999). “Nanoparticles and nanotechnology research.” Journal of Nanoparticle Research. 1:1-6.

Roco, M.C. (2003). “Broader societal issues of nanotechnology.” Journal of Nanoparticle Research. 5:181-189.

Roelofsen, A., J.E.W. Broerse, Tj. de Cock Buning and J.F.G. Bunders. (2008) “Interactive vision assessment on ecological genomics: constructing the guiding visions of technology developers as a first step.” Technological Forecasting and Social Change. Accepted for publication.

Rohracher, H. (2001). “Managing the technological transition to sustainable construction of buildings: a socio-technical perspective.” Technology Analysis and Strategic Management. 13(1):137-150.

Roszek, B., W.H. de Jong and R.E. Geertsma. (2005). “Nanotechnology in medical applications: state-of-the-art in materials and devices.” RIVM report 265001001/2005

Růžička, J. (1983). “Flow injection analysis – From test tube to integrated microconduits.” Analytical Chemistry. 55(11):1040-1053.

Schot, J.W. (1992) “Constructive technology assessment and technology dynamics: the case of clean technologies” Science, Technology, and Human Values. 17(1):36-56.

Schot, J.W. (2001). “Towards new forms of participatory technology development.” Technology Analysis and Strategic Management. 13(1):39-52.

Schot, J.W. and A. Rip. (1997). "The past and future of Constructive Technology Assessment." Technological Forecasting and Social Change. 54:251-268.

Schumpeter, J.A. (1942). "The Process of Creative Destruction." London, Unwin University Books.

Schwartz, P. (1991). "The art of the long view; planning for the future in an uncertain world." New York, Doubleday.

Shifman, J. (2000). "Telling fish about water." Proceedings of Congress 2000 – Fundamental Problems of Natural Sciences and Engineering. St. Petersburg, Russia. 1(1): 396-400.

Smith, M.R. and L. Marx. (1994). "Does technology drive history? The dilemma of technological determinism." Cambridge, The MIT Press.

Smits R.E.H.M., A. Leyten and P. den Hertog. (1995). "Technology Assessment and technology policy in Europe: new concepts, new goals, new infrastructures." Policy Sciences. 28: 272-299.

Smits R.E.H.M. and Th. Weijers. (1990). "Technology Assessment: Watchdog or Integral Part of Technology Policy, state of the art of (European) TA and agenda for the 90's." TNO-STB. Apeldoorn.

Smits, R.E.H.M. (1994). "Elk land krijgt de technologie die het verdient, maar lang niet altijd die welke het nodig heeft." [Every country gets the technology it deserves, but by far not always the technology it needs.] Inaugural speech. Catholic University of Tilburg.

Smits, R.E.H.M. (2000). "Innovation in the university." Inaugural speech. Utrecht University.

Smits, R.E.H.M. and J. Leyten. (1991). "Technology Assessment: waakhond of speurhond?" [Technology Assessment: watchdog or tracker dog?] Dissertation. Vrije Universiteit van Amsterdam. Zeist, Kerckebosch.

Smits, R.E.H.M. and P. den Hertog. (2007). "Technology assessment and the management of technology in economy and society." International Journal of Foresight and Innovation Policy. 3(1):28-52.

Smits, R.E.H.M. (2002). Innovation studies in the 21st century. Questions from a user's perspective. Technological Forecasting and Social Change, Vol. 69, pp. 861-883

Smits, R.E.H.M., R.O. van Merkerk, D.H. Guston and D. Sarewitz. (forthcoming 2008). "Strategic Intelligence (1): The role of TA in systemic innovation policy" In Smits, R.E.H.M., P. Shapira and S. Kuhlman (ed.) Innovation Policy book.

Suurs, R.A.A., M.P. Hekkert. (2007). "Patterns of Cumulative Causation in the Formation of a Technological Innovation System: The case of Biofuels in the Netherlands." Paper presented at the DRUID Winter Conference. 27 January.

Terry, S.C., J. H. Jerman, J. B. Angell. (1979). "A gas chromatographic air analyzer fabricated on a silicon wafer." IEEE Trans. Electron indices. ED-26:1880-1886.

Thorsen, T., S.J. Maerkl and S.R. Quake. (2002). "Microfluidic large-scale integration." Science. 298:580-584.

Tűbke, A., K. Ducatel, J. Gavigan and P. Moncada-Paternò-Castello. (ed.). (2002). "Strategic Policy Intelligence: current trends, the state of play and perspectives." IPTS Technical Report Series. EUR 20137 EN. IPTS, Seville.

Tüdos, A.J., G.A.J. Besselink and R.B.M. Schasfoort. (2001). "Trends in miniaturized total analysis systems for PoC." Lab on a Chip. 1:83-95.

Tushman, M.L. and P. Anderson. (1986). "Technological discontinuities and organizational environments." Administrative Science Quarterly. 31(3):439-465.

Unruh, G.C. (2000). "Understanding carbon lock in." Energy Policy. 28:817-830.

Utterback, J.M. (1994). "Mastering the dynamics of innovation." Boston, Harvard Business School Press.

Van Boxsel, J. (1994). "Constructive Technology Assessment: a new approach for technology assessment developed in the Netherlands and its significance for technology policy." In Aichholzer, G. and G. Schienstock (ed.). Technology Policy: towards an integration of social and ecological concerns. Berlin/New York, Alter de Gruyter. 181-203.

Van de Ende, J., K. Mulder,M. Knot, E. Moors and P. Vergragt. (1998). Traditional and modern technology assessment: toward a toolkit, Technological Forecasting and Social Change. 58(1-2):5-22.

Van de Poel, I. (1998). "Changing technologies: a comparative study of eight processes of transformation of technological regimes." Dissertation. Twente University. Almelo, Twente University Press.

Van de Poel, I. (2000). "On the role of outsiders in technical development." Technology Analysis and Strategic Management. 12(3):383-397.

Van de Ven, A.H., D.E. Polley, R. Garud and S. Venkataraman. (1999). "The Innovation Journey." New York/Oxford, Oxford University Press.

Van den Belt, H. and A. Rip. (1987). "The Nelson-Winter-Dosi model and synthetic dye chemistry." In Bijker, W., T. Hughes and t. Pinch (ed.). The social construction of technological systems. New directions in the sociology and history of technology. Cambridge, The MIT Press.

Van der Heijden, K. (1996). "Scenarios: the art of strategic conversation." Chichester, John Wiley and Sons Ltd.

Van Eijndhoven, J.C.M. (1997). "Technology Assessment: product of process?" Technological Forecasting and Social Change. 54:269-286.

Van Est, Q.C. (1999). "Winds of change." Dissertation. University of Amsterdam.

Van Lente, H. (1993). "Promising technology: the dynamics of expectations in technological development." Dissertation. Twente University. Twente University Press.

Van Lente, H. (2000). "Forceful futures: from promise to requirement." In Brown, N., B. Rappert and A. Webster (ed.). Contested futures: a sociology of prospective techno-science. London, Ashgate Publishing Company. 43-64.

Van Lente, H. and A. Rip. (1998). "Expectations in technological developments: an example of prospective structures filled in by agency." In Disco, C. and B. van der Meulen. (ed.). Getting new technologies together. New York, Walter de Gruyter. Chapter 7. 203-229.

Van Lente, H., J. Willemse, C. Vorstman and J.F. Modder. (2003). "Scenario planning as policy instrument: four scenarios for biotechnology in Europe." Innovation: management, policy and practice. 5:4-14.

Van Merkerk, R.O. and A. van den Berg. (2006). "More than technology alone." Lab on a Chip. 6:838-839.

Van Merkerk, R.O. and D.K.R. Robinson. (2006). "Characterising the emergence of a technological field: expectations, agendas and networks in Lab-on-a-chip technologies." Technology Analysis and Strategic Management. 18(3/4):411-428.

Van Merkerk, R.O. and H. van Lente. (2005). "Tracing emerging irreversibilities in emerging technologies: the case of nanotubes." Technological Forecasting and Social Change. 72:1094-1111.

Van Merkerk, R.O. and H. van Lente. (forthcoming 2008). "Asymmetric positioning and emerging paths: the case of Point-of-are." Futures. Accepted for publication.

Van Merkerk, R.O. and R.E.H.M. Smits. (forthcoming 2008). "Tailoring CTA for emerging technologies." Technological Forecasting and Social Change. Accepted for publication.

Verpoorte, E. (2002). "Microfluidic chips for clinical and forensic analysis." Electrophoresis. 23:677-712.

Verpoorte, E., A. Manz, H. Lüdi, A.E. Bruno, F. Maystre, B. Krattiger, H.M. Widmer, B.H. van der Schoot and N.F. de Rooij. (1992). "A silicon flow cell for optical detection in miniaturized total chemical analysis systems." Sensors and Actuators B. 6:66-70.

Vig, N.J. and H. Paschen. (1999). "Parliaments and technology: the development of Technology Assessment in Europe." Albany, State University of New York Press.

Von Hippel, E. (1976). "The dominant role of the users in the scientific instrument innovation." Research Policy. 5:212-239.

Wack, P. (1985). "Scenarios: shooting the rapids." Harvard Business Review. 63(6):139-150.

Wang, J. (2000). "From DNA biosensors to gene chips." Nucleic Acids Research. 28(16):3011-3016.

Whitesides, G.M. (2006). "The origins and the future of microfluidics." Nature. 442:368-373.

Woolley, A.T. and R.A. Mathies. (1994). "Ultra-high-speed DNA fragment separations using microfabricated capillary array electrophoresis chips." Proceedings of the. National Academy of Sciences. USA. 91(24):11348-11352.

