

# Philosophy of Interdisciplinarity

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**Jan Cornelius Schmidt**

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## Chapter 8

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### Technology and the future

Advancing prospective technology assessment

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# 8 Technology and the future

## Advancing prospective technology assessment

### On the continuous production of pressing problems

As has been shown, we find under the umbrella of the most far-reaching, problem-oriented type of interdisciplinarity a dialectic of two main orientations: an *instrumentalist-strategic* and a *critical-reflexive* one. However, the critical-reflexive orientation of interdisciplinarity is not to be seen as an antagonistic approach but rather as one that is complementary to the instrumentalist account. To further clarify the relationship between the two orientations, we will look at a prominent field of interdisciplinary inquiry that deals with what is referred to as “real-world” problems.

Many grand challenges that societies are facing worldwide are related to environmental problems, including the highly debated sustainability and global change issues. Most of the problems have been induced by the widespread and intensive use of artefacts and technology in the global capitalist economy (Euler 1999). Since the 1960s in the US and from the late 1980s in Europe, a new interdisciplinary approach has become established and institutionalized to deal with these problems: Technology Assessment (TA). In TA projects, scholars from different disciplines such as engineering, natural and social sciences, and the humanities work together in multidisciplinary teams (Grunwald 2019). The overall objective of TA is to generate knowledge for political decision-making. This kind of policy consultancy aims to foster and facilitate the societal and political shaping of technoscientific advancement by politicians and legislation. TA counteracts the pessimistic commonplace perception of an internal momentum in the evolution of technology that is typically called “technological determinism.” In TA, the advancement of technical systems is seen as being anti-deterministic; the basic purpose of TA is to identify and then to assess new technologies as early as possible—in principle in their *statu nascendi*—in order to shape their further development.

In spite of the impressive history of TA spanning more than 40 years, various concerns and points of critique have been articulated. Petra Gehring (2006), for instance, raises objections against TA and also against applied ethics in maintaining: Both (TA and applied ethics) are blind and tame because they fail to tackle the underlying self-propelling knowledge

dynamics of the hybrid sociotechno-economic system and its power mechanism; therefore, they are not capable of addressing the production of technoscientific problems; they are neither fundamental enough nor far-reaching enough to change the issues we face today. The objection does not only assert that TA comes too late in the day; the criticism levelled at the lateness of TA—interlaced with scepticism about the instrumentalist approaches in many variants of TA—pursues a further intention: to urge TA to address the underlying technoscientific knowledge dynamics with its inherent tendency to continuously produce new problems. That is to say, on a more fundamental level, TA is not critical enough since it fails to consider the background of the issues we face today.

Taking up this line of argumentation, I will expand the concept of TA in order to foster deeper and broader critical reflection reaching right down to the point where the problems are being created. With that goal in mind, I will sketch a critical-reflexive interdisciplinary approach in TA. Such an approach can be called *Prospective Technology Assessment* or, more precisely, *Prospective Sciences and Knowledge Assessment* (ProTA) (Liebert and Schmidt 2010). ProTA aims to facilitate self-awareness, self-reflection, and self-criticism—briefly, self-enlightenment—in the sciences and engineering, in the academy and the research system, and furthermore in science politics and society at large. An endeavour of this kind, which intends to hinder the creation of new problems, matches perfectly with the concept of critical-reflexive interdisciplinarity proposed in this book.

In general, ProTA can be regarded as being paradigmatic for the *Philosophy of Interdisciplinarity* since it is a normative-descriptive hybrid at the interface between science, society, and politics. In this sense, TA is not only interdisciplinary but also necessarily philosophic in nature.

## Extending the scope

ProTA covers a broader and deeper scope than established TA concepts in that the former focuses on specific and somewhat under-exposed aspects.<sup>1</sup> Notably, ProTA incorporates a critical-reflexive understanding of interdisciplinarity. Its point of departure is the recognition of the inherent ambivalence of technoscientific knowledge production that is constitutive for science-based technologies in late-modern societies. Referring to this ambivalence, the orientation framework of ProTA has four components or dimensions, which will now be briefly outlined below. In addition, I will present a diagnosis of the current technoscientific situation.

ProTA considers, *first* of all, the dimension of time in the emergence of a novel kind of technology or, to be more precise, of technoscientific knowledge: it favours an *early-stage orientation*. Because we live in a science-based knowledge society, the high relevance of scientific knowledge at the beginning and throughout the entire innovation process cannot be disputed. Science and research are deemed to be the fundamental driving forces determining our societal future. While we know that innovation processes

are not linear chains and have to be framed from a complex, nonlinear, and interactive perspective,<sup>2</sup> the relevance of initial decisions at the early stages of specific projects and programs is not to be overestimated. Consequently, ProTA has to deal mainly with science or technoscience and not just with technology and the diffusion of technical systems; it addresses the basis of our knowledge production dynamics—the root and source of the emergence of novel technical systems. ProTA therefore should be thought of more as science, technoscience, or knowledge assessment. The early-stage approach of ProTA goes right to the epicentre of academic knowledge production and is characteristic of a critical-reflexive account. Seen from that angle, the traditional idea (and rhetoric) of technoscientific knowledge being value-free becomes nothing but a myth.

*Second*, because the consequences and impacts of technologies are hard to anticipate in concrete terms at the early stages, ProTA addresses purposes, intentions, potentials, and visions. Of central interest here are the consideration of technoscientific (realistic) potentials and their demarcation from (unrealistic) visions, promises, and hypes. Because pure basic research and purposefully applied research are today highly intermingled,<sup>3</sup> purposes migrate far into science and laboratory practice. Science in its inner constitution is purpose-driven and strongly value-laden. Accessing and assessing purposes, including the options for realizing the potentials, are key elements of ProTA. We know—or at least could know—much at the very beginning of science and research processes: during the phases of agenda setting and the development of research corridors. In principle, negative side effects and risks can be identified very early on. An early anticipation of unintended consequences is feasible—without obtaining strongly prognostic-predictive knowledge. There is an obvious reason for this. Many present-day and future technologies are based on predecessor technologies or on a synergetic combination of already-established technologies. The knowledge about these is already present, for instance, in the field of future nuclear technology. Thus, ProTA is concerned with the state-of-the-art in the sciences or technosciences. On this basis, it discloses the various kinds of non-knowledge on different levels (uncertainties, ignorance, and risks) and it considers possible non-knowables. It is guided by the precautionary principle that has been adopted in order to deal with uncertain but nonetheless relevant knowledge (Manson 2002). In sum, ProTA facilitates public and intra-scientific discourse on the intentions, potentials, and visions of a novel or expanded technoscientific field or both. It revisits, reflects on, and potentially revises the purposes and potentials at all stages of the technoscientific innovation process.

