Synthetic Biology as Technoscience and the EEE Concept of Responsibility

Armin Grunwald

Abstract Two fields of reflection on synthetic biology are related to each other: the debate on the understanding of the specific scientific character of synthetic biology on the one hand with reference to the notion of technosciences, and the debate on Responsible Research and Innovation on the other. The target is asking for the consequences and implications of classifying synthetic biology as a technoscience which implies blurring the traditional distinction between basic and applied sciences—for attributing and distributing responsibility. To this end, the EEE model of responsibility will be introduced (empirical, ethical, epistemological). Building on this concept the specific responsibility constellation in the field of synthetic biology will be analysed. Concluding, the necessities of conceptualising ethics as an accompanying reflection on the scientific and technological advances including the consideration of their relationship to the governance of science within the democratic system are taken under consideration.

1 Introduction and Overview

In this chapter I would like to relate two fields of reflection on synthetic biology to each other: the debate on the *understanding* of the specific scientific character of synthetic biology on the one hand with reference to the notion of *technosciences* (Kollek and Döring 2012), and the debate on *Responsible Research and Innovation* (Grunwald 2011; von Schomberg 2012) on the other. The target is asking for the consequences and implications of classifying synthetic biology as

A. Grunwald (✉)
Institute for Technology Assessment and Systems Analysis (ITAS),
Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
e-mail: Armin.grunwald@kit.edu

B. Giese et al. (eds.), *Synthetic Biology*, Risk Engineering,
DOI 10.1007/978-3-319-02783-8_13

technoscience—which implies blurring the traditional distinction between basic and applied sciences—for attributing and distributing *responsibility*.

Synthetic biology is confronted with high expectations for innovation, primarily in the fields of energy, health, and sustainable development. The knowledge gathered by molecular biology, nanotechnology, biotechnology and information technology shall be combined to implement new functions in living systems by modifying bio-molecules or the design of cells, or by designing artificial cells and, perhaps, complete organisms. Therefore, the *convergence* of different fields of science and technology is crucial to this approach (Roco and Bainbridge 2002).

The traditional self-understanding of biology as natural science aiming at *understanding* processes of life is challenged by synthetic biology (Ball 2005) which shifts its target to *redesigning* life or *newly creating* living entities far beyond the understanding of how life works. This shift transforms biology, on the one hand, into an engineering science (de Vriend 2006), while it simultaneously remains, on the other, a cognition-oriented science belonging to the field of "new and emerging sciences and technologies" (NEST). This two-fold structure of synthetic biology prevents classifying it either as applied or as basic science and allows for referring to the ongoing debate on *technosciences* (see Sect. 2).

The postulates of 'responsible development' in scientific-technological advancement, and of 'responsible innovation' in the field of new products, services and systems have been discussed for some years now with increasing intensity (von Schomberg 2012; Grunwald 2011). Responsible innovation adds explicit ethical reflection to shaping technology and innovation, and involves normative questions of responsibility and their backing in ethical theory (Grunwald 2012a). Beyond ethical reasoning, any reflection on NEST developments must necessarily involve epistemological consideration of the status of the prospective knowledge on developments under consideration and on the uncertainties involved. Furthermore, responsible research, development and innovation also have to deal with *empirical* issues of power distribution, of the involvement of stakeholders and users, of organising governance and communication processes, etc. Therefore, the concept of responsible development and innovation has to integrate ethical, epistemological, and empirical issues (EEE).

In this chapter, I will explore the consequences of the classification of synthetic biology as technoscience for the responsibility debate and the respective governance. To this end, I will first briefly explain the classification of synthetic biology as technoscience (Sect. 2) and introduce the EEE model of responsibility (Sect. 3). Building on these argumentations I will then look for the specific responsibility constellation in the field of synthetic biology referring to the notion of technoscience which results in a differentiated picture of the distribution of responsibility (Sect. 4). Concluding, I will point to the necessities of conceptualising ethics as an accompanying reflection on scientific and technological advances, including the consideration of their relationship to the governance of science within the democratic system (Sect. 5).

2 Synthetic Biology as Technoscience[1]

The biological self-concept aiming at an *understanding* of life processes based on traditional natural science is reframed in synthetic biology. Synthetic biology no longer is satisfied with investigating life which already exists but aims at a redesigning or even reinventing nature. A turn towards artificial forms of life is characteristic of all definitions whether created by designing anew, or redesigning existing life (Grunwald 2012a). The targeted design of cells requires ample understanding of all essential sub-cellular processes and interaction. However, the current body of knowledge is still far from sufficient. In the ongoing research activities of synthetic biology, the main aim therefore is to gain insight into structures and functions of natural systems which is closer to analytical science rather than engineering. By moving more and more towards engineering, design and creation, synthetic biology will develop more towards an engineering science (de Vriend 2006) with a duality of cognition and design (Banse et al. 2006).