Yin, R.K. (1994). "Case study research: design and methods." Thousand Oaks, Sage Publications. 2nd edition.

Yole Développement. (2003). "Technologies and markets trends in biochips and microfluidic chips." Yole White Paper. February.

Yoshida, J.-I., A. Nahaki, T. Iwasaki and S. Suga. (2005). "Enhancement of chemical selectivity by microreactors." Chemical Engineering Technology. 28(3):259-266.

Appendix A Scenario changes as expressed in follow-up interviews

Workshop No. 1

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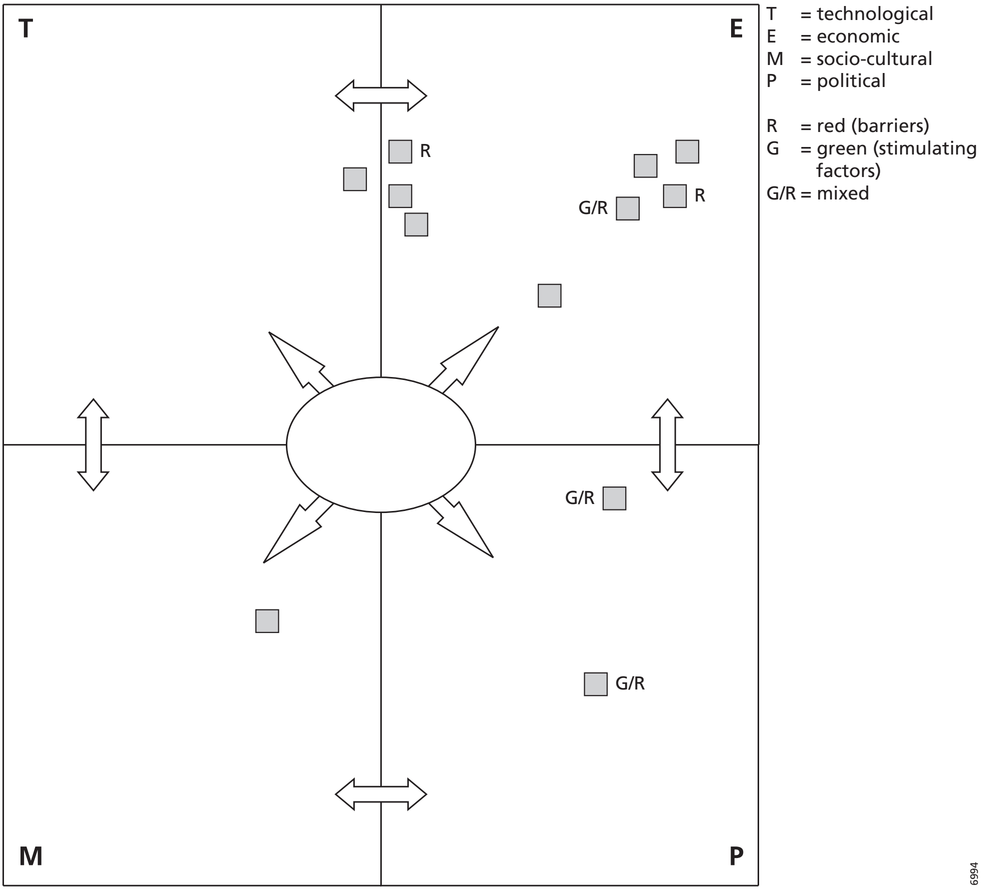


Figure A.1: Location of diverging issues from scenarios from workshop No. 1
Workshop No. 1 is an insider workshop with scenario presentation

Workshop No. 2

....

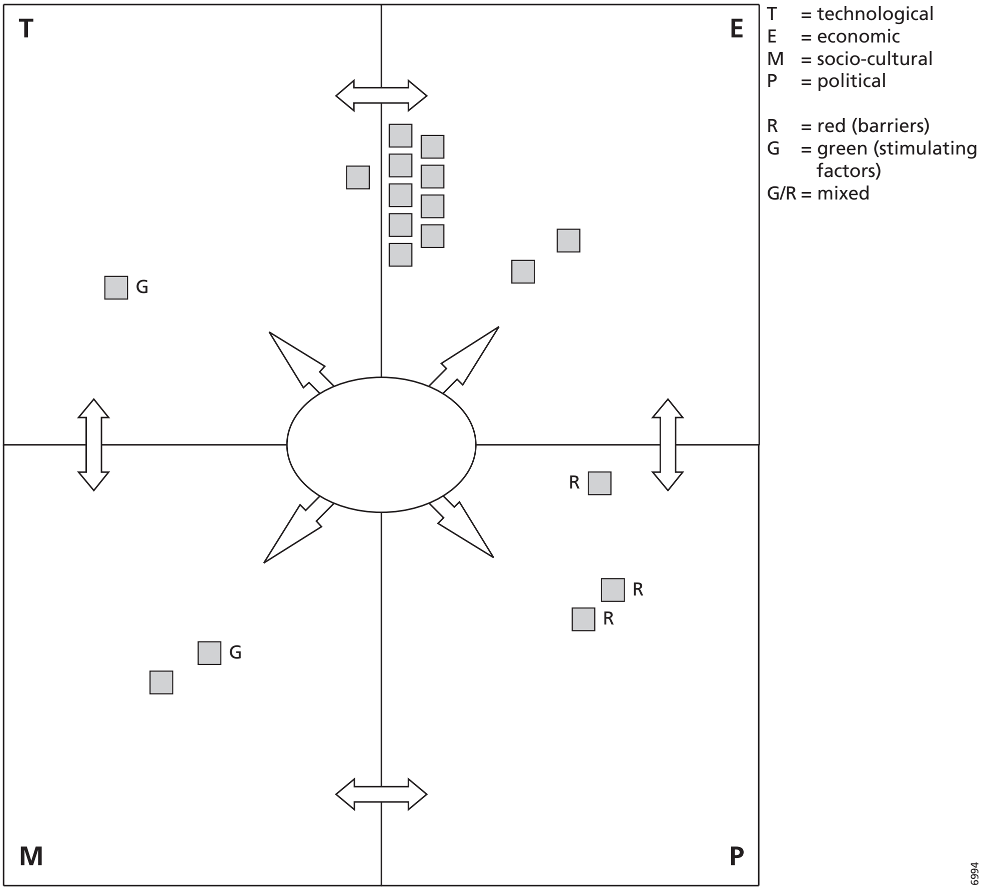
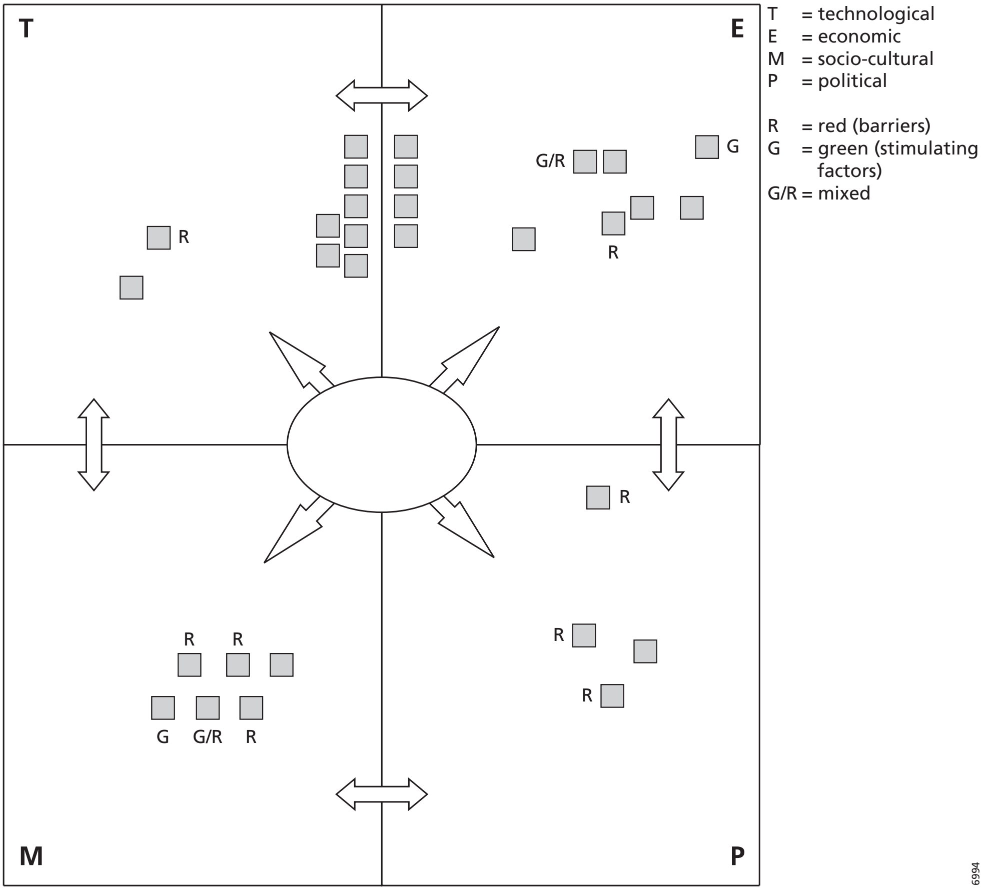


Figure A.2: Location of diverging issues from scenarios from workshop No. 2
Workshop No. 2 is a mixed workshop with scenario presentation

Workshop No. 3

……



T = technological
E = economic
M = socio-cultural
P = political

R = red (barriers)
G = green (stimulating factors)
G/R = mixed

Figure A.3: Location of diverging issues from scenarios from workshop No. 3
Workshop No. 3 is an insider workshop with issue selection