*Third*, ProTA is *shaping-oriented*. As such, it initiates reflexive search procedures to find and assess alternative paths and trajectories of technoscientific advancement. To accomplish this approach, it does not stand for an uninvolved observer's perspective, as has been predominant in classic concepts of expertise and policy advice—a typically instrumentalist viewpoint. To the contrary, in creating knowledge, ProTA brings together those

involved in the overall process of developing, designing, shaping, and moderating technoscientific knowledge. In other words, the addressees as well as the participants in ProTA are also those who are actively involved in, or contribute to, the shaping process: scientists, engineers, politicians, university leaders, academy administrators, and program managers. Overall, the shaping orientation is based on an analysis and critique of the current state of the joint science, technology, and innovation system. The analysis reveals that the scientification and technization of society and the life-world in conjunction with the complementary socialization of science and technology are central features of late-modern societies. The optimistic faith in science and technology prevalent in the 1960s and 1970s, which held that these processes can be intentionally planned, steered, and effectively controlled, is gone. Science, technology, and society are intertwined in a great variety of ways. New concepts and approaches, such as governance, engender hope that—in lieu of steering the production of technoscientific knowledge—shaping the procedures could improve scientific–societal co-activity. They also call into question the externalist perspective and the assumptions of classic, control-oriented action theory, which are most prominent in the instrumentalist notions of prediction and control. Based on such an analysis of the status quo, the point of departure of ProTA is the observation that the boundary between the intra-scientific and extra-scientific realms—in other words, between the academic system and society—is becoming blurred. In this regard, ProTA can be seen as a kind of engaged and participatory research to shape technoscientific knowledge production.

*Fourth*, ProTA focuses on the technoscientific core of an emerging or novel type of technology. It is an assessment based on a detailed examination of the technoscientific knowledge envisioned or already available in the field under consideration—which includes the feasible or already realized technical systems, the experimental setups, and the technical artefacts and infrastructures. Scientific and engineering knowledge is very much required in order to enable an analysis of this kind. Scientists and engineers have to become involved when a ProTA is carried out, for example, in the political arena concerning novel research and development programs. Although ProTA focuses on the technoscientific core, it does not do so in a narrow sense. On the contrary, it is strongly embedded in the societal sphere. For instance, societal values and visions play a central role in the pursuit of technoscientific knowledge and thus in the development of the technoscientific core. ProTA uncovers the values driving visionary technical design processes and, if necessary, criticizes them. Consequently, consideration of the deeper knowledge produced at the technoscientific core is indispensable. The status of current research and the intra-scientific dynamics may also be scrutinized to clarify the extent to which there is potential for the visions to be fulfilled. Addressing and assessing the technoscientific core—as central elements of future-relevant discussions regarding technoscientific potentials, intended impacts, expected results, and non-intended consequences—are really what make ProTA a truly interdisciplinary enterprise.

Thus, ProTA provides a fourfold orientation for a critical-reflexive approach. It focuses on the early stages of a development (first point above), on purposes, intentions, visions, and potentials (second) related to technoscientific knowledge in order to (fourth) enable alternatives in the design and shaping (third) of the novel technoscientific knowledge under consideration.

### Normative anchor

In addition to the fourfold orientation framework, ProTA—as a critical-reflexive kind of interdisciplinary practice—explicitly reflects on its normative fundament. The fundament can be delineated by referring to two criteria based on philosophical considerations (Liebert and Schmidt 2010).

The first criterion was developed by Hans Jonas (1984) in his *Imperative of Responsibility* and is related to the heuristics of fear and to a prudent manner regarding action.<sup>4</sup> We can say that Jonas formulated a *preservation principle* aimed at achieving a conservative preservation of our life-world and genuine human life. The second, somewhat complementary criterion is related to Neo-Marxist thinker Ernst Bloch's (1995) utopian *Principle of Hope*, which addresses the open horizon of the desired future. In his anti-dualist materialist dialectics, Bloch sees man and the world as unfolding in a non-teleological way. He envisions what he calls an *alliance technology* that serves mankind *and* is concurrently in resonance and harmony with nature. Let me now elaborate somewhat on the twofold normative framework.

Jonas uses the term non-reciprocal to describe responsibility. The crucial aspect here is not the relationship between equals but the asymmetric relation: the responsibility *for* somebody or something, *for* others. It is a responsibility for other humans, for future generations, for animals, for embryos, or for nature. The concept of non-reciprocity encompasses the responsibility *of* scientists *for* other human beings (i.e., those who are affected by research outcomes) and *for* the natural environment. The “so-being” of the world calls us to preserve it. We therefore can ask in concordance with Jonas: Do our approach to nature and our ways of producing knowledge contain ethical core elements to secure the permanence of “genuine human life”? That is not the case: According to Jonas, we have to shift ethical reflection to an earlier phase, where scientific knowledge is generated. Ethics and (scientific) knowledge should not be deemed separable from each other. Societal responsibility has to be part of the whole research process from the very beginning.

Now let us look at a complementary approach offered by Bloch's *unfolding principle*. According to Bloch, what needs to be done is to positively define the envisioned directions of technoscientific progress or, in other words, to *unfold* and to constitute the societal future we desire. The current *so-being* with its deficiencies and problems is the point from which the unfolding principle takes its departure. With its strict, forward-looking

perspective, the unfolding principle is aimed at enabling decisions on what is *desirable* and *possible* beyond what already exists: How would we like to live in the future while acknowledging the plurality of different ways of life? To answer this central question, we need to consider both the values behind our wishes for the future and the technoscientific options for moving in the desired direction. A prerequisite, as we have seen earlier, is to address and assess the technoscientific core. Such an assessment relates to the desired future; it is a value-sensitive process for which explicit reflection on normative backgrounds is indispensable. Some dimension of this kind of approach towards constituting the desired future and the unfolding potential can be identified in the field of discourse ethics (Habermas 1993). Discourse ethical procedures claim to form a fundament of deliberative considerations of this nature within future-oriented goal-setting processes: In a power-free discourse, interlaced with a mutual recognition of interests and sense of values, we can debate and examine what is universally acceptable and what is not. The discourse must not necessarily lead to a consensus. Well-founded and transparent dissenting opinions could also prove helpful and serve as a basis for individual, institutional, and political decisions, which should always be structured in a reversible manner.