Living systems are examined within the context of their technical function, and cells are interpreted as machines—consisting of components analogous to the components of a machine which have to co-operate in order to fulfil the overall function. For example, proteins and messenger molecules are understood as such components that can be duplicated, altered or newly compounded in synthetic biology. A "modularisation of life" is thereby made as well as an attempt to identify and standardise the individual components of life processes. In the tradition of technical standardisation, gene sequences are saved as models for various cellular components of machines. Following design principles of mechanical and electrical engineering, the components of living systems shall be put together according to a building plan in order to obtain a functioning whole. The recombination of different standardised bio-modules (sometimes called 'bio-bricks') allows for the design and creation of different living systems. With the growing collection of modules, out of which engineering can develop new ideas for products and systems, the number of possibilities grows exponentially. The engineering approach of synthetic biology can easily be seen by looking at the language used: this is classical language of engineering, especially of mechanical and electrical engineering as well as that of informatics. The area of life under consideration is thus modelled as an ensemble of machines:

> Although it can be argued that synthetic biology is nothing more than a logical extension of the reductionist approach that dominated biology during the second half of the twentieth century, the use of engineering language, and the practical approach of creating standardised cells and components like in an electrical circuitry suggests a paradigm shift. Biology is no longer considered 'nature at work', but becomes an engineering discipline (de Vriend 2006, p. 26).

[1] This section builds on earlier work of the author on the understanding of synthetic biology. In particular it extends to what has been published by Grunwald (2012a, b).

Examples of such changes in the language are: haemoglobin as vehicle, synthesis of adenosine-triphosphate as generator, nucleosome as digital database, polymerase as copy machine, or membranes as electrical fences (Grunwald 2012a). The language used by synthetic biology proves it to be epistemologically bound to a technical view of the world and technical intervention.

This is one side of the coin—however, there is also another. The scientific-technical development of the past decades has made the traditional border between technology and the sciences more permeable. One aspect of this is that technical interventions in the sphere of molecular biology have led to genetic engineering, which can be understood as a classical (natural) science but as technology as well. This observation led to the notion of *technoscience* (Latour 1995) describing recent developments in science and engineering as overcoming traditional borders. This diagnosis also applies to synthetic biology (Kollek and Döring 2012). In particular, it has consequences for the assignment of responsibility because the traditional border between technology-oriented applied science and cognition-oriented basic research is disappearing While traditionally basic research is confronted with expectations to take over responsibility only for the research process itself but not for possible later out-comes in terms of technology, the situation in applied science is different. Because its target is to develop knowledge to be used and applied, e.g. in technology, the reflection on responsibility issues related to those applications intimately belongs to applied research. Following the diagnosis of synthetic biology being a technoscience belonging to both areas or none of them—gives rise to the question of distribution of responsibilities specifically regarding this situation.

3 The EEE Concept of Responsibility[2]

The notion of responsibility assumes a—more or less—clear meaning and idea of this responsibility. However, this might be misleading, at least in the field of science and technology. Concerns have been expressed (Beck 1986) that responsibility would be an empty phrase without reliable meaning; that it would merely show the character of an appeal and of moralisation of conflicts, that it would not be able to contribute to problem-solving, that the uncertainty of knowledge about future consequences of today's decisions would render any considerations of that responsibility ridiculous. Thus the complex governance of modern science and technology involving many actors would lead to the effect of "thinning" responsibility.

[2] **This section develops further clarifications on the notion of responsibility given in Grunwald (2012a, c). The notion of an EEE concept builds on earlier work but is presented here for the first time in this form.**

These concerns require a more in-depth look at the concept of responsibility (Lenk 1992; Grunwald 1999). Responsibility is neither a quasi-ontological predicate nor a natural object, but the result of a social process, namely of an act of attribution, whether actors attribute responsibility to themselves, or if the attribution of responsibility is made by others. The process of attributing responsibility takes place relative to *rules of attribution* (Jonas 1979). Assignments and attributions of responsibility take place in concrete social and political spaces. These involve and affect concrete actors in concrete constellations—therefore putting emphasis on the socio-political dimension of responsibility (Grunwald 2012c) which can be investigated empirically by the social and political sciences. Thus, attributions and assignments of responsibility, *ex post* as well as *ex ante*, are part of life-world practices and of the governance of the respective area. Often those processes are implicit and rely on established and recognized practices; in cases of ambiguity, indifference or conflict, however, they must be made explicit.

The notion of responsibility is often characterised by changes and alterations to sentence structure and word placement which are used to validate intention in the con-text of responsibility (Lenk 1992). A four-place reconstruction generally seems to be suitable for discussing issues of responsibility in scientific and technical progress:

- *someone* (an actor, e.g. a synthetic biologist) assumes responsibility or is made responsible (responsibility is assigned to her/him) for
- *something* (such as the results of actions or decisions, e.g. for avoiding biosafety or bio-security problems) relative to
- *rules and criteria* (in general the normative framework valid in the respective situation, see Grunwald 2012a, Chap. 3, e.g. rules of responsible behaviour given in a Code of Conduct) and relative to the
- *knowledge available* (knowledge about the impacts and consequences of the action or decision under consideration, including also meta-knowledge about the epistemological status of that knowledge and uncertainties involved).