Workshop No. 4

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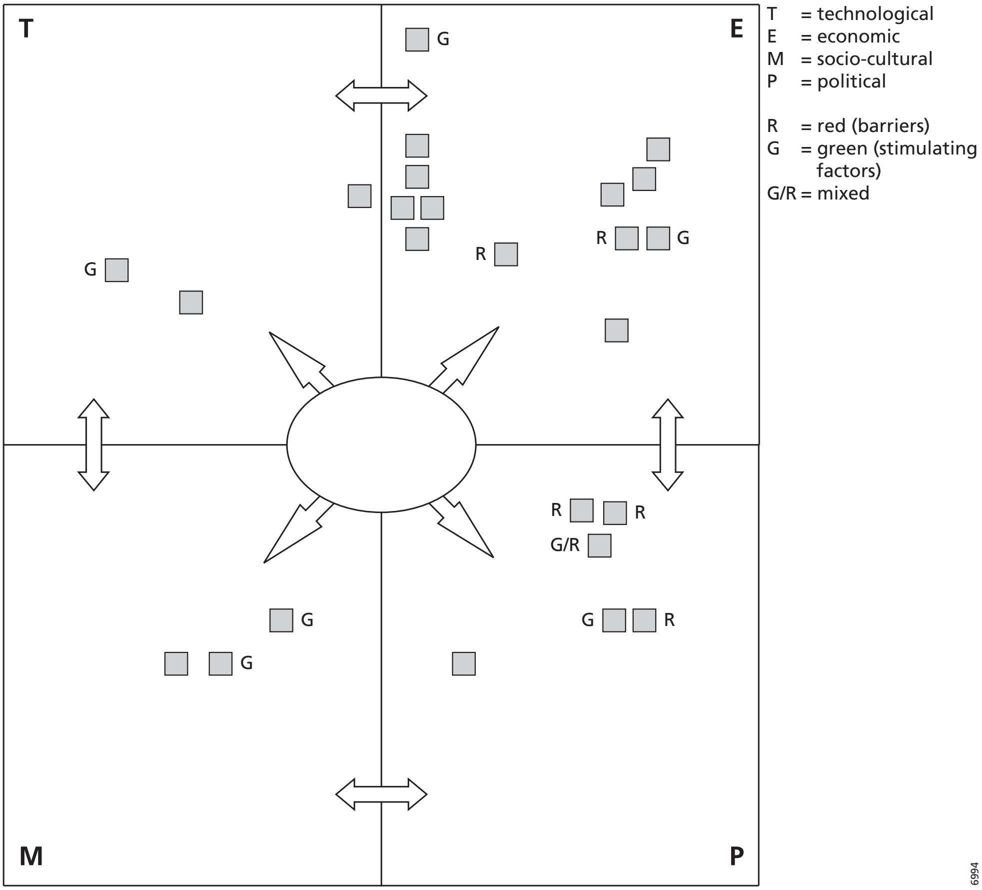

Figure A.4: Location of diverging issues from scenarios from workshop No. 4
Workshop No. 4 is a mixed workshop with issue selection

Summary

Intervening in emerging nanotechnologies

A CTA of Lab-on-a-chip technology

When a new technology emerges questions will be raised about the new potentials, about the directions of the development, and about possibilities for intervention. This thesis studies the dynamics of a particular technological field, Lab-on-a-chip technology, and the ability to steer its developments.

In general, there are many possible technology options for new science and technology that can benefit society, but not all are equally desirable or feasible. For instance, societal struggles around the introduction of nuclear energy and genetically modified organisms (GMOs) indicate that the embedment of new science and technology in society is not always flawless. In other words, the societal embedment of new science and technology is an important and timely issue. The prime interest of this thesis is to improve the shaping of emerging technologies in the early stage of technological developments and innovation processes. This interest is reflected in two research questions. *How to understand the dynamics of emerging technologies?* and *How to design constructive intervention in order to improve the quality of innovation processes in emerging technologies?*

Emerging technologies have characteristics that distinguish them from later-stage technologies. Emerging technologies show a great deal of fluidity and open ends. Actors are faced with a high level of uncertainty about the outcomes (innovations), yields, and strategies to be taken. In their actions and interactions, actors operating in emerging technological fields are mainly guided by expectations and visions.

One of the main assumptions of this research is that when interaction between different actors were to take place in a constructive and broader manner at an earlier stage of the development process of new science and technology, the eventual societal embedment can be increased. The idea is that when broader considerations can be taken into account and evaluated from a wider perspective at an early stage, this can alter the decisions taken in the development of new science and technology and during innovation processes. To facilitate such interaction between various actors in the early stages, an intervention is to be designed, applied, and evaluated. When designing an intervention a thorough insight is required into the dynamics at stake. A key perception regarding interventions in early-stage technologies is that the Collingridge dilemma makes it difficult to intervene constructively. This dilemma notes that in the early stages, opportunities to develop and apply new science and technology seem limitless, yet no one knows which technology options will eventually become successful. While the outcomes can be estimated at a later stage changes are difficult to make due to earlier decisions and investments. In this research it is explored whether constructive intervention focusing on stimulating broadening and enriching to improve the quality of innovation processes might be a feasible approach to circumvent the Collingridge dilemma. Such an intervention not only aims at improving the quality of innovation processes, but also offers opportunities to increase the societal embedment of new science and technology.

Chapter 2 provides theoretical building blocks and conceptualisation for understanding emerging technological fields and for designing and evaluating constructive interventions. Relevant theories from science and technology studies (STS) and innovation studies literature are discussed. In this chapter a theoretical framework is designed that stresses three particular elements of the dynamics of emerging technologies: 1) how over time early entrenchment sets in, 2) how actors relate to each other and how this influences interactions, and 3) how interaction between actors is organised. For each of these elements a concept is developed to provide theoretical support, namely emerging irreversibilities, positioning, and spaces.

For the first element; entrenchment is a result of ongoing interactions between actors and the decisions that are taken in relation to technological developments. As a result, certain patterns (e.g., collaborations or search heuristics) emerge that make some actions and interactions easier, and constrain others. These patterns are labelled as emerging irreversibilities. The extent to which these patterns are actually irreversible is the litmus test of how influential the pattern actually is. Emerging irreversibilities denote a first ordering and a decrease in fluidity of emerging technological fields.

The second element emphasises that interactions between actors make up a large part of the ongoing processes in and around technological developments. In understanding interactions it is important to know how actors relate to each other, and which roles and positions are emerging in the emerging technological field. Positions here are considered as accepted or established roles. This means that different actors see the same role for an actor. For emerging technologies it is argued that many positions still have to become established. In emerging technological fields, actors mainly act and interact upon expectations and visions. In expectations and visions, the future positions of actors are manifested through positioning. It therefore makes sense to study projected, or prospective, positions.

Thirdly, interactions between different actors often do not simply occur, they are organised. Organised interaction can take on many different forms and shapes. The concept of space is used to capture the different forms of organised interaction. Spaces allow a variety of actors to assemble for deliberation, negotiation, and aggregation. The effects of (new) spaces emphasise that organised interactions have an influence on the dynamics of emerging technological fields.

Chapter 2 then continues by introducing Technology Assessment (TA) as a form of Strategic Intelligence (SI). Strategic Intelligence is an umbrella term that covers approaches that support actors to play their role in innovation processes by providing them with tailor-made information. It is argued that the intervention developed in this thesis can best build upon a particular type of TA, namely the 'loci of alignment' variant of Constructive TA. Insights are provided into how constructive interventions in general can lead to broadening and enriching of thinking, actions, and interactions of actors in their normal working environment. A conceptual scheme is developed to relate constructive intervention to broadening and enriching as an overall effect. It is therefore argued that the productivity of the intervention can be operationalised in terms of broadening and enriching.

The same case is used throughout this thesis: Lab-on-a-chip technology. Lab-on-a-chip technology has its roots in microtechnology fabrication technologies, which enabled the fabrication of fluidic chips at the end of the 1980s. In a Lab-on-a-chip, fluids are guided through miniaturised channels. The design of the chip determines the chip's capabilities in terms of possible analysis. Nowadays, a few companies have Lab-on-a-chip based products on the market and several applications of the technology are in use. These applications are mainly used as research equipment, but there are also examples of applications used as bedside monitoring devices in hospitals. Lab-on-a-chip technology is an emerging technology.

The remainder of Chapter 3 provides the research design for both research topics. For the first research topic, it is first explained how a detailed historical narrative can be constructed for a particular emerging technological field. Subsequently, the focus turns to the three elements of the dynamics of emerging technologies. For each element an approach by which the element can be studied is both developed and explained.

For the research design of the second research topic, firstly, a 3-step CTA approach is designed that focuses on stimulating broadening and enriching by means of constructive intervention. This is taken up in the approach by facilitating broad interactions for various actors. Individual socio-technical scenarios are used to prepare the actors for multilogue workshops. During these workshops the scenarios come back and are now discussed by a group of participants. To be able to draw methodological lessons on 'how to design' constructive intervention in emerging technologies that is based on CTA methodology, two permutations are added to the intervention design: 1) in the way scenarios are used during the workshops (scenario presentation versus issue selection) and 2) in the actor composition (insiders versus a mix of insiders and outsiders).