In addition to elements of deontological and virtue ethics (Jonas) and of discourse ethics (akin to the thinking of Bloch), utilitarian concepts are indispensable to the concept of ProTA. The consideration of consequences is inherent to utilitarian approaches. It is naturally of relevance for any kind of TA which enquires into intended and unintended effects and outcomes. The significant utilitarian arguments are those underlining that good intention and convincing justifications do not suffice. At the same time, putting emphasis on the outcomes implies—conversely—that the motives, intentions, visions, and interests (in relation to scientific action) are somewhat under-exposed. A major drawback of the utilitarian approach of choosing between conflicting benefits is that it can prevent us from considering and posing fundamental questions. Moreover, utilitarian perspectives often promote the seizing of alleged chances in the absence of proven risks and thus there is an emerging tendency to annul the balance between the principles of preservation and unfolding that is central for ProTA.

To summarize, ProTA incorporates elements of the most common ethical concepts. It fills deontological concepts with material-normative or virtue-ethical content—some would call it “metaphysical”—which is related to the *preservation principle* proposed by Hans Jonas. Discourse ethics is central insofar as it enables a deliberative goal- and vision-setting process that can be linked to Bloch’s *unfolding principle*. In addition, utilitarian-consequentialist thinking is—at least to some extent—indispensable in order to appropriately include outcomes, consequences, decisions, and actions pertaining to concrete research programs. In any event, ProTA can hardly avoid being underpinned by concepts of ethics.

## Synthetic biology – a case study

To elaborate the discussion further, I will present an example of ProTA in the field of synthetic biology. This field is reputedly a key technoscience of the future.

In 2010, the research entrepreneur Craig Venter announced the forthcoming advent of an epochal break and envisioned a fundamental shift in our technical capabilities. Synthetic organisms

are going to potentially create a new industrial revolution if we can really get cells to do the production we want; [...] they could help wean us off of oil, and reverse some of the damage to the environment like capturing back carbon dioxide.

(Venter 2010)

Venter's visionary claim was evidently induced by the success of his team in the *Creation of a Bacterial Cell Controlled by a Chemically Synthesized Genome*—as his article in *Science* magazine was titled (Gibson et al. 2010).

In fact, the hype that Venter generated has actually set off another huge wave. He has been accused of “playing God” or, at least, of advocating a dangerous type of “hubris.” Although such concerns and objections to Venter's optimism are key elements in the formation of public opinion and political deliberation, both extreme positions—Venter's and that of his critics—often lead to a deadlock. Maintaining them would mean missing opportunities to engage in shaping this new technoscientific wave. In this respect, the concept of ProTA enables, from a critical-reflexive perspective, an earliness approach providing relevant background information for analysing and assessing the new technoscientific wave (Liebert and Schmidt 2010). ProTA, as we have seen, can be regarded as an endeavour that extends and expands established TA concepts by focusing on specific and somewhat underexposed elements in the existing concepts. It is based on a fourfold orientation framework, as described above: an earliness orientation, an intention orientation, a shaping orientation, and an orientation towards the technoscientific core.<sup>5</sup>

In the following, I will examine in more detail how the fourth orientation of ProTA, which is certainly intertwined with the other three, applies to the field of synthetic biology. The thesis presented here is that the major essence of the technoscientific core of “synthetic biology” is the idea(l) of harnessing self-organization—including the ability to set off complex dynamical phenomena—for technical purposes.

Synthetic biology is still in its infancy. The societally relevant ethical issue demanding consideration at this early stage in the technology's development is that, should a technology based on self-organization ever be attained and implemented, we would enter a new technological era in which technical systems possessed high levels of autonomy and agency properties. The risks would be hard to assess. The systems would “take on a life of their own such



that we no longer appear to perceive, comprehend, or control them” (Nordmann 2008b, 176). The new type of technology could be called “late-modern,” indicating that it is ontologically different from, and an extension of, the recent modern kind of technology.

### Scrutinizing the visions

What does the technoscientific core of synthetic biology consist of, and what is the common denominator of synthetic biology? The exact meaning of the umbrella term “synthetic biology” is, in fact, not at all clear. New labels and trendy watchwords generally play a key role in the emergence of new technoscientific waves. Synthetic biology is certainly no exception in that it is an extremely popular buzzword widely encountered in debates on research politics, as was the notion of nanotechnology more than a decade ago.<sup>6</sup>

All TA scholars and ethicists are aware of the fact that labels are strongly normative. Labels are not innocent or harmless. They carry content and form the backbones of visions. They are roadmaps towards the future and can quickly turn into reality; they shape the technoscientific field and determine our thinking, perception, and judgment. Labels help to foster hopes and hypes as well as concerns and fears; their implicit power to create or close new research trajectories and development roadmaps can hardly be overestimated. Labels are part of what could be described as “term politics,” regulating and shaping the specific field with a “gatekeeper function” that decides who is *in* and who is *out*; whose research field can be deemed “synthetic biology” and whose is merely a subfield of traditional biotechnology. Labels are relevant with respect to funding, publication opportunities, reputation, and career. Thus, they determine and sway our future in one way or another. To what does the umbrella term “synthetic biology” refer? Is there a unifying arc? What visions do synthetic biologists have, and how likely will their visions be achieved? Three popular visions or definitions<sup>7</sup> of synthetic biology stand out.<sup>8</sup>