Though the first two places are, in a sense, trivial in order to make sense of the word "responsible," they indicate the fundamental social context of assigning responsibility which inevitably is a process among social actors. The third and fourth places open up essential dimensions of responsibility: the dimension of rules and criteria comprise principles: norms and values being decisive for the judgment of whether a specific action or decision is regarded responsible or not . This constitutes the *ethical dimension* of responsibility. The knowledge available and its quality, including all the uncertainties, form its *epistemic dimension*. My thesis is that relevant questions arise in all of these three dimensions and that all three dimensions must be considered in prospective debates over scientific responsibility of synthetic biology and beyond, in new and emerging science and technologies NEST (Grunwald 2012c):

- The *empirical dimension* of responsibility seriously considers that the attribution of responsibility is an act of specific actors which affects others. It refers to the basic social constellation of assignment processes. Assignment of responsibility must, on the one hand, take into account the possibilities of actors to influence their actions and decisions in their respective fields. Issues of accountability and power must be taken into account. On the other, attributing responsibilities has an impact on the governance of that field. Shaping that *governance* is the ultimate goal of debating issues of assigning and distributing responsibility *ex ante*. Relevant questions are: How are capabilities, influence, and power to act, as well as decisions taken in the field, considered? Which social groups are affected, and should they help determine the distribution of responsibility? Do the questions under consideration concern issues to be debated at the "polls" or can they be delegated to groups or subsystems? What consequences would a particular distribution of responsibility have for the governance of the respective field, and would it be in favour of desired developments?

- The *ethical dimension* of responsibility is reached when the question is posed for criteria and rules for judging actions and decisions under consideration as responsible or irresponsible, or for helping to find out how actions and decisions could be designed to be (more) responsible. Insofar as normative uncertainties arise (Grunwald 2012a), e.g. because of ambiguity or moral conflicts, ethical reflection on these rules and their justifiability is needed. Relevant questions are: What criteria allow distinguishing between responsible and irresponsible actions and decisions? Is there consensus or controversy on these criteria among the relevant actors? Can the actions and decisions in question (e.g., about the scientific agenda or about containment measures to prevent bio-safety problems) be regarded as responsible with respect to the rules and criteria?
- The *epistemic* dimension asks for the knowledge about the subject of responsibility and its epistemological status and quality. This is a particularly relevant issue in debates on scientific responsibility because, frequently, statements about the impact and consequences of science and new technology show a high degree of uncertainty. The comment that nothing else comes from "mere possibility arguments" (Hansson 2006) is an indication that, in debates over responsibility, it is essential that the status of the available knowledge about the accountable future is determined and is critically reflected upon from an epistemological point of view (Grunwald 2012a, Chap. 10). Relevant questions are: What is really known about prospective subjects of responsibility? What could be learned through more research, and which uncertainties are pertinent? How can different uncertainties be qualified and compared to each other? And what is at stake if worse comes to worst?

Debates over responsibility in technology and science frequently focus exclusively on the *ethics* of responsibility (Durbin 1987). However, regarding the analysis given so far, this is only part of the field and neglects the empirical as well as the epistemological dimension of responsibility. It seems that the familiar criticisms towards responsibility reflections (see above) of being simply appellative, of epistemological blindness, and of being politically naïve, are related to narrowing responsibility to its ethical dimension. The brief theoretical analysis above showed that the issue of responsibility is not only one of abstract ethical judgment but necessarily includes issues of concrete social contexts. Governance factors must be treated empirically as well as the issue of the epistemological quality of the knowledge available. Meeting those criticisms and making the notion of responsibility work is claimed to be possible by considering the EEE dimensions of responsibility together.

4 Synthetic Biology: The Responsibility Constellation

In this section I would like to briefly unfold the responsibility constellation specific to the field of synthetic biology by referring to ongoing debates on responsibility in this area (Grunwald 2012a, c). As a first step, an impression which might be the subject of responsibility in current synthetic biology should be given.

4.1 Synthetic Biology: Subjects of Responsibility

A first task to make the notion of responsibility more tangible is to clarify those issues of responsibility we are talking about, or *should* talk about in the field of synthetic biology. This seems to be a prerequisite to any substantial responsibility debate avoiding a mere rhetorical use of this term. Possible subjects of responsibility debates and assignments in synthetic biology could be, on the one hand, future developments resulting from current research. Most people would think about those issues first. On the other, however, there are also issues of current research itself. The following list of elements could be understood as possible subjects of responsibility in synthetic biology, and shall give an impression of what the ethics of responsibility could include in this field; though it cannot claim to be comprehensive:

- the *goals and objectives, even visions* of current research in synthetic biology: these could be confronted with questions of whether they are responsible or could be made responsible by modifications
- envisioned, projected or even merely imagined *products* of synthetic biology in terms of materials, technological systems and services based on knowledge provided by synthetic biology. These might include highly welcome outcomes, such as new and better drugs; but also problematic and unwanted developments such as biological weapons
- possible future *knowledge* of synthetic biology which could influence not only our engineering capabilities, but also our understanding of life and of ourselves
- consequences for *actor constellations and power distribution*: how could developments emerging out of synthetic biology influence power constellations and influence, e.g. in the related economies?