Secondly, an evaluation scheme is developed in order to assess the overall as well as relative effects of the 3-step CTA approach. To assess the overall effect, a proxy of two sets of effect indicators is used, namely 1) indicators for knowledge uptake and use and 2) quality indicators for CTA activities. By evaluating the overall effects an assessment is made of the feasibility of the approach. The evaluation scheme for the relative effects comprises three phases: 1) assessing differences in interaction processes during the workshops, 2) assessing differences in broadening and enriching afterwards, and 3) constructing attribution stories.

In Chapter 4 three tools are developed that support the methodology developed in Chapter 3. Both in studying the dynamics of emerging technologies and in intervening in emerging technologies the analyst is confronted with a complex situation. Various actors and entities interact in the evolution of emerging technological fields. The developed tools aim to visualise and map particular dynamics, processes, and interactions. These tools are not only supportive to the research performed in this thesis, but also have a value of their own because they can be used in other studies as well.

Firstly, *socio-technical mapping* is offered as a type of mapping that can be used to dynamically visualise the various social and technical elements in a technological field. It is argued that literature addresses the value of socio-technical mapping, but never actually presents socio-technical maps. In an attempt to close this gap, a simple mapping tool is developed that is capable of visualising different actors, visions, and guiding artefacts, but, for example, does not show the relations between these entities. Secondly, a *three-level framework* is a type of map that puts special emphasis on multi-level dynamics, but also recognises multi-actor constellations. Three interrelated levels are distinguished: (i) locally, within a research group or company, (ii) more in general, within a scientific community or industry, and (iii) more global and diffuse, in society at large. Such a tool can help research in the dynamics of possible emerging technologies as it can visualise the various actors that become influenced by the emerging irreversibility. Thirdly, to construct individual *socio-technical scenarios* an instrument is developed to support the interviews in which scenario construction takes place. This tool is used to address the different interrelated aspects (technical, economic, political, and socio-cultural) in a balanced way. The result is a rich and coherent story of the future that can be formulated in a one to two hour interview. The emphasis in developing this interview instrument is on simplicity, however, without loosing a broad perspective on technological developments and innovation processes.

Chapter 5 discusses empirical findings related to the first research topic. The aim here is twofold: 1) to provide empirical data to construct a historical narrative and to investigate the three elements, by which the understanding of the dynamics of emerging technologies can be improved, and 2) to use and test the tools developed in Chapter 4.

The chapter starts with an overview of the case of Lab-on-a-chip technology and its history. The *historical narrative* serves as the first round in understanding the dynamics in the emerging Lab-on-a-chip field and functions as a background for the reader. In constructing the history the emphasis in the data collection is on expressions of expectations, agendas, and actor arrangements. The historical narrative indicates that the Lab-on-a-chip field has grown in terms of different types of actors. No type of actor has retreated from the field, which underlines the emerging character of the Lab-on-a-chip field.

The next step concerns the analysis of two cases of possible *emerging irreversibilities*. It is found that the strength of (possible) emerging irreversibilities (influential patterns) depends on the reach of the influence on different (types of) actors and different levels. The strength also depends on the period and persistence, where reinforcement of the pattern strengthens the emerging irreversibility. Furthermore, the patterns found turns out to be not all that irreversible. It is observed that the possibility to make fluidic chips with polymers influenced different actors in the Lab-on-a-chip field. However, no black-boxing of choosing polymers for particular problems could be observed. Nonetheless, polymers seem to be the preferred choice for biologists experimenting with living biological samples. This is an example of a pattern that if continued to be reinforced, is likely to become irreversible, i.e. the search heuristic becomes black-boxed. In the case of microreactors, synthetic chemists became connected to the Lab-on-a-chip field. This influenced what is now seen as Lab-on-a-chip technology: analysis and synthesis, rather than analysis alone (as was the case when it first emerged). Whether this link is irreversible could not be observed, but each time the link is reinforced it becomes stronger. In terms of entrenchment the possible emerging irreversibilities does indicate entrenchment, choices and investments were made. How entrenched the field of Lab-on-a-chip technology with respect to the provided examples really is, is difficult to say. At least, the influences of polymer and microreactors are not completely irreversible, which means that there is no lock-in. From the analysis it is concluded that certain directions are being taken that, at least on the short term, are likely to be reinforced.

Socio-technical scenarios are used to study patterns in prospective *positioning*. By doing so it is found that although a vision can be generally recognised, how a vision is interpreted by different actors is certainly not self-evident. Furthermore in the case of Point-of-care testing, the relations between actors are often found to be undetermined and unilateral, rather than mutually and recognisable. This results in a very open situation where many relations still can and have to be formed and shaped.

Interactions become organised in *spaces* which exist on different levels of aggregation. Actors can use old or create new spaces to organise interactions they find necessary or worthwhile to explore. Through interactions in spaces, actors can connect for shorter or longer periods of time. In the case of the '1st Lab-in-a-cell workshop' it is observed that collaboration between the BIOS research group (University of Twente, the Netherlands) and the Medisch Spectrum Twente (a regional hospital in Enschede, the Netherlands) was strengthened as an effect of organised interaction during this workshop. In both cases the link between the characteristics and the effects can only be partially explained. Over time, the characteristics of spaces can change, and with that the potential effects. This is most clearly observed in the case of the Lab-on-a-chip field, which assorted more effects when it continued to reinforce itself and became more influential.

In addition, worthy of note is that, throughout the different investigations, it becomes evident that the current Lab-on-a-chip field situation is still rather open-ended. The historical narrative shows that there has been quite some build-up in proof-of-principles, commercial interest, and actor arrangements. However, when looking in more detail at the aspect of entrenchment and relations between actors, no findings of directions that became ingrained in the actions and interactions of the involved actors can be presented.

Each section in this chapter uses a particular method, tool, or scheme to support writing a historical narrative or studying one of the three elements of the dynamics of emerging technologies. Reflection on the chapter discusses how the tools functioned and advantages, shortcomings, and suggestions for improvement are mentioned.

The results of an evaluation of the intervention in the field of Lab-on-a-chip technology in the Netherlands are discussed in Chapter 6. This intervention ran between May 2005 and February 2006, and used the 3-step CTA approach. By evaluating the overall effects, it is found that broadening and enriching in the normal working environment had indeed occurred. Exemplary for this result is that about 75% of the participants indicated that they now take into account more actors and aspects in their work. That broadening and enriching occurs is important as it indicates that the 3-step CTA approach is a feasible approach to improve the quality of innovation processes, and with that -at least partly- supports actors to deal with the Collingridge dilemma through constructive intervention.

A pre-developed evaluation scheme is used to evaluate the relative effects in relation to the workshop permutations. It is found that scenario presentation has a higher chance to trigger contestation and that a mixed actor composition is more likely to result in more efficient discussion. A combination of an insider workshop with scenario presentation offers the highest chance of a less productive workshop. Reversing the argument, when organising workshops that strive to broaden and enrich, mixed workshops with issue selection (No. 4) are considered the preferred choice.

In the reflection part of this chapter, further issues regarding the evaluation scheme as well as the application of the intervention are discussed. Most prominent is the reflection on the limited effect in terms of initialised action. This observation can be better understood by putting this result in the light of different 'faces of impact', the intramural effect, and differences between conceptual and instrumental knowledge use.

The seventh and final chapter presents conclusions for both research topics as well as the mutual benefits of both research topics. Furthermore the insights gained in this research are discussed in the broader context of CTA, the Collingridge Dilemma, and innovation policies.

Concluding the first research topic, by studying cases of (possible) *emerging irreversibilities*, the analyst looks for patterns that influence actors. Examples are patterns in the way actors interact or solve certain problems. In the cases of polymer and microreactors, such patterns are found and early entrenchment is demonstrated. If biologists continue to use polymers for experimenting with living biological samples, the choice for polymers can become black-boxed and this would make it irreversible. When the two fields of (traditional) microreactors and Lab-on-a-chip technology continue to meet and work together, the physical combination between analysis and synthesis on chips can become inseparable.

Additionally, expressions of envisioned roles can be used to indicate *how actors relate to each other*. More than once relations appear to be tentative, one-way, and undetermined. Due to the open-endedness of the situation, the course of Point-of-care developments and its implementation by using Lab-on-a-chip technology, is unpredictable and malleable.

By studying *spaces*, organised interaction can be understood in relation to the characteristics of spaces. Especially for emerging technologies, new spaces provide occasion, opportunities, and possibilities for new interactions to become organised. This is often necessary as old structures are not always sufficient and adequate. Finally, given that actors can become bound in and through spaces, this binding can have shorter or longer term effects on the dynamics of emerging technologies.

From the second research topic it is concluded that applying constructive intervention using the 3-step CTA approach leads to broadening and enriching in the normal working environment of participants. This is seen as an improvement of the quality of innovation processes in the field of Lab-on-a-chip technology because hereby the actors' ability to deal with the Collingridge dilemma increases. These results also indicate a preference for mixed workshops with issue selection. In relation and complementary to other CTA-inspired approaches, the 3-step CTA approach offers an attractive setup to stimulate broadening and enriching in early-stage technological fields.

Between the two research topics there is synergy and by this, results from the first research line can be used to improve interventions as developed in the second line. Here, suggestions are presented how the design and application of interventions can be supported and improved. An example of this is the use of the results of case studies that provide insights into emerging irreversibilities as an input to workshops.

Discussing policy implications, it is concluded that the government, in its role as 'guardian' of the innovation system, can strengthen innovation processes by facilitating (C)TA activities. In its role as the problem-owner for domains such as health care, safety, and environment, the various governmental agencies can make use of (C)TA activities and incorporate the results in policy-making. The same applies with regard to various other private and public organisations. In the Bsik funded NanoNed programme (of which this research is a part) (C)TA contributes to facilitate the interface between knowledge production and use. Overall, there is room for improvement of the embedding of (C)TA in ongoing technological developments and innovation processes.