*First*, the *engineering vision* frames synthetic biology as being radically new since it is said to bring an engineering approach to the scientific discipline of biology. This vision is governed by the ideal of making new genomes or transforming existing genomes by the insertion of new genes/gene sequences or by the elimination of existing genes. An engineering understanding is advocated by a High-Level Expert Group of the European Commission: “Synthetic biology is the engineering of biology: the synthesis of complex, biologically based (or inspired) systems [...]. This engineering perspective may be applied at all levels of the hierarchy of biological structures [...]. In essence, synthetic biology will enable the design of ‘biological systems’ in a rational and systematic way” (European Commission 2005, 5). This comes close to the definition given by Pühler et al. (2011), who see synthetic biology as “the birth of a new engineering science.” Similarly, others view synthetic biology as “an assembly of different approaches

unified by a similar goal, namely the construction of new forms of life” (Deplazes and Huppenbauer 2009, 58). The engineering definition is generally based on the assumption that before synthetic biology arose, there was a clear dividing line between biology as an academic discipline, on the one hand, and engineering/technical sciences, on the other. Biology is regarded as a pure science aiming at fundamental descriptions and explanations. In contrast, engineering sciences appear to be interested primarily in intervention, construction, and creation. Seen in that light, biology and engineering sciences have traditionally been perceived to be—in terms of their goals—like fire and ice. The proponents of the engineering definition believe that the well-established divide between the two disciplines is becoming blurred. Today, engineering goals are being transferred to the new subdiscipline of biology. According to the advocates of this definition, these goals have never been characteristics of other subdisciplines of biology (*divergence from traditional biology*). The essential claim is that we are experiencing an epochal break or a qualitative shift in the aims and approaches of biology as well as in how the field is understood: In this light, biology is aimed not at theory but at technology. Synthetic biology appears to epitomize the ideal of the technoscientification, technicization, or engineering of biology.

*Second*, the *artificiality vision* in regard to synthetic biology is related to the former definition but is concerned more with objects than with goals. According to the European Union (EU) project TESSY (“Towards a European Strategy for Synthetic Biology”), synthetic biology deals with “bio-systems [...] that do not exist as such in nature” (TESSY 2008). In an equivalent sense, others have stated that synthetic biology encompasses the synthesis and construction of “systems, which display functions that do not exist in nature” (European Commission 2005, 5). The German Science Foundation, together with the Academy of Technical Sciences and the National Academy of Sciences Leopoldina, similarly identifies the emergence of “new properties that have never been observed in natural organisms before” (DFG et al. 2009, 7). It defines synthetic biology by the non-naturalness or unnaturalness of the constructed and created bio-objects. *Divergence from nature* appears to be the *differentia specifica* of synthetic biology, and nature is seen as the central anchor and negative foil for this definition. Whereas bio-systems were traditionally natural (i.e., they occurred exclusively *within* and were created *by* nature alone), the claim here is that, from now on, bio-systems can also be artificial (i.e., created intentionally by humans). That is certainly a strong presupposition, which is also linked to the idea of a dichotomy between nature and technical objects. The dichotomy can be traced back to the Greek philosopher Aristotle, who drew a demarcation line between *physis* (nature) and *techné* (arts and technical systems). In spite of Francis Bacon’s endeavours at the very beginning of the modern epoch to eliminate the dichotomy and naturalize technology, the nature–technology divide broadly persists in the above definition. In a certain sense, the artificiality definition of synthetic biology presupposes the ongoing plausibility of the Aristotelian concept

of nature, neglects the Baconian one, and argues for an epochal break in understanding bio-objects and bio-nature: These are not given, they are fabricated.

*Third*, the *extreme gene technology/biotechnology vision* leads either to synthetic biology being seen in a more relaxed light or, on the contrary, to its being condemned as a continuation of trends already perceived as terrible and dangerous in the past. According to the proponents of this definition, we are experiencing just a slight shift and mainly a continuation, not an epochal break; nothing is really new under the sun. Synthetic biology merely extends and complements biotechnology. Drew Endy (2005, 449), a key advocate of synthetic biology, perceives only an “expansion of biotechnology.” Similarly, but from a more critical angle, the Action Group on Erosion, Technology and Concentration (2007) defines synthetic biology as an “extreme gene technology,” mainly because it is based on gene synthesis and cell techniques such as nucleotide synthesis, polymerase chain reaction, or recombined cloning. The basic methods, techniques, and procedures have been well established since the late 1970s. Although there have been tremendous advances from a quantitative standpoint, it is hard to discern any qualitative progress in the core methods. The extreme biotechnology definition rarely deals with goals or objects, but with methods and techniques. Its proponents claim (1) that, implicitly, methods constitute the core of synthetic biology, (2) that there has been no breakthrough in the synthetic/biotechnological methods, and moreover (3) that a quantitative advancement cannot induce a qualitative one. Briefly, this position perceives a *continuation in methods*—in contrast to a divergence from biology or nature as perceived in the former two definitions.

We are faced with a plurality of three different conceptions of what “synthetic biology” means or, speaking in normative terms, what it should mean. The three visions or definitions—the engineering, the artificiality, and the extreme biotechnology vision—tell three different stories. Each one exhibits some degree of plausibility and conclusiveness. In spite of their apparent differences, all are concerned (first) with disciplinary biology or biological nature and (second) with a rational design ideal in conjunction with a specific understanding of technology, technical systems, and engineering action. However, that is not the whole story.

*First*, the focus on biology as a standalone discipline, including a discipline-oriented framing, prevents an exhaustive characterization of the new technoscientific wave: Synthetic biology is at its nucleus far more *interdisciplinary* than disciplinary. This point needs to be taken into account when seeking an adequate definition: Biologists, computer scientists, physicists, chemists, material scientists, medical researchers, and people from different engineering sciences are engaged in synthetic biology. Because various disciplinary approaches, methods, and concepts coexist in synthetic biology, the term seems to serve as a label for a new interdisciplinary field. Accordingly, a biology bias would surely be overly simplistic and entirely inadequate; framing synthetic biology as merely a new subdiscipline of biology would

represent a far too narrow approach. It is not sufficient to provide a clear understanding of synthetic biology. Thus, we need to ask whether we are dealing with a much more fundamental technoscientific wave than simply a change in one particular discipline or academic branch.

*Second*, in line with what is referred to as bionano or nanobio research, the three definitions look at synthetic biology from the angle of technology and engineering. This manner of approach appears plausible in some respects: Synthetic biology extends and complements advancements in nanotechnology and hence spurs a position that can be called “technological reductionism” (Schmidt 2004, 35f). Technological reductionists aim to eliminate the patchwork of engineering sciences by developing a fundamental technology or a “root, core, or enabling technology” (ibid., 42). The slogan fostered by technological reductionists is: shaping, designing, constructing, and creating the world “atom-by-atom.” Eric Drexler is a prominent advocate of technological reductionism. He argues that there are

two styles of technology. The ancient style of technology that led from flint chips to silicon chips handles atoms and molecules in bulk; call it bulk technology. The new technology will handle individual atoms and molecules with precision; call it molecular technology.