- the *science system*: we might ask for its ability and willingness to develop and establish reflective accompanying procedures to monitor and assess the ongoing research in synthetic biology, with respect to social, political, ethical, cultural and other dimensions: are the preconditions of taking over responsibility fulfilled by current structures and institutions in science?
- *research funding*: funding policies clearly influence the advance of synthetic biology. Therefore, the direction and the themes of research funding in synthetic biology are subject to possible responsibility debates. In particular, facing scarcity of resources, the current priority-setting in the allocation of financial and personal resources to synthetic biology research might be considered more or less responsible regarding other, perhaps more urgent, fields of research
- the *legal and political framework* which would influence the further advance and direction of research in synthetic biology (e.g. regulation or incentive programmes)
- *current research*: it might be assessed with respect to responsibility criteria, e.g. precautionary measures, safety of the researchers, observance of animal protection rules in case of animal experiments, etc.
- providing knowledge-based and normatively reflected *policy advice* could also be seen as a subject of responsibility in this field
- increasing society's *awareness* with regard to advances of synthetic biology, and supporting an open dialogue about the further direction of research might also be a subject of responsibility assignment.

This list shows a high variety of different types of subjects of responsibility. Partially, they are directly linked with specific actors; partially it is not clear to whom which aspect of responsibility should be assigned. The variety of subjects, in combination with the variety of actors possibly made responsible, opens up a broad field of debate about legitimate, adequate, effective and efficient distributions of responsibility in our field of consideration. Obviously, developing a comprehensive responsibility theory of synthetic biology would go far beyond the scope of this essay. Therefore, I will restrict myself to a few fields in the remainder of this chapter.

4.2 Dimensions of Responsibility

The list presented above clearly illustrates that the empirical constellation is heterogeneous and will involve different types of actors, reaching from the biologists themselves to regulators, funding agencies and policymakers, up to civic organisations and private citizens. Assignment of responsibility must, on the one hand, be based on normative pictures of how society should work and how science should serve society, e.g. on ideas of a deliberative democracy or on ambitious concepts of modern governance of science in society (Siune et al. 2009). On the other hand, empirical investigation of the mutual relations of actors, and their capabilities to influence specific developments, must also be considered. Responsibility assignments and resulting distributions are a complex mixture in regard to combination of normative and empirical insight. For the field of synthetic biology it would be valuable to consider this constellation in more depth (see few remarks in Sect. 5).

Defining sensible subjects for responsibility debates strongly depends on the epistemological dimension. A fundamental challenge to responsibility debates about far-ranging future developments in science and technology is the inevitably high degree to which material other than knowledge is involved. Future scenarios of the development of synthetic biology, of its useful outcome to society, and of the consequences of the real-world use of those products, systems and services are highly uncertain. In the context of responsibility, the question arises whether future products, systems and services based on synthetic biology's knowledge could be sensible subjects to responsibility assignments today at all. The following quote taken from a visionary paper on synthetic biology supports serious doubt about this:

> Fifty years from now, synthetic biology will be as pervasive and transformative as is electronics today. And as with that technology, the applications and impacts are impossible to predict in the field's nascent stages. Nevertheless, the decisions we make now will have enormous impact on the shape of this future (Ilulissat-Statement 2008, p. 2).

These statements express (a) that the authors expect synthetic biology will lead to deep-ranging and revolutionary changes, (b) that our decisions today will have high impact on future development, but (c) we have no idea what that impact will be. If this were true, there would be no chance of assigning responsibility; even speaking about responsibility would no longer have a valid purpose. Any ethics of responsibility would be obsolete because of a missing subject (Bechmann 1993): our complete lack of knowledge about future developments, and their relation to today's decision-making. This would make reflections on the desirability or acceptability of those future developments impossible; or would make completely arbitrary any conclusions on today's attribution of responsibility. Analogously, the critics of speculative nano-ethics (Nordmann 2007; Roache 2008; Grunwald 2012a, Chap. 10) have pointed out that no legitimate conclusions could be drawn if the ethical reflection addresses merely speculative and arbitrary futures ("mere possibility arguments," cf. (Hansson 2006)). The epistemological task is to examine both the cognitive and evaluative content of the prospective knowledge used in responsibility debates to describe the subject of responsibility as clearly as possible. In this context the vision assessment approach has been proposed in order to uncover the epistemological and ethical grounding of NEST visions (Grunwald 2009). It aims at uncovering the epistemological and normative ingredients of future statements in order to permit more well- informed and more rational formation of opinion, assessment and decision making on the attribution of responsibilities.