Chapter 7 concludes by discussing the institutionalisation of (C)TA. The basic assumption underlying this discussion is that (C)TA should be viewed and organised as an integral part of innovation processes, innovation policies, and innovation systems at an early stage. Integrating (C)TA activities in innovation systems would stimulate and facilitate the involvement of a variety of relevant actors in decision-making about societal and economically successful directions of emerging technologies. By this the capability of these parties to improve the societal embedment of technology options at an early stage will increase. As a consequence the quality of innovation processes will increase from an economic as well as a societal point view. The final conclusion of this thesis then is that interventions that use the 3-step CTA approach can enhance the capabilities of various actors to handle the Collingridge dilemma productively and by this contribute to the improvement of the successful embedment of science and technology in society.

Samenvatting

Interveniëren in emergente nanotechnologieën

Een CTA van Lab-on-a-chip technologie

Iedere keer dat er een nieuwe technologie opkomt, worden er vragen gesteld over het potentieel, de ontwikkelingsrichtingen en de mogelijkheden om te interveniëren. Dit proefschrift bestudeert de dynamiek van een bepaald technologisch veld, Lab-on-a-chip technologie, en de mogelijkheid om de ontwikkelingen te sturen.

In het algemeen zijn er voor nieuwe wetenschap en technologie vele mogelijkheden voor technologie opties waar de maatschappij baat bij kan hebben. Echter, niet al deze opties zijn even wenselijk en haalbaar. Maatschappelijke worstelingen rond de introductie van kernenergie en genetisch gemodificeerde organismen (GMO's) laten bijvoorbeeld zien dat de inbedding van nieuwe wetenschap en technologie in de maatschappij niet altijd vlekkeloos verloopt. Met andere woorden, de maatschappelijke inbedding van nieuwe wetenschap en technologie is een belangrijk en actueel onderwerp. Het hoofddoel van dit proefschrift is het verbeteren van het vormingsproces van emergente technologieën in een vroege fase van hun ontwikkeling en van hun innovatieprocessen. Deze interesse wordt uitgedrukt in twee onderzoeksvragen. *Hoe kan de dynamiek van emergente technologieën begrepen worden?* En *hoe kan constructieve interventie worden ontworpen zodat de kwaliteit van innovatieprocessen in emergente technologieën verbetert?*

Emergente technologieën hebben onderscheidende karakteristieken in vergelijking met technologieën die zich in latere fasen bevinden. Deze technologieën zijn zeer fluïde en de ontwikkeling is nog erg open. Actoren worden verder geconfronteerd met een hoge mate van onzekerheid over de uitkomsten (innovaties), de opbrengsten en de te volgen strategie. In hun acties en interacties worden actoren die in emergente technologische velden opereren vooral geleid door verwachtingen en visies.

Eén van de belangrijkste aannames van dit onderzoek is dat wanneer in een vroeg stadium van ontwikkeling van wetenschap en technologie de interacties tussen verschillende actoren op een constructieve en bredere manier plaatsvinden, dat dan de uiteindelijke maatschappelijke inbedding wordt vergroot. Het idee hierachter is dat als op een eerder tijdstip overwegingen meegenomen en geëvalueerd worden vanuit een breder perspectief, dit de beslissingen die genomen worden tijdens de ontwikkeling van nieuwe wetenschap, technologie en innovatieprocessen kan veranderen. Om dergelijke interacties tussen diverse actoren in een vroeg stadium te faciliteren, dient er een interventie te worden ontwikkeld, toegepast en geëvalueerd. Bij het ontwerpen van een interventie is het noodzakelijk dat een gedegen inzicht in de dynamieken van technologisch ontwikkeling aanwezig is. Een belangrijk inzicht voor interventies in opkomende technologieën is dat het zogenaamde Collingridge dilemma het moeilijk maakt om op een constructieve manier te interveniëren. Dit dilemma geeft aan dat in de vroege stadia van ontwikkeling de mogelijkheden om nieuwe wetenschap en technologie te ontwikkelen en toe te passen onbegrensd lijken, hoewel nog niemand weet welke technologie opties uiteindelijk succesvol zullen zijn. In latere stadia zijn de uitkomsten beter te voorspellen, maar kunnen er door de eerder genomen beslissingen en gedane investeringen moeilijk veranderingen worden ingepast. In dit onderzoek wordt onderzocht in hoeverre constructieve interventie die gericht is op het stimuleren van verbreding en verrijking met als doel de kwaliteit van innovatieprocessen te verbeteren, een geschikte aanpak kan zijn om het Collingridge dilemma te omzeilen. Een dergelijke interventie richt zich niet alleen op het verbeteren van de kwaliteit van innovatieprocessen, maar biedt ook mogelijkheden om de maatschappelijke inbedding van nieuwe wetenschap en technologie te vergroten.

Hoofdstuk 2 reikt de theoretische bouwstenen en de conceptualisatie aan voor het begrijpen van emergente technologische velden en voor het ontwerpen en evalueren van constructieve interventie. Relevante theorieën uit de wetenschap- en technologiestudies (STS) en innovatiewetenschappen literatuur worden besproken. Verder wordt er in dit hoofdstuk een theoretisch raamwerk ontwikkeld dat de nadruk legt op drie elementen in de dynamiek van emergente technologieën: 1) hoe door de tijd ontwikkelingen verankerd raken (entrenchment); 2) hoe actoren zich tot elkaar verhouden en hoe dit invloed heeft op interacties; en 3) hoe interacties tussen actoren georganiseerd zijn. Voor elk van deze elementen is een concept ontwikkeld dat dient als theoretische ondersteuning, namelijk 'emergente irreversibiliteiten', 'positioneren' en 'ruimtes' (spaces).

Het eerste element, het feit dat ontwikkelingen verankerd raken, is het resultaat van voortdurende interacties tussen actoren en de beslissingen die genomen worden in relatie tot de technologische ontwikkelingen. Dit leidt tot het ontstaan van bepaalde patronen (zoals samenwerking of zoekrichtingen) die sommige acties en interacties makkelijker maken en andere juist bemoeilijken. Deze patronen worden hier emergente irreversibiliteiten genoemd. De mate waarin deze patronen daadwerkelijk irreversibel zijn, is de lakmoesproef voor de daadwerkelijke invloed van de patroon. Emergente irreversibiliteiten duiden dus op de eerste ordening van interactiepatronen en een vermindering in de fluïditeit van emergente technologische velden.

Het tweede element benadrukt dat interacties tussen actoren voor een groot deel de voortdurende processen in en om technologische ontwikkelingen bepalen. Om interacties te kunnen begrijpen is het belangrijk om te weten hoe actoren zich tot elkaar verhouden en welke rollen en posities zich aan het vormen zijn. Posities worden hier beschouwd als geaccepteerde of gevestigde rollen. Dit houdt in dat verschillende actoren dezelfde rol toedichten aan een bepaalde actor. Specifiek voor emergente technologieën is dat vele posities zich nog moeten stabiliseren. Acties en interacties geschieden in emergente technologische velden vooral op basis van verwachtingen en visies. In verwachtingen en visies wordt gepositioneerd om de toekomstige posities van actoren uit te drukken. Het is daarom nuttig om geprojecteerde, of te verwachten, posities te bestuderen.

Ten derde, interacties tussen verschillende actoren vinden niet zomaar plaats, maar zijn georganiseerd. Georganiseerde interactie kan vele vormen aannemen. Het concept van ruimtes wordt hier gebruikt om de verschillende vormen van georganiseerde interactie in onder te brengen. Ruimtes stellen een variëteit aan actoren in staat om samen te komen om te overleggen, te onderhandelen en tot conclusies te komen. De effecten van (nieuwe) ruimtes benadrukken dat georganiseerde interactie invloed heeft op de dynamiek van emergente technologische velden.

Hoofdstuk 2 gaat verder door het introduceren van Technology Assessment (TA of technologieaspectenonderzoek) als een vorm van strategische intelligentie (SI). Strategische intelligentie is een parapluterm voor benaderingen die actoren kunnen ondersteunen om hun rol te spelen in innovatieprocessen door het beschikbaar stellen van informatie op maat. Het argument wordt aangedragen dat de interventie die ontwikkeld wordt in dit proefschrift het beste kan voortborduren op een specifiek type TA, namelijk de zogenoemde 'loci of alignment' variant van Constructieve TA. Verder wordt uitgelegd hoe constructieve interventie in het algemeen kan leiden tot verbreding en verrijking van gedachtes, acties en interacties in de normale werkomgeving van actoren. Een conceptueel schema wordt ontwikkeld dat de relatie legt tussen constructieve interventie en verbreding en verrijking als een totaal effect.

Door dit gehele proefschrift wordt dezelfde casus gebruikt welke in hoofdstuk 3 wordt geïntroduceerd: Lab-on-a-chip technologie. Lab-on-a-chip technologie is geworteld in de microfabricagetechnologie, die het aan het eind van de jaren '80 mogelijk maakte om vloeistofchips te vervaardigen. In een Lab-on-a-chip worden vloeistoffen geleid door geminiaturiseerde kanalen. Het ontwerp van de chip bepaald het vermogen van de chip om bepaalde analyses uit te kunnen voeren. Vandaag de dag hebben enkele bedrijven producten op basis van Lab-on-a-chip technologie op de markt en worden er enkele toepassingen gebruikt. Zij worden vooral gebruikt als onderzoeksinstrumenten, maar er zijn ook voorbeelden van toepassingen die gebruikt worden als instrument om ter plaatse bepalingen te kunnen doen, bijvoorbeeld in ziekenhuizen aan het bed bij de patiënt (Point-of-care testen). Lab-on-a-chip technologie is een emergente technologie.