(Drexler 1990, 4)

Interestingly, recent technological reductionism (“molecular technology”), Drexler upholds, complements and perfects the traditional (“bulk”) technology. The three definitions of synthetic biology described above concur strongly with technological reductionism; it certainly seems plausible to put synthetic biology in the context of this new type of technology-oriented reductionism. But whether that is all that can, or should, be said to characterize synthetic biology remains to be clarified. It is absolutely clear that synthetic biology differs from nanotechnology, which can be viewed as a paradigm of a technological reductionist approach (Schmidt 2004). Many synthetic biologists claim to pursue an approach that is complementary to nanotechnology and has been called a “systems approach” or, in a more visionary sense, “holistic.” Given the widespread reference to “system,” along with the alleged successful application of “systems thinking,” synthetic biology seems to involve a convergence, or dialectical relationship, of seemingly contradictory concepts: (systems) holism and (technological) reductionism with its strong control ambitions and emphasis on rational engineering. This inherent dialectic is obviously central to an appropriate understanding of synthetic biology. The three definitions presented so far do not encompass this point.

In light of that omission, our characterization of synthetic biology (and its technoscientific core) has to go beyond the three narrow definitions given above. Although it is neither erroneous nor misguided to see synthetic biology (i) as a subdiscipline of biology and (ii) as a technologically reductionist position, this conception is one-sided, biased, and limited in

depth and scope. It needs to be supplemented with an approach that also takes fundamental tendencies in science and technoscience in general into consideration and focuses in more detail on the technoscientific core of the emerging technoscientific wave.

## Deepening the analysis

### *Synthetic biology aims to harness self-organization for technical purposes*

To arrive at a more fitting and more comprehensive characterization of synthetic biology, we should not restrict ourselves to goals (as in definition 1), to objects (“ontology,” as in definition 2), or to methods (“methodology,” as in definition 3) but also consider the underlying principles and concepts within the technoscientific field, namely the technoscientific core. This requirement is central to the approach of ProTA. Thus, we need to include a fourth definition—the *systems or self-organization definition*—that is prevalent in synthetic biology research programs.

Synthetic biology makes use of the self-organization power of nature for technological purposes: “Harnessing nature’s toolbox” in order to “design biological systems,” as David A. Drubin, Jeffrey Way, and Pamela Silver (2007) state. Even back in 2002, before synthetic biology had been broadly discussed (although its main ideas were already on the table), Mihail Roco and William Bainbridge (2002, 258) *anticipated new frontiers in research and development by* “learning from nature.” They perceived the possibility of advancing technology by “exploiting the principles of automatic self-organization that are seen in nature.” According to Alain Pottage and Brad Sherman (2007, 545), the basic idea of synthetic biology is to “turn organisms into manufactures” and to make them “self-productive.” The paradigm of self-organization and self-productivity is implicitly or explicitly articulated in many papers on synthetic biology. Pier Luigi Luisi and Pasquale Stano (2011) also advocate an understanding of synthetic biology based on self-organization:

Synthetic cells represent one of the most ambitious goals in synthetic biology. They are relevant for investigating the self-organizing abilities and emergent properties of chemical systems—for example, in origin-of-life studies and for the realization of chemical autopoietic systems that continuously self-replicate—and can also have biotechnological applications.

Jean-Pierre Dupuy (2004, 12f) discerns that “[t]he paradigm of complex, self-organizing systems is stepping ahead at an accelerated pace, both in science and in technology.” Jordan Pollack puts self-organization at the very centre of his vision of designing advanced biomaterial. Pollack’s goal is to “break [...] the limits on design complexity,” as his article is entitled. “We think that in order to design products ‘of biological complexity’ that could make use

of the fantastic fabrication abilities [...], we must first liberate design by discovering and exploiting the principles of automatic self-organization that are seen in nature” (Pollack 2002; in Roco and Bainbridge 2002, 161).<sup>9</sup>

In fact, the systems approach of putting the self-organization power of bioengineered entities at the very centre of the new technoscientific wave has enjoyed an impressive evolution over the last three decades. It goes back to one of the most popular and highly controversial publications by K. Eric Drexler in the early 1980s. Drexler talks about “self-assembly,” “engines of creation,” and “molecular assemblers.” “Order can emerge from chaos without anyone’s giving orders [... and] enable[s] protein molecules to self-assemble into machines” (Drexler 1990, 22f.). “Assemblers will be able to make anything from common materials without labor, replacing smoking factories with systems as clean as forests.” Drexler goes further and claims that emergent technologies “can help mind emerge in machine.” Richard Jones (2004) takes up Drexler’s ideas and perceives a trend towards self-organizing soft machines that will change our understanding of both nature and technology. From a different angle but in a similar vein, the 2009 report “Making Perfect Life” of the European Technology Assessment Group (2009, 4) refers to advances in synthetic biology: “Synthetic biology [...] present[s] visions of the future [...]”

Technologies are becoming more ‘biological’ in the sense that they are acquiring properties we used to associate with living organisms. Sophisticated ‘smart’ technological systems in the future are expected to have characteristics such as being self-organizing, self-optimizing, self-assembling, self-healing, and cognitive.<sup>10</sup>

(*ibid.*)

Alfred Nordmann (2008b, 175) sees a new understanding of technology emerging in the field “where engineering seeks to exploit surprising properties that arise from natural processes of self-organization.” A “shift from” what Nordmann describes as “nature technologized” to “technology naturalized” can be observed, which “is usually hailed as a new, more friendly as well as efficient, less alienated design paradigm” (*ibid.*, 175).

Synthetic biology—it is interesting to observe—does not stand alone: Self-organization also plays a constitutive role in other kinds of emerging technologies such as

1. Artificial intelligence, machine learning, robotics, autonomous software agents, and bots;
2. Nano- and nanobio-technologies;
3. Cognitive and neuro-technologies.