These considerations show that debates on responsibility in synthetic biology should not rely on mere speculative futures as subjects of inquiry. The difference between technoscience and traditional engineering sciences, is rooted in its character (see above), in that reliable images of future products and technological systems are difficult to achieve. As a consequence, responsibility considerations in synthetic biology today relate mainly to current research rather than to future products, their consequences and expected, but epistemologically unqualifiable, innovations and risks (IRGC 2009, p. 7). This diagnosis focuses on the responsibility of scientists as individual professionals and that of science as a system to current research as a main subject of responsibility.

It is thus not surprising that the well-known conference held in Asilomar in 1975 is repeatedly cited as a model for future steps in the field of synthetic biology (Boldt and Müller 2008). That conference took place under circumstances in which a global spirit of optimism regarding genetic engineering could be observed, while at the same time the first signs of public criticism and demands for state regulation could be heard. The outcome of the conference was that genetic engineers committed themselves to taking responsibility and exercising caution. Interpretations of the conference are controversial (Grunwald 2012c). On the one hand, it was praised as a positive example of science proactively assuming responsibility; on the other hand, it mainly served the purpose of pre-empting state regulation so that genetic engineers could carry on conducting their research with as little interference as possible (de Vriend 2006). The recent controversy on the role of self-regulation in synthetic biology (Maurer et al. 2006) versus the claim of civic organisations involved in the governance of that field (Grunwald 2012a, Chap. 7) may be interpreted as a follow-up to the earlier controversy on the interpretation of Asilomar. This points to the same critical issue of determining the adequate relation between science's autonomy and society's claim of involvement in the governance of science (Siune et al. 2009). This issue makes clear that classifying synthetic biology as technoscience makes it more difficult to deal with the socio-political context of responsibility compared to the debates on basic and applied research. While science's autonomy is usually regarded with high value in basic research; society's voice and involvement in applied research is frequently welcomed. Thus the situation in synthetic biology seems to be ambiguous because it does not belong to only one type of research. Instead, a kind of "NEST-ethics" (NEST: new and emerging sciences and technologies) seems to be required (Swierstra and Rip 2007) which might be regarded as one of the predecessors of the idea of Responsible Research and Innovation (Grunwald 2011; von Schomberg 2012).

In view of the existing experience with genetically modified organisms and their regulation, and of the often speculative nature of reflections on the consequences of synthetic biology, it is not immediately clear what the *specific* challenges are that synthetic biology poses to the *ethical* dimension of responsibility considerations. The moral issues posed by synthetic biology resulting in challenges to responsibility can be classified according to the different normative frameworks and sets of rules that are affected: the question regarding how to deal with risks, normative uncertainties about the moral status of artificial living things, and the issue of human hubris or "playing God."

In view of the fact that, compared to traditional gene technology, synthetic biology leads to a further increase in the depth of man's interventions in living systems, and that the pace of innovation continues to increase, the precautionary principle will tend to become even stronger, in as much as we operate in the same normative framework (Paslack 2012). The responsibility of scientists will form a major issue in the run-up to *adequate* regulation. In particular, issues of bio-safety and bio-security are frequently discussed (de Vriend 2006). The ethical dimension touches questions such as: how safe is safe enough, what risk is acceptable according to which criteria, and is it legitimate to weigh expected benefits against the risks, or are there knock-out arguments morally forbidding cost/benefit comparisons? All these questions are well-known to many fields of risk ethics (Rescher 1983; Shrader-Frechette 1991) but must be answered anew in the particular context of synthetic biology.

The production of new living things or technically strongly modified ones by synthetic biology will raise the question of their moral status. With respect to its moral status—and various bioethical positions differ on this considerably—a difference in principle is made between the living and nonliving objects of ethical reflection, the question will be whether synthetically produced living things are also accorded this moral status. Assigning different moral statuses to such forms of "life" could lead to different answers on the questions of responsibility.

In synthetic biology, man moves from being a modifier of what is present to a creator of something new, at least according to the visions of some biologists:

> In fact, if synthetic biology as an activity of creation differs from genetic engineering as a manipulative approach, the Baconian *homo faber* will turn into a creator (Boldt and Müller 2008, p. 387).

In 2005 a high-level expert group on behalf of the European Commission called it likely that work to create new life forms will give rise to fears, especially that of synthetic biologists "playing God." Concerning responsibility issues the question could be (and is!) raised whether humans would run out of being able to act responsibly at all if they started "Playing God". However, this type of argument seems to be more an indicator of uneasiness with fast scientific advance rather than an ethical argument per se.

In summarising these thoughts and regarding the focus of this chapter on the consequences of classifying synthetic biology as a technoscience, it becomes clear that it is primarily the epistemological dimension of responsibility which makes a difference to traditional sciences. The combination of the "engineering" approach of synthetic biology with its openness to applications and its enabling character leads to a situation where the subject of responsibility should be seen more in the process of current research rather than in speculative future products. Taking over responsibility therefore means being responsible for current processes of research, defining the research agenda, determining objectives and goals and supporting current societal debates on synthetic biology instead of talking about responsible or irresponsible future outcomes of synthetic biology.