Het resterende deel van hoofdstuk 3 geeft de onderzoeksopzet voor beide onderzoekslijnen (begrijpen van de dynamiek van en interveniëren in emergente technologieën). Voor de eerste onderzoekslijn wordt allereerst uitgelegd dat het mogelijk is om voor een bepaald technologisch veld een gedetailleerde historische beschrijving te maken. Vervolgens verschuift de aandacht naar de drie elementen van de dynamiek van emergente technologieën. Voor elk element wordt een specifieke aanpak ontwikkeld waarmee de elementen kunnen worden bestudeerd.

Voor de onderzoeksopzet van de tweede onderzoekslijn wordt eerst een drie-stappen-CTA-benadering ('3-step CTA approach') ontworpen die gericht is op het stimuleren van verbreding en verrijking door middel van constructieve interventie. In deze benadering komt dit tot uitdrukking door het faciliteren van een brede interactie tussen diverse actoren. Individuele socio-technische scenario's worden gebruikt om de actoren voor te bereiden op groepsbijeenkomsten (workshops). In deze workshops komen de scenario's weer terug en kunnen de deelnemers de scenario's bediscussiëren. Om ook methodologische lessen te kunnen trekken over hoe constructieve interventie in emergente technologieën op basis van CTA methodologie kan worden ontworpen, worden er twee permutaties aan het ontwerp toegevoegd: 1) hoe de scenario's tijdens de workshops worden gebruikt (het presenteren van scenario's versus het selecteren van geschilpunten); en 2) in de compositie van de actoren (direct betrokkenen versus een mix van direct en indirect betrokkenen).

Vervolgens wordt er een evaluatieschema ontwikkeld dat het mogelijk maakt het totale als ook de relatieve effecten van de '3-step CTA approach' te beoordelen. Om de totale effecten te beoordelen, wordt gebruik gemaakt van een benadering (proxy) die bestaat uit twee sets van effectindicatoren, namelijk: 1) indicatoren voor de opname en het gebruik van kennis; en 2) kwaliteitsindicatoren voor CTA-activiteiten. Door de totale effecten te evalueren wordt een beoordeling gemaakt van de haalbaarheid van de aanpak. Het evaluatieschema voor de relatieve effecten bestaat uit drie fasen; 1) het beoordelen van verschillen in interactieprocessen tijdens de workshops; 2) het beoordelen van verschillen in verbreding en verrijking na de workshops; en 3) het construeren van zogenaamde 'attribution stories'.

In hoofdstuk 4 worden drie hulpmiddelen ('tools') ontwikkeld die de methodologie uit hoofdstuk 3 ondersteunen. Zowel in het bestuderen van de dynamiek van emergente technologieën als ook in het interveniëren in emergente technologieën wordt de analist geconfronteerd met een complexe situatie. Diverse actoren en diverse entiteiten hebben wisselwerking met elkaar tijdens de evolutie van een opkomend technologisch veld. De tools die hier ontwikkeld worden proberen bepaalde dynamieken, processen en interacties inzichtelijk te maken. Deze tools zijn niet alleen zeer behulpzaam bij het onderzoek in dit proefschrift, maar kunnen ook nuttig zijn voor andere studies.

Als eerste tool wordt *'socio-technical mapping'* naar voren geschoven om op een dynamische manier de diversiteit van sociale en technische elementen in een technologisch veld in kaart te brengen. De literatuur benoemt de waarde van deze vorm van kartering, maar laat geen resultaten zien. In een poging om deze leemte op te vullen wordt hier een eenvoudige kartering ontwikkeld die de gebruiker in staat stelt om verschillende actoren, visies en artefacten in kaart te brengen, maar bijvoorbeeld niet de relaties tussen deze entiteiten. De tweede tool, een *'three-level framework'*, is een type kartering met een speciale nadruk op de dynamiek tussen verschillende niveaus, maar verliest tegelijkertijd de diversiteit aan actoren niet uit het oog. Er worden drie met elkaar gerelateerde niveaus onderscheiden: (i) lokaal, in een onderzoeksgroep of bedrijf; (ii) meer in het algemeen, in een wetenschapsgemeenschap of industrie; en (iii) nog breder en diffuus, in de maatschappij. Een dergelijke tool kan het onderzoek naar de dynamiek van mogelijke emergente irreversibiliteiten ondersteunen, omdat het in kaart brengt welke actoren door de emergente irreversibiliteit worden beïnvloed. Voor de derde tool, met als doel het construeren van individuele *socio-technische scenario's*, wordt er een interviewinstrument ontwikkeld. Deze tool wordt gebruikt om de verschillende met elkaar in relatie staande aspecten (technisch, economisch, politiek en maatschappelijk) op een gebalanceerde manier te adresseren. Het resultaat is een rijk en coherent toekomstverhaal dat in een één à twee uur durend interview kan worden opgesteld. In de ontwikkeling van dit interviewinstrument ligt de nadruk op eenvoud, hoewel een brede kijk op technologische ontwikkeling en innovatieprocessen niet verloren mag gaan.

Hoofdstuk 5 bediscussieert de empirische bevindingen met betrekking tot de eerste onderzoekslijn. Het doel is tweeledig: 1) het aanreiken van empirische data om een gedetailleerde historische beschrijving te maken en voor het onderzoeken van de drie elementen waardoor het begrip van de dynamiek van emergente technologieën kan worden vergroot; en 2) het gebruiken en testen van de tools die in hoofdstuk 4 zijn ontwikkeld.

Het hoofdstuk begint met het geven van een overzicht van de casus (Lab-on-a-chip technologie) en de bijbehorende geschiedenis. Een *gedetailleerde historische beschrijving* dient als een eerste ronde in het begrijpen van de dynamiek en functioneert als achtergrond voor de lezer. In het opstellen van de historische beschrijving ligt de nadruk vooral op expressies van verwachtingen, agenda's en actorrelaties. De geschiedenis van Lab-on-a-chip technologie laat zien dat het veld is gegroeid in termen van verschillende typen actoren. Er is geen type actor dat zich terug heeft getrokken uit het veld, wat het emergente karakter van Lab-on-a-chip technologie onderstreept.

De volgende stap bestaat uit het analyseren van twee casussen van mogelijke *emergente irreversibiliteiten*. Wat blijkt is dat de sterkte van (mogelijke) emergente irreversibiliteiten (invloedrijke patronen) afhangt van de invloed op verschillende (typen) actoren over verschillende niveaus. De sterkte hangt ook af van de periode en volharding waarin het herhalen van het patroon een versterkend effect heeft op de emergente irreversibiliteit. Het blijkt verder dat de gevonden patronen eigenlijk niet zo irreversibel zijn. De mogelijkheid om vloeistofchips te maken van polymeren heeft de actoren weldegelijk beïnvloed, maar er heeft geen standaardisering (black-boxing) plaatsgevonden in de keuze om polymeren te gebruiken voor bepaalde problemen. Echter, voor het experimenteren met levend materiaal lijken biologen de voorkeur te geven aan het gebruik van polymeren. Dit is een voorbeeld van een patroon dat, als het frequent wordt herhaald, waarschijnlijk irreversibel wordt wat wil zeggen dat (de zoekrichting voor) het oplossen van bepaalde problemen wordt gestandaardiseerd. In het geval van microreactoren raakten synthetisch chemici betrokken bij het veld van Lab-on-a-chip technologie. Dit feit heeft invloed gehad op wat nu als Lab-on-a-chip technologie wordt gezien; een nadruk op analyse en synthese in plaats van op analyse alleen (wat in de beginjaren het geval was). Of deze betrokkenheid irreversibel is kon niet worden vastgesteld, maar elke keer dat de betrokkenheid wordt bevestigd, wordt het ook meer irreversibel. In termen van 'entrechment' geeft deze mogelijke emergente irreversibiliteit inderdaad een zekere mate van verankering weer. Bepaalde keuzes en investeringen zijn immers al gemaakt. Hoe verankerd het veld van Lab-on-a-chip technologie in relatie met deze voorbeelden werkelijk is, is moeilijk te zeggen. Deze voorbeelden laten wel zien dat de invloed van microreactoren en het gebruik van polymeren niet volledig irreversibel is, wat betekent dat er nog geen lock-in is ontstaan. Uit de analyse kan verder geconcludeerd worden dat bepaalde richtingen wel degelijk zijn ingeslagen die, tenminste op de korte termijn, zichzelf waarschijnlijk zullen herhalen en daardoor versterkt worden.

Voor het bestuderen van patronen in toekomstgericht *positioneren* worden socio-technische scenario's gebruikt. Op deze manier wordt gevonden dat, hoewel een visie algemeen wordt herkend, de specifieke invulling door verschillende actoren behoorlijk kan verschillen. In het geval van Point-of-care testen blijkt dat de relaties tussen actoren meestal ongedefinieerd en eenzijdig zijn in plaats van wederzijds en herkenbaar. Dit resulteert in een zeer open situatie waarin vele relaties nog gevormd kunnen en moeten worden.