Moreover, self-organization in technical systems serves as a leitmotif in science policy: “Unifying science and engineering” seems possible by “using the concept of self-organized systems” (Roco and Bainbridge 2002,

10/84). Self-organization appears to be the conceptual kernel of the ideal of the *convergence of technologies* and also seems central to any kind of *enabling technology* (ibid.; Schmidt 2004). The above list of examples shows that synthetic biology is not unique; it can be perceived as being only a prominent example or as the spearhead of a universal trend in technology.

### *Synthetic biology as late-modern technology*

If we take the visionary promises as serious claims, they announce the emergence of a new type of technology. We do not know whether the promises can be fully kept. However, if this were to be the case, we would encounter a different kind of technology, including novel risk issues having ethical relevance: a *late-modern technology*.

Late-modern technology has nothing to do with our established perception of traditional technical systems. It shows nature-like characteristics; it does not present the appearance of being technology; it seems to be “un-technical” or “non-artificial”; the signs and signals, the tracks and traces of technology are no longer visible (Hubig 2006). Technical connotations have been peeled off; well-established demarcation lines are blurred. Late-modern technology seems to possess an intrinsic momentum of rest and movement within itself—not an extrinsic one. Such characteristics come close to the Aristotelian and common life-world understanding of nature: Technology *is* alive, or *appears* to be alive, as nature always has been. The internal dynamics (i.e., activity, change, and growth) of self-organization technology make it hard to draw a demarcating line between the artefactual and the natural in a phenomenological sense: Nature and technology seem indistinguishable. Even where it is still possible to differentiate between the artificial and the natural (e.g., in robotics), we are confronted with an ever-growing number of artefacts displaying certain forms of behaviour that traditionally have been associated with living systems. The words used by Schelling and Aristotle to characterize nature also seem to apply to technology: A late-modern technical system is “not to be regarded as primitive” because it appears to act by itself: (a) it creates and produces, (b) it selects means to ends, and (c) it makes decisions and acts according to its environmental requirements. Technology evidently presents as an acting subject: “Autonomy”—a term central to our thought tradition—is ascribed to these systems.

What is behind this trend towards a *phenomenological convergence* of nature and technology or, in other terms, towards the *phenomenological naturalization of technology*—apart from “technological reductionism”? To answer this question, we need to examine the claims made by the advocates of synthetic biology. Far more relevant and foundational, it seems, is the aspect we could call *nomological convergence*, which engenders a fundamental trend towards the *nomological naturalization of technology*. Mathematical structures describing self-organization in technical systems are said to converge with those in nature. Although the objects might differ,



their behaviour and dynamics show a similarity. According to M.E. Csete and J.C. Doyle (2002, 1664), “advanced technologies and biology are far more alike in systems-level organization than is widely appreciated.” The guiding idea(l) of nomological convergence dates back to the cyberneticist and structural scientist Norbert Wiener. He defined structure-based convergence with regard to specific “structures that can be applied to and found in machines and, analogously, living systems” (Wiener 1968, 8).<sup>11</sup> The physicist and philosopher Carl Friedrich von Weizsäcker pointed out some 50 years ago:

Structural sciences encompass systems analysis, information theory, cybernetics, and game theory. These concepts consider structural features of different objects regardless of their material realm or disciplinary origin. Time-dependent processes form a common umbrella that can be described by an adequate mathematical approach and by using the powerful tools of computer technology.<sup>12</sup>

(Weizsäcker 1974, 22f)

Today, we can add self-organization theories which encompass nonlinear dynamics, complexity theory, chaos theory, catastrophe theory, synergetics, fractal geometry, dissipative structures, autopoiesis theory, and others. Following the first wave of structural and systems sciences such as information theory, game theory, and cybernetics (Bertalanffy, Wiener, Shannon, and von Neumann) in the 1930s and 1940s, we are now experiencing a second wave (Maturana, Varela, Prigogine, Haken, Foerster, Ruelle, and Thom) that began in the late 1960s. Self-organization, macroscopic pattern formation, emergent behaviour, self-structuring, growth processes, the relevance of boundary conditions, and the Second Law of Thermodynamics (entropy law) with its irreversible arrow of time are regarded as conceptual approaches to disciplinarily different types of objects, based on evolutionary thinking in complex systems. Assisted by the spread of computer technology, concepts of self-organization had a tremendous impact on scientific development in the second half of the 20th century.

### **Tracing the technoscientific core**

The thesis proposed in this chapter is that synthetic biology harnesses, or aims to harness, self-organization capability for technical purposes. However, the term “self-organization” is not very precisely defined. Since Kant’s and Schelling’s coining of “self-organizing beings,” the concept of self-organization has been in flux, although the term seems to have retained its essential meaning, which is the immanent creation and construction of novelty:

- the emergence of novel systemic properties—new entities, patterns, structures, functionalities, and capacities.



Notwithstanding the philosophical debate on the notion and characteristics of novelty, the following are widely accepted criteria to specify “self-organization”:<sup>13</sup>

- dynamics, processes, time-dependency, and historicity;
- internality or “autonomy” (the notion of “self” in “self-organization”);
- irreducibility of the description;
- unpredictability of the self-organized or emergent phenomena.

In consequence, self-organization processes are generally non-separable from their environment; they are hard to control by an external actor. “The engineers of the future will be the ones who know that they are successful when they are surprised by their own creations” (Dupuy and Grinbaum 2006, 289). In brief, the notion of self-organization is, from an engineering perspective, linked to characteristics such as “productivity/creativity,” “processuality,” and “autonomy.” These terms are frequently used by synthetic biologists.

I have stated that harnessing self-organizing power for technological purposes is at the core of synthetic biology. But what is at the core or root of self-organization? Basically, the answer I propose is that *instabilities* turn out to be essential for self-organization; they are constitutive to all systems or structural theories (cp. Schmidt 2011).<sup>14</sup> According to Gregory Nicolis and Ilya Prigogine (1977, 3f), “instabilities are necessary conditions for self-organization.” As seen in the previous chapter, instabilities are generally situations in which a system is on a razor’s edge: criticalities, flip or turning points, thresholds, and watersheds. They generate sensitive dependencies, bifurcations, and phase transitions. The classic-modern *strong* type of causation does not govern these processes; rather, it is the *weak* causation that enables feedback procedures and amplification processes. Instabilities can induce random-like behaviour, deterministic chance, and law-based noise, which are inherently linked to uncertainty. The most prominent example to illustrate instability is the “butterfly effect.” The beating of a butterfly’s wings in South America can have a tremendous impact on the weather in the US and cause a thunderstorm (Lorenz 1963; Lorenz 1989; Schmidt 2011a).