5 Concluding Remarks

The specific responsibility constellation of synthetic biology which is related with its character as technoscience is complex in particular because it includes, on the one hand, issues of current research in accordance with good scientific practice and established moral standards and, on the other, far-ranging but highly speculative visions and expectations. Responsibility always has to be assigned in a respectively present situation, with respect to present expectations and rules of assignment. Keeping this in mind will allow us to derive some orientation for related responsibility debates in the years to come.

5.1 Responsibility Today Facing Future Prospects

The increasing possibilities for the recombination of life "modules" such as those that are studied, duplicated and modified in synthetic biology (Sect. 2), make the possibility of "shaping technology" in the "strong understanding" (Grunwald and Hocke-Bergler 2010, p. 160) seem unrealistic. Even the promise of prospective impact research and the assessment thereof seem unrealistic. However, there is a whole spectrum of other possibilities of influencing the governance of synthetic biology by assigning responsibilities ("weak understanding" according to (Grunwald and Hocke-Bergler 2010, p. 160)). This opens up two types of options for shaping and influencing: (1) the design of current research and (2) the design of current debates on synthetic biology. Both options offer the opportunity to talk constructively and substantially about responsibility subjects and constellations. It is noteworthy in this context that both draw from the current situation, not from issues of a speculative future society in which synthetic biology could or would have major impact:

1. Taking the widespread impossibility of prospective impact research seriously can focus promising design on the *current research* of synthetic biology. This occurs factually and demands no prospective analysis, but can be confronted, for example, with the well-known concerns of "bio-safety" and of "bio-security". Or the possibilities and limitations of a "do-it-yourself" technology could be considered. Along the way, the next research subjects can also be debated over along with decision processes and criteria. Perspectives and experiences of responsible research and innovation can add to the inter- and trans-disciplinary insight and design process.
2. Likewise, without a glance into the future, we can debate on visions for the future and possibly also on other "futures" of synthetic biology, since these are voiced *today* and determine a good portion of the social debate, which ranges from expectations of salvation from the looming global energy crisis to the fear of "playing God." Design extends here to contributions to the social debate—with possible, but not definite consequences for the further pathway

of synthetic biology. Design is meant here as the shaping of the social context of debates over synthetic biology so that "responsible innovation" and "responsible research and development" are possible. The significance of conceptual, heuristic and hermeneutic questions grows. In the, often times, speculative estimation of the development potential of synthetic biology, it is important to clarify what is at stake in all these considerations. A "hermeneutic technology assessment" (Grunwald 2012b) would on the one hand clarify current debates as well as prepare for up and coming debates in which it could then, for example, be about concrete technology design. Within this context, a "vision assessment" (Grunwald 2009) would study the cognitive as well as evaluative content of tech-based visions and their impact. They would be the fundamental building blocks of a cognitively informed and normatively oriented dialogue—a dialogue, for example, between experts and the public; or between synthetic biology, ethics, research funding, the public and regulation. In the assignment of responsibility in synthetic biology, the realisation and support of such a dialogue is, without a doubt, of major importance—and it would affect many actors such as biologists, journalists, policy-makers, civic organisations and even private citizens.

5.2 Responsibility Reflection as Concomitant Activity

Since the very beginning of ethical reflection on science and technology, a discussion has been ongoing about what the appropriate relation in time is between scientific-technological advance and reflection on responsibility. The rapid pace of innovation in technology has led to concerns that ethical deliberations often come too late (Moor and Weckert 2004). Reflection then could, at best, only act as a repair service for problems which are already out in the open. In contrast, the "ethics first" model postulates comprehensive ethical reflection on the possible impact *in advance* of the technological development. It is in principle possible for responsibility ethics to reflect and discuss the normative implications of items long before their entry into the market because scientific and technical knowledge will make early ideas available about the items, their capabilities, and their societal impacts (both risks as well as chances). However, responsibility reflection in the "ethics first" model has to deal with the situation that the relevant knowledge about technology and its consequences is uncertain and preliminary—the epistemological dimension (see Sect. 3 in this chapter) will restrict its feasibility.

Responsibility reflections and assignments made during the very early stages of a development in synthetic biology could provide orientation for shaping the relevant *process* of scientific advance and technological development (for example, with regard to the question of equity, or of the risk of misuse). As the knowledge of synthetic biology grows, and with it the development of products and services, it will then be possible to continuously concretize the—initially abstract—estimates and orientations on the basis of newly acquired knowledge; and finally, to carry out an ethically reflected technology assessment with specific assignments of responsibility. In this sense, responsibility reflection in all three dimensions is an ongoing process accompanying scientific and technological advances. In the course of this reflection its subjects will change (see Sect. 4.1). As well, as new actors will appear in the range of possible persons and groups to whom responsibility may be assigned.