Interacties raken georganiseerd in *ruimtes*, welke op verschillende aggregatieniveaus bestaan. Actoren kunnen zowel oude ruimtes gebruiken, maar ook nieuwe ruimtes creëren om interacties te organiseren. Door de interacties die actoren in bepaalde ruimtes hebben, kunnen ze voor kortere of langere tijd aan elkaar verbonden worden. In het geval van de '1st Lab-in-a-cell workshop' bleek dat de samenwerking tussen de onderzoeksgroep BIOS (Universiteit Twente) en het Medisch Spectrum Twente (een lokaal ziekenhuis in Enschede) werd versterkt als een effect van de georganiseerde interacties tijdens deze workshop. In beide gevallen kon de relatie tussen de eigenschappen van de ruimte en de effecten slechts gedeeltelijk worden verklaard. In de loop van de tijd kunnen de eigenschappen van een bepaalde ruimte veranderen en daarmee ook de potentiële effecten. Dit was het meest duidelijk in het geval van het Lab-on-a-chip veld, waar de ruimte resulteerde in grotere effecten wanneer het zichzelf voortdurend versterkte en meer invloed kreeg.

Het is benoemenswaardig dat in het onderzoek naar de verschillende elementen steeds weer gevonden wordt dat de toekomst van het veld van Lab-on-a-chip technologie nog behoorlijk open ligt. De gedetailleerde historische beschrijving laat zien dat er een basis ligt in het aantal proof-of-principle's, de commerciële interesse en de gevormde samenwerkingsrelaties. Echter, als we nu gedetailleerder kijken naar het aspect van 'entrenchment' en de relaties tussen actoren, dan valt op dat er geen enkele richting echt ingebed is in de acties van en interacties tussen de verschillende betrokken actoren.

Elke sectie in dit hoofdstuk maakt gebruik van een bepaalde methode, tool of schema dat het schrijven van de historische beschrijving ondersteunt dan wel het onderzoek naar een van de elementen van de dynamiek van emergente technologieën helpt. Een reflectie op het hoofdstuk beschrijft hoe de tools functioneerden en welke voordelen, tekortkomingen en suggesties voor verbetering er zijn.

Het resultaat van de evaluatie van de interventie in het veld van Lab-on-a-chip technologie in Nederland wordt bediscussieerd in hoofdstuk 6. Deze interventie werd uitgevoerd tussen mei 2005 en februari 2006 en maakte gebruik van de '3-step CTA approach'. Uit de evaluatie van de totale effecten volgt dat verbreding en verrijking in de normale werkomgeving inderdaad plaatsvond. Exemplarisch voor dit resultaat is dat 75% van de deelnemers aangaven nu meer actoren en aspecten in ogenschouw te nemen tijdens hun werk. Dat verbreding en verrijking optreedt, is een belangrijk resultaat, omdat het aangeeft dat de '3-step CTA approach' een mogelijke aanpak is om de kwaliteit van innovatieprocessen te verbeteren en daarmee – tenminste gedeeltelijk – actoren ondersteunt in het omgaan met het Collingridge dilemma.

Een van tevoren ontwikkeld evaluatieschema wordt gebruikt om de relatieve effecten als gevolg van de workshoppermutaties te evalueren. Hieruit blijkt dat het presenteren van scenario's de kans op het vastlopen van de discussie vergroot en dat bij een gemengde actorcompositie de discussie waarschijnlijk efficiënter verloopt. Een combinatie van een workshop met alleen direct betrokkenen en het presenteren van scenario's geeft de grootste kans op een minder productieve bijeenkomst. Als we het argument omdraaien, bij het organiseren van een bijeenkomst waarin gestreefd wordt naar verrijking en verbreding, heeft een workshop waarin geschilpunten worden geselecteerd als start van de discussie en met een gemengde actorcompositie (Nr. 4) de voorkeur.

In de reflectie op dit hoofdstuk wordt het evaluatieschema als ook het uitvoeren van de interventie bediscussieerd. Het meest opmerkelijk is het beperkte effect in termen van geïnitieerde acties van de deelnemers. Deze observatie kan beter worden begrepen na een discussie van verschillende 'faces of impact', het intramurale effect en verschillen tussen conceptueel en instrumenteel gebruik van kennis.

Het zevende en laatste hoofdstuk presenteert de conclusies voor beide onderzoekslijnen en besteed ook aandacht aan de wederzijdse voordelen van beide. Verder worden de verkregen inzichten bediscussieerd in de bredere context van CTA, het Collingridge dilemma en innovatiebeleid.

Voor de eerste onderzoekslijn kan het volgende geconcludeerd worden. Bij het bestuderen van gevallen van (mogelijke) *emergente irreversibiliteiten* zoekt de analist naar patronen die actoren beïnvloeden. Voorbeelden zijn interactiepatronen tussen verschillende actoren of de manier waarop actoren bepaalde problemen oplossen. In de gevallen van microreactoren en het gebruik van polymeren werden dergelijke patronen inderdaad gevonden, wat aantoont dat er een zekere mate van vroege verankering is ontstaan. Als biologen polymeren blijven gebruiken voor het experimenten met levend materiaal kan de keuze voor polymeren de standaard worden, wat het irreversibel maakt. Als de twee velden van (traditionele) microreactoren en Lab-on-a-chip technologie elkaar blijven ontmoeten en samenwerken, kan de fysieke combinatie van analyse en synthese op vloeistofchips onafscheidbaar worden.

Expressies van voorgestelde toekomstige rollen kunnen worden gebruikt om te bepalen *hoe actoren zich tot elkaar verhouden*. Het blijkt dat relaties tussen actoren voornamelijk één kant op gaan en vaak ongedefinieerd zijn. Door deze openheid van de situatie zijn de ontwikkelingsrichtingen van Point-of-care toepassingen en de implementatie van Lab-on-a-chip technologie hierin uiterst onzeker en eenvoudig te veranderen.

Door het bestuderen van *ruimtes* kan georganiseerde interactie begrepen worden in relatie met de eigenschappen van de bestudeerde ruimte. Specifiek voor emergente technologieën geven nieuwe ruimtes een aanleiding, gelegenheid en de mogelijkheid voor nieuwe interacties om georganiseerd te raken. Vaak is dit zelfs nodig, omdat oude structuren niet altijd toereikend zijn in de nieuwe situatie. Tot slot, gegeven dat actoren verbonden kunnen raken in en door ruimtes kan deze verbondenheid een kortere dan wel langere invloed hebben op de dynamiek van emergente technologieën.

In de tweede onderzoekslijn kan geconcludeerd worden dat het toepassen van constructieve interventie die gebruik maakt van de '3-step CTA approach' leidt tot verbreding en verrijking in de normale werkomgeving van de deelnemers. Dit wordt gezien als een verbetering van de kwaliteit van innovatieprocessen in het veld van Lab-on-a-chip technologie aangezien de actoren hierdoor beter in staat zijn om te gaan met het Collingridge dilemma. Deze resultaten laten ook een voorkeur zien voor workshops waarin geschilpunten worden geselecteerd als start van de discussie en met een gemengde actorcompositie. In relatie met en complementair aan andere door CTA geïnspireerde aanpakken biedt de '3-step CTA approach' een aantrekkelijke opzet om verbreding en verrijking in de vroege stadia van technologische velden te stimuleren.

Er is synergie tussen de twee onderzoekslijnen en hierdoor kunnen resultaten uit de eerste onderzoekslijn worden gebruikt om interventies te verbeteren zoals ontwikkeld in de tweede onderzoekslijn. Er worden suggesties gepresenteerd hoe het ontwerp en de uitvoering van interventies daadwerkelijk kunnen worden ondersteund en verbeterd. Een voorbeeld hiervan is door gebruik te maken van de resultaten van gevalsstudies die het inzicht in emergente technologieën verbeteren als input voor groepsbijeenkomsten.

Door het bediscussiëren van beleidsimplicaties kan worden geconcludeerd dat de overheid, in haar rol van hoeder van het innovatiesysteem, innovatieprocessen kan versterken door het organiseren van (C)TA-activiteiten. In haar rol als probleemeigenaar voor gebieden als gezondheidszorg, veiligheid en het milieu kunnen ook de verschillende overheidsinstanties gebruik maken van (C)TA-activiteiten en de resultaten hiervan implementeren in beleid. Hetzelfde geldt voor verschillende andere private en publieke organisaties. In het door Bsik gefinancierde NanoNed programma (waar dit onderzoek een onderdeel van is) draagt (C)TA bij aan het faciliteren van interfaces tussen het toepassen en de productie van kennis. In zijn totaliteit is er ruimte voor de verbetering van de inbedding van (C)TA in de voortdurende technologische ontwikkelingen en innovatieprocessen.

Hoofdstuk 7 besluit met het bediscussiëren van de institutionalisering van (C)TA. De onderliggende aanname van deze discussie is dat (C)TA al in een vroeg stadium moet worden gezien en georganiseerd als een integraal onderdeel van innovatieprocessen, innovatiebeleid en innovatiesystemen. Het integreren van (C)TA-activiteiten in innovatiesystemen zal de betrokkenheid van diverse relevante actoren bij de besluitvorming over sociaal en economisch succesvolle ontwikkelingsrichtingen van emergente technologieën stimuleren en faciliteren.

Hierdoor zal het vermogen van deze partijen om de sociale inbedding van technologie opties te vergroten juist toenemen. Een bijkomend gevolg hiervan is dat de kwaliteit van innovatieprocessen zowel in sociaal als economisch opzicht zal toenemen. De slotconclusie van dit proefschrift is dan ook dat interventies die gebruik maken van de '3-step CTA approach' het vermogen van diverse partijen om op een productieve manier om te gaan met het Collingridge dilemma verbetert en er hierdoor een bijdrage geleverd kan worden aan de succesvolle inbedding van wetenschap en technologie in de maatschappij.