Unstable systems show certain limitations with regard to predictability, reproducibility, testability, and reductive explainability. An isolation or separation of the systems from their environment is impossible because they are continuously interacting with it. In general, instability should not be equated with the collapse of a system. Insofar as present-day engineers intend to make use of self-organization power, they have to provoke and stimulate instabilities: Self-organization requires that a system’s dynamics pass through unstable situations. To put it metaphorically, late-modern technology can be considered the technoscientific attempt to initiate and stimulate a *dance on the razor’s edge*. This specific, highly sensitive technological core is the basic object of interest for accomplishing an early assessment;

and it is at the very centre of the concerns raised by Hans Jonas, who was a precursor in anticipating an instability-based complex technology.

### **Assessing the technoscientific core**

The instability-based type of technology is somewhat ambivalent because it obviously carries an internal conflict or considerable dialectic that cannot be overcome by minor modifications of the technical system itself.

On the one hand, instabilities constitute the core of self-organization and hence of technologically relevant self-productivity. On the other hand, instabilities are intrinsically linked to obstacles and limitations, not only with regard to the construction and design accomplished by the technical systems but also with regard to the possibility of subsequently controlling and monitoring the systems. When instabilities are present, tiny details are of major relevance; minor changes in some circumstances can cause tremendous, unforeseeable effects; unstable systems lack predictability. Owing to empirical-practical and fundamental-principle uncertainties, the tiny details are hard to control. Paradoxically, although they are constructed by humans, the systems remain fundamentally inaccessible and elude comprehension and control (Nordmann 2008b; Köchy 2011).

On account of these limitations, technology and instability were traditionally like fire and ice.<sup>15</sup> According to the classic-modern view of technology, instabilities exist in nature but ought to be excluded from technical systems. If instabilities arose, the traditional objective was to eliminate them. Controllability, based on predictability, expectability, and robustness, seemed feasible only when stability was guaranteed. Technology was equated with and defined by stability. Today, synthetic biologists—in line with computer scientists working in artificial intelligence and machine learning—are widening our understanding (and our concept) of technology by ascribing both stability *and* instability to technology. At the same time, it is still an open question whether the late-modern kind of technical system can be conclusively called “technology” or even whether it is a “technically possible technology” at all—to paraphrase the sociologist and system theorist Niklas Luhmann (2003, 100f). It can convincingly be argued that traditional “rational design” approaches in engineering and technology, which are typically based on assumptions of stability, have their limitations in the late-modern field of technology (cp. Giese et al. 2013). Alfred Nordmann (2008b, 173) states from a critical angle: “No longer a means of controlling nature in order to protect, shield, or empower humans, technology dissolves into nature and becomes uncanny, incomprehensible, beyond perceptual and conceptual control.” Whenever instabilities are involved, non-knowledge, uncertainties, and ignorance also prevail and, in principle, cannot be eliminated; problems with regard to monitoring and controlling emerge. Late-modern technical systems have a life of their own; instabilities render engineering (construction/design and monitoring/controlling) difficult (Kas-tenhofer and Schmidt 2011).

It is highly interesting that the ethics of Hans Jonas is well equipped to address and to assess this novel kind of technology. Jonas's new future-oriented imperative—"Act so that the effects of your action are compatible with the permanence of genuine human life'" (Jonas 1984, 11)—is much informed by his general reflection on the ambivalence encountered in the advancement of science and technology and especially evident in the technoscientific core of emerging technologies. Jonas anticipated the characteristics and limits of "engineering biology" even back in the mid-eighties (Jonas 1987, 163).<sup>16</sup> In extension to Jonas's terminology, I use the term "late-modern technology" to underline that we are experiencing a qualitative change in what we now consider technology. Jonas diagnoses a historically new technoscientific era and perceives a radical "newness of biologically based technology" (*ibid.*, 163).<sup>17</sup> He draws a dividing line between the classic engineering type of technology—including what he calls the "art of the engineer" or, synonymously, "engineering art"—and a biologically based type of technology. As Jonas argues, this new type of technology differs in a qualitative way from our common perception and understanding of what technology is or could be.

In th[is latter ...] case of dead substances, the constructor is the one and only actor with respect to a passive material [= classic-modern technology.] [In contrast, in the case of the] biological organism, activity meets activity: biological technology is collaborative; it is self-activity of an active [= living] 'material'.<sup>18</sup>

(*ibid.*, 165)

Jonas lists characteristics of this new type of technology:

- self-activity, processuality, and autonomy;
- irreversibility, time-dependency, and historicity (birth and death);
- complexity, evolution, and growth;
- individuality, non-experimentability, and obstacles regarding reproducibility;
- collaborativeness and interactive causation as a different kind of causality (*ibid.*, 163ff).

Jonas argues that, since biologically based technology inevitably carries an internal activity, engineering "means releasing the bio-object into the stream of becoming in which the engineer and constructor is also drifting" (*ibid.*, 168).<sup>19</sup> Looking at the present wave of synthetic biology, Jonas's anticipation and, in particular, his differentiation between "engineering art" and "biologically based engineering" are certainly very fascinating. However, Jonas does not take his distinctly phenomenological description any further. In consonance with the argumentation developed in this chapter, it is not the organismic alone that constitutes the central difference but also instability-based self-organization. Jonas's approach is much more fundamental than Jonas himself seems to have assumed. Closer examination of the new

type of technology provides a further argument in support of the need for a heuristics of fear comprising the precautionary principle and the imperative of responsibility.