Currently, there is the chance and also the time for concomitant reflection, as well as the opportunity to integrate the results of our reflection into the scientific agenda and design of technology, thereby contributing to the further development of this promising field of advanced science and technology (similar to what (Moor and Weckert 2004) expected for accompanying reflection on nanotechnology). In view of the still visionary nature of the many prospects in synthetic biology, and of the very long time spans within which the realization of certain milestones can be expected, the chances are good that responsibility reflection and the social discussion will not come too late. On the contrary, they can accompany scientific-technical progress critically and, in particular, can help influence science's agenda by providing ethically reflected advice, without sharing naïve and unrealistic expectations of shaping technology in a "strong understanding" (see above).

5.3 Responsibility Reflection Must Be Embedded in Democracy

A frequently mentioned question is *which* responsibility *should* be attributed to scientists in the field of synthetic biology. The answers often demand that scientists are supposed to reflect on the consequences of their actions in a manner that constitutes a complete assessment of the technology. This is often done with the implicit hope that scientists—if they assessed the results of their own actions comprehensively—would make judgments in a responsible manner and act accordingly, and that negative and unintended consequences could be largely, or even completely, avoided (cf. in this direction also (Presidential-Commission 2010, p. 13).

However, there are obstacles and limitations to be observed. There is a need for *social* consultation, deliberation and evaluation (on state sponsorship of research, on government policy toward science and technology, and on regulating the context of technical development by means of legislation, judicial decisions, or economic measures) extending beyond the capability of individual scientists. Relevant actors, stakeholders and citizens must be involved due to a modern understanding of the governance of science (Siune et al. 2009), even if this makes the empirical, socio-political dimension of responsibility much more complicated. Neither individual scientists nor disciplines such as synthetic biology or even philosophy can address these questions alone with any expectation of success. Scientists in synthetic biology are experts in their fields, but not in the possible social consequences of their actions; and not for the question of the acceptability of uncertain risks and dealing with them.

When it comes to assigning responsibility, a broader approach is therefore necessary; one that does justice to the realities of an extensive division of labour, citizens' claims for democratic participation, and the specific *regularities in the sciences*. Responsibility must be shared among science, politics, authorities, and the democratic public. In particular, the need for transparency in the sciences, politics and the public sector, demands strict and democratic deliberation on the agenda of synthetic biology (Habermas 1968).

To take demands seriously for participation by a democratic public as well as for decision-making processes that are politically legitimate, however, does not free synthetic biology of all responsibility. These fields are justifiably expected to provide transparent information to the public. This is particularly true for potentially worrying developments. Faced by such developments, society might initiate ethical reflection or technology assessment in order to systematically analyse and evaluate the challenges ahead. The specific responsibility of scientists to provide information at an early stage lies in the fact that they possess particular cognitive competence in their own area, and are the first to have certain information. This responsibility also extends to participation in interdisciplinary and social dialogues, as well as political counselling. Science, including synthetic biology, is part of society, not something external to it. The expectation of science is that it reflects on its role in society and actively accepts this role in its many aspects.

Summarizing these thoughts briefly shows that it is essential to consider the ethical, the epistemic, and the empirical dimension of responsibility altogether, rather than restricting the debate to one or two of them. Taking this result seriously implies that responsibility issues should not be dealt with by ethicists alone, but by interdisciplinary teams involving also philosophers of science, political and social scientists, governance researchers and the biologists themselves—in cooperation with independent actors outside the field of science.

References

Ball, P. (2005). Synthetic biology for nanotechnology. *Nanotechnology, 16*(1), R1–R8. doi:10.1088/0957-4484/16/1/R01.

Banse, G., Grunwald, A., König, W., & Ropohl, G. (2006). *Erkennen und Gestalten. Eine Theorie der Technikwissenschaften*. Berlin: edition sigma.

Bechmann, G. (1993). Ethische Grenzen der Technik oder technische Grenzen der Ethik? *Geschichte und Gegenwart Vierteljahreshefte für Zeitgeschichte, Gesellschaftsanalyse und politische Bildung, 12*, 213–225.

Beck, U. (1986). *Risikogesellschaft. Auf dem Weg in eine andere Moderne*. Frankfurt am Main: Suhrkamp.

Boldt, J., & Müller, O. (2008). Newtons of the leaves of grass. *Nature Biotechnology, 26*(4), 387–389. doi:10.1038/nbt0408-387.

de Vriend, H. (2006). *Constructing life: Early social reflections on the emerging field of synthetic biology*. Den Haag: Rathenau Instituut. Working Document 97.

Durbin, P. (1987). *Technology and responsibility*. Dordrecht: Reidel Publishing.

Grunwald, A. (1999). Verantwortungsbegriff und Verantwortungsethik. In A. Grunwald (Ed.), *Rationale Technikfolgenbeurteilung* (pp. 172–195). Berlin: Springer.

Grunwald, A. (2009). Vision assessment supporting the governance of knowledge–the case of futuristic nanotechnology. In G. Bechmann, V. Gorokhov, & N. Stehr (Eds.), *The social integration of science. Institutional and epistemological aspects of the transformation of knowledge in modern society* (pp. 147–170). Berlin: Edition sigma.