Woord van dank

“Wat gebeurt er toch met de technologie die ontwikkeld wordt in laboratoria?” Toen die vraag tijdens mijn studietijd in Groningen eenmaal bij mij ging leven werd ik steeds minder ‘een bèta’. Eerst van technische natuurkunde de bedrijfskunde in en de afgelopen vier jaar in de innovatiewetenschappen. Voor innovatiewetenschappers is het de kunst om door ‘van alles een beetje te weten’ en door ‘het combineren van verschillende invalshoeken’ een meerwaarde te creëren. Sociaal gezien is dit in een promotietraject niet anders, alleen dan met de mensen die je om je heen verzamelt. De ‘ups en downs’ worden het best gecreëerd en opgevangen als dit een gevarieerde groep mensen is, zowel op inhoudelijk maar zeker ook op sociaal vlak. Het is dan ook deze groep mensen aan wie ik veel te danken heb bij het vormgeven, het uitvoeren en het afronden van dit proefschrift.

Ruud, Arie en Harro. Als begeleiders, bedankt dat jullie mij het vertrouwen hebben gegeven (en dit door de jaren hebben gehouden) om er een mooi promotietraject van te maken. Ik heb het met plezier gedaan, hoewel het één na laatste loodje (het rond krijgen van de structuur van het proefschrift) best een behoorlijke dobber was. Ruud, het overzicht dat je bewaart (en bewaakt) op de grote lijnen van het verhaal waren een ware stimulans. Arie, je conceptuele vernieuwing is inspirerend en je detailcommentaar meestal zeer constructief. Harro, je deur stond altijd open waar na ik meestal weer verdween met een verhelderende schets om hier vervolgens op verder te kunnen bouwen.

Het AIO-traject bij de onderzoekschool WTMC (Wetenschap Techniek en Moderne Cultuur) heb ik met plezier gevolgd. De workshops en summerschools waren gezellig en tegelijkertijd schetsten ze voor mij een beeld van de verschillende manieren waarop je naar wetenschap en technologieontwikkeling kan kijken.

Dan zou ik graag de mensen die tijd voor mij vrij hebben gemaakt, zowel in het opzetten als uitvoeren van mijn onderzoek willen bedanken. Specifiek de deelnemers aan de workshops, ik was blij verrast dat jullie in grote getallen naar Utrecht kwamen en met enthousiasme hebben meegedaan. Ik hoop dat jullie veel hebben gehad aan het maken van de scenario’s en de discussies tijdens de workshops.

Jan Taco, je onuitputtende enthousiasme blijft opmerkelijk, maar zeker ook belangrijk in het moeilijke vak van zorginnovatie. Ik weet zeker dat onze wegen nog regelmatig zullen kruisen en tot mooie dingen zullen leiden en niet in de minste plaats omdat ik het erg plezierig vind om met je samen te werken.

Steven, Arjan en Huub. Bedankt voor de welkome afwisseling op het schrijfproces dat ik in Utrecht doormaakte. Het heeft mij doen inzien dat mijn aanpak ook waarde heeft in het bedrijfsleven. Voor Medimate, houd alsjeblieft vast aan jullie uitdagende sociale benadering van 'concurrent engineering' en het wordt een mooi en succesvol bedrijf.

Tim, Ria, Jeroen, Jan, Andreas, Johan, Emile en Arnold. Zeker, ondernemerschap is bovenal en creatieve en persoonlijke bezigheid. Juist daarom was het goed dat ik zelf de workshops zou begeleiden. Bedankt voor jullie betrokkenheid.

David, thanks for the international experience. I enjoyed the US to the full as well as staying in your group for two months. Here, I also would like to thank Jim, Eric, Cynthia, Dave, Daniel, Ira, Barbara, Patrick and Walter for making the experience complete. Ronnie, Frankie en Jorrit; Santa Barbara, San Fransisco, Salt Lake City en andere plekken in Amerika zal ik mij blijven herinneren. 'Shop till you drop', das logischhh!

De groep innovatiewetenschappen was bovenal een plek om lekker te werken met een juiste balans tussen werk en afleiding. Voor deze werksfeer moet ik iedereen bedanken. Ineke, het hart van de groep, voor de 'namiddagbabbel' kun je voorlopig gelukkig nog steeds op kamer 10.11a terecht. De AIO-groep groeide, organiseerde meer activiteiten, werd steeds hechter en daarmee kwamen ook vriendschappen. Tessa, het was super om je kamergenoot te zijn. Veel lol en ook een luisterend oor voor het persoonlijke dingen waren erg prettig. Zorg jij dat Willie zijn functie behoud?! Inie, op zijn tijd een beetje zwelgen is prima, maar daarna wel met een brede lach weer aan de slag. We blijven zeker fitnessen en recoveren. Simoon, keep looking for those ent-wifes! Once found, it will forever tip the balance to the 'good'. Wouter, ik vond het erg leuk dat we zo spontaan en actief hebben kunnen samenwerken. Maryse, het is goed om te zien dat je nu ook wel eens 'nee' zegt. Klaas, Jon, ik blijf altijd in voor spontane borrels.

Vrienden en familie, ik wil jullie bedanken voor een rijk gevulde wereld waarin het werk, de wetenschap en het proefschrift op de achtergrond verdwenen. Toch was er altijd interesse en zeker ook steun als dit nodig was.

Mijn Sassie, je hebt alleen het laatste anderhalf jaar meegemaakt en daarmee ook meteen het moeilijkste stuk. Hierin was jouw steun onmisbaar. Vele avonden, weekenden en een vakantie moesten worden opgeofferd. Die vakantie gaan we zeker zo snel mogelijk inhalen, maar dan wel samen met onze Oliver de Labrador.

Rutger van Merkerk
Utrecht, oktober 2007

Curriculum Vitae

Rutger Olof van Merkerk was born in ’s-Hertogenbosch, The Netherlands, on 16 January 1978. He completed his secondary education at the Ulenhof College in Doetinchem in 1994. After one year of secondary technical school in Electrical Engineering at the Hanze University Groningen he moved on to the University of Groningen to get a masters degree in Applied Physics with a specialisation in Materials Science. In 2000 he carried out a placement in industry at Gasunie Research. He also holds a master degree in Business Administration with a specialisation in Small Business and Entrepreneurship from the same university. This degree included an industrial placement at Applied NanoSystems BV.

From 2003-2007 Rutger worked as a PhD candidate at the Copernicus Institute for Sustainability and Innovation, Department of Innovation and Environmental Sciences, University of Utrecht, The Netherlands. The results are presented in this thesis. The PhD project was carried out in a larger research programme called NanoNed.

Over the last year he worked part-time as a consultant in health care innovation at Medimate BV, a university spin-off of the University of Twente, Enschede, The Netherlands. At 1 November 2007 Rutger began a new challenge at the University Medical Center Utrecht as a project leader in the recently initiated Medical Technological Innovation Centre.

Boon, W. and R.O. van Merkerk. (forthcoming 2008). “Prospective Positioning of Industrial Players: the case of theranostics.” Technology Analysis and Strategic Management. 20(6).

Onck, P.R., R. van Merkerk, J.Th.M. de Hosson and I. Schmidt. (2003). “Fracture of metal foams: in situ testing and numerical modelling.” Proceedings of MetFoam 2003: Cellular Metals: Manufacture, Properties, Applications. MIT Verlag, Berlin, Germany. 393-398.

Onck, P.R., R. van Merkerk, J.Th.M. de Hosson and I. Schmidt. (2004). “Fracture of Metal Foams: In situ Testing and Numerical Modelling.” Advanced Engineering Materials. 6(6):429 432.

Smits, R.E.H.M., R.O. van Merkerk, D.H. Guston and D. Sarewitz. (forthcoming 2008). “Strategic Intelligence (1): The role of TA in systemic innovation policy” In Smits, R.E.H.M., P. Shapira and S. Kuhlman (ed.) Innovation Policy book.

Van Merkerk, R.O. and A. van den Berg. (2006). “More than technology alone.” Lab on a Chip. 6:838-839.

Van Merkerk, R. and W. Boon. (2007). “Industry strategies on theranostics: need for structural alignment.” Drug Discovery World. Fall:61-69.

Van Merkerk, R.O. and D.K.R. Robinson. (2006). “Characterising the emergence of a technological field: expectations, agendas and networks in Lab-on-a-chip technologies.” Technology Analysis and Strategic Management. 18(3/4):411-428.

Van Merkerk, R.O. and H. van Lente. (2004). “Tracing Emerging Irreversibilities in Emerging Technologies: the case of nanotubes.” In Scapolo, F. and E. Cahill (ed.). New horizons and Challenges for Future-oriented Technology Analysis. Proceedings of the EU-US Scientific Seminar: New Technology Foresight, Forecasting & Assessment Methods. December.

Van Merkerk, R.O. and H. van Lente. (2005). "Tracing emerging irreversibilities in emerging technologies: the case of nanotubes." Technological Forecasting and Social Change. 72:1094-1111.

Van Merkerk, R.O. and H. van Lente. (forthcoming 2008). "Asymmetric positioning and emerging paths: the case of Point-of-are." Futures. Accepted for publication.

Van Merkerk, R.O. and J.T. te Gussinklo. (2006). "Nanotechnologie vergt veel experts." [Nanotechnology demands many experts.] Friesch Dagblad. Opinion page. 11 November.

Van Merkerk, R.O. and R.E.H.M. Smits. (2006). "Tailoring Constructive Technology Assessment for Emerging Technologies." Proceedings of PATH Conference, 4-7 June 2006, Edinburgh.

Van Merkerk, R.O. and R.E.H.M. Smits. (forthcoming 2008). "Tailoring CTA for emerging technologies." Technological Forecasting and Social Change. Accepted for publication.