Grunwald, A. (2011). Responsible innovation: Bringing together technology assessment, applied ethics, and STS research. *Enterprise and Work Innovation Studies, 7*, 9–31.

Grunwald, A. (2012a). *Responsible nanobiotechnology. Philosophy and ethics*. Singapore: Pan Stanford Publ.

Grunwald, A. (2012b). Synthetische Biologie als Naturwissenschaft mit technischer Ausrichtung. Plädoyer für eine Hermeneutische Technikfolgenabschätzung. *Technikfolgenabschätzung—Theorie und Praxis, 21*(2), 10–15.

Grunwald, A. (2012c). Synthetic biology: moral, epistemic and political dimensions of responsibility. In R. Paslack, J. S. Ach, B. Luettenberg, & K. Weltring (Eds.), *Proceed with caution?—Concept and application of the precautionary principle in nanobiotechnology* (pp. 243–259). Münster: LIT Verlag.

Grunwald, A., & Hocke-Bergler, P. (2010). The risk debate on nanoparticles: contribution to a normalisation of the science/society relationship? In M. Kaiser, M. Kurath, S. Maasen, & C. Rehmann-Sutter (Eds.), *Governing future technologies. Nanotechnology and the rise of an assessment regime* (pp. 157–177). Dordrecht: Springer

Habermas, J. (1968). Verwissenschaftlichte Politik und öffentliche Meinung. In J. R. Habermas (Ed.), *Technik und Wissenschaft als Ideologie* (pp. 120–145). Frankfurt: Suhrkamp.

Hansson, S. O. (2006). Great uncertainty about small things. In J. Schummer & D. Baird (Eds.), *Nanotechnology challenges—implications for philosophy, ethics and society* (pp. 315–325). Singapore: World Scientific Publishing.

Ilulissat-Statement. (2008). *Synthesizing the future. A vision for the convergence of synthetic biology and nanotechnology. Views that emerged from the Kavli futures symposium. The merging of bio and nano: Towards cyborg cells*, Ilulissat, Greenland, 11–15 June 2007.

International Risk Governance Council (IRGC). (2009). Risk governance of synthetic biology. Genf.

Jonas, H. (1979). *Das Prinzip Verantwortung: Versuch einer Ethik für die technologische Zivilisation.* Frankfurt am Main.

Kollek, R., & Döring, M. (2012). Science- und/oder Technology-Assessment? TA-Implikationen der komplexen Beziehung zwischen Wissenschaft und Technik. Einführung in den Schwerpunkt. *Technikfolgenabschätzung—Theorie und Praxis, 21*(2), 4–9.

Latour, B. (1995). *Wir sind nie modern gewesen. Versuch einer symmetrischen Anthropologie*. Berlin: Akademie Verlag.

Lenk, H. (1992). *Zwischen Wissenschaft und Ethik*. Frankfurt: Suhrkamp.

Maurer, S., Lucas, K. & Terrel, S. (2006). *From understanding to action: Community based options for improving safety and security in synthetic biology.* Berkeley: University of California. Download: http://syntheticbiology.org/SB2Declaration.html

Moor, J., & Weckert, J. (2004). Nanoethics: Assessing the nanoscale from an ethical point of view. In D. Baird, A. Nordmann, & J. Schummer (Eds.), *Discovering the Nanoscale* (pp. 301–310). Amsterdam: Ios Pr.

Nordmann, A. (2007). If and then: A critique of speculative nanoethics. *Nanoethics, 1*(1), 31–46.

Paslack, R. (2012). *Proceed with caution?—concept and application of the precautionary principle in nanobiotechnology*. Münster: LIT Verlag.

Presidential-Commission. (2010). In P. Commission (Ed.), *Recommendations on synthetic biology*. Washington.

Rescher, N. (1983). *Risk. A philosophical introduction to the theory of risk evaluation and management*. Lanham: University Press of America.

Roache, R. (2008). Ethics, speculation, and values. *Nanoethics, 2*(3), 317–327.

Roco, M. C. & Bainbridge, W. S. (2002). Converging technologies for improving human performance: Integrating from the nanoscale. *Journal of Nanoparticle Research*, *4*. Download: http://www.ingentaconnect.com/content/klu/nano/2002/00000004/00000004/05099721

Shrader-Frechette, K. S. (1991). *Risk and rationality. Philosophical foundations for populist reforms*. Berkeley: University of California.

Siune, K., Markus, E., Calloni, M., Felt, U., Gorski, A., Grunwald, A., et al. (2009). *Challenging futures of science in society. Report of the MASIS expert group*. Brussels: European Commission.

Swierstra, T., & Rip, A. (2007). Nano-ethics as NEST-ethics: Patterns of moral argumentation about new and emerging science and technology. *Nanoethics, 1*(1), 3–20.

von Schomberg, R. (2012). Prospects for technology assessment in the 21st century: The quest for the “right” impacts of science and technology. An outlook towards a framework for responsible research and innovation. In M. Dusseldorp & R. Beecroft (Eds.), *Technikfolgen abschätzen lehren*. Opladen: Springer.