In searching for *an ethics for the technological age*, Jonas (1984) anticipates that our notion and understanding of “technology” seem to be changing. Let us, for a moment, like Jonas assume that a late-modern type of technology could, in principle, become technically feasible, applicable, and successful. We would then be faced with new challenges such as restrictions with regard to predictability or limited control—the flip side of self-organization. The fundamental properties of such a late-modern technology (evolution, growth, autonomy, and self-productivity) have the power to change the world we live in. Metaphorically speaking, those who dare to stimulate and induce instabilities are, at the same time, provoking a risky *dance on the razor’s edge*. “Because engineered micro-organisms are self-replicating and capable of evolution,” Jonathan B. Tucker and Raymond A. Zilinskas (2006) argue, “they belong in a different risk category than toxic chemicals or radioactive materials.” In fact, this objection already applies to a number of classic substances in biotechnology. But the related challenges in the realm of synthetic biology seem to go much deeper and could be regarded as more pressing. Notably, the extent to which the *principle of similarity and resemblance*, which constitutes the backbone of any risk assessment, is applicable to the substances and tissues used in synthetic biology remains open to debate. This principle is based on the assumption that if a new (bio-)system has some similarity to one that is known, the new system will behave in a similar way as the well-known one and exhibit essentially similar properties. But many self-organizing bio-systems are not all that similar, owing to their intrinsic instability and the production of novel features, functionalities, or substances. How, then, are they to be compared to other, well-known bio-systems? Such questions are ethically relevant, Jonas argues; they challenge the feasibility of an assessment and, consequently, also of ethics.

According to Jonas, it is of ethical relevance that non-knowledge, ignorance, and uncertainty are co-produced with the productiveness of the late-modern technical systems—that is a central point made by Jonas with his *heuristics of fear*. Non-knowledge and uncertainty are by-products and do not simply emerge in the societal context of diffusion, use, and consumption. Instability-based technology takes on a life of its own. Jean-Pierre Dupuy (2004, 10) is citing Jonas when he argues, “The novel kind of uncertainty that is brought about by those new technologies [...] is intimately linked with their being able to set off complex phenomena in the Neumannian sense” (cp. Dupuy and Grinbaum 2006, 289).<sup>20</sup> Because of the “unpredictable behavior [...] engineers will not know how to make [...] these] machines until they actually start building them” (Dupuy 2004, 18). In a similar tenor, scholars from Prigogine’s Brussels school of complexity have raised concerns regarding control options: We have “focused on designing and implementing artificial self-organizing systems in order

to fulfill particular functions. Such systems have several advantages. [...] However, [d]isadvantages are limited predictability and difficulty of control” (Heylighen 2002).<sup>21</sup> The disadvantages become obvious when we consider the new and unknowable, instability-based risks and the “unknown unknowns.” This thinking concurs with what Alfred Nordmann perceived as a “limit [that] could [...] be reached where engineering seeks to exploit surprising properties that arise from natural processes of self-organization” (Nordmann 2008b, 175). We are on the way to “surrender[ing] control to pervasive technical systems” (ibid., 182).

## Summary and prospect

One might raise doubts as to whether well-established concepts of TA can address and assess the novel type of technology. According to Dupuy and Grinbaum (2006, 293), “none of these [TA] tools is appropriate for tackling the situation we are facing now.” What Dupuy and Grinbaum are expressing is certainly true of classic TA approaches. However, as this chapter sketches, more recent directions in TA such as ProTA offer prospects to enable an early assessment. ProTA analyses the technoscientific core in detail. It is particularly relevant when it is a case of inquiring into alternatives (a) *within* or (b) *to* the technoscientific core itself and, based on this, searching for new or different directions in science, technology, and innovation policy (Schmidt 2016).

A central question emerges in this context (ad a): Can we identify research and development trajectories of synthetic biology that are aimed at designing bio-systems having internal safety features—for example, cell-free systems that share certain positive properties or desired functionalities with cell-based systems but are essentially less fraught with instability and therefore not capable of strong forms of self-organization?<sup>22</sup> Other questions address a more positive direction: Do certain subfields of synthetic biology carry realistic potential to meet the requirements for sustainable development?

In addition (ad b), a key issue on a much more fundamental and certainly more pressing level is whether our late-modern society should really foster and facilitate a “late-modern technology”—a technology that is inherently unstable and linked with the ability to set off self-organizing, complex, and autonomous dynamics.<sup>23</sup> Late-modern technology differs from the classic-modern type of technology with regard to three main categories of characteristics.

First, *phenomenological characteristics*: Late-modern technical systems are based on self-organization. They appear to be un-technical and non-artificial. They show autonomous behaviour and agency properties: Signs and signals, tracks and traces of technology are no longer visible. Culturally established borders are becoming blurred. This universal trend is leading towards a *phenomenological naturalization of technology*. Second, *nomological or ontological characteristics*: The nomological core of late-modern

technology is instability—as a necessary condition for self-organization. Instabilities are intentionally built into the technical systems and their material structures. Here, we can perceive a trend that could be called *nomological naturalization of nature*. Third, *methodological, epistemological, and action-theoretical characteristics*: Late-modern technology is different from other types of technology in that certain criteria are absent. A late-modern technical system is hardly (a) separable from its environment and from the context of application; it lacks (b) reproducibility, (c) predictability, and (d) testability/describability; it gives rise to limitations with regard to (e) constructing and creating; and it eludes (f) monitoring and controlling.

Therefore, this kind of technology has, or if realized to its full extent would have, a life of its own. It could be regarded as a “naturalized technology” (Nordmann 2008b), denoting a *phenomenological* as well as a *nomological naturalization of technology*. Whether late-modern technology can be conclusively called “technology” and whether it is “as a technical system technically possible at all” remain open to debate (Luhmann 2003, 100).<sup>24</sup> Nevertheless, technical systems, devices, things, and objects based on instabilities and showing self-organizing phenomena are beginning to populate our life-world. From an ethical perspective, we need to address this instability-based, late-modern type of technology and undertake the task of developing procedures either to restrict and contain or to shape and deal with it.

Hans Jonas was precursory in this respect (Jonas 1987). His future-oriented ethics might serve as a fundament for a further assessment of synthetic biology. The anti-utopian precautionary principle—with its recognition of an objective indeterminacy of real futures and the limits of knowledge—constitutes a conservatism appreciating the “responsibility for existence.” Jonas already anticipated the ethical challenges of this novel kind of technology back in the late 1970s. ProTA, in alignment with Jonas’s ethics, could offer an interdisciplinary, critical-reflexive approach that enables us to analyse and assess the technoscientific core of this new wave of emerging technologies. From Jonas, we can learn that the central criterion for an ethical assessment of an emerging technoscientific wave is—to paraphrase Kant—that the condition for the possibility of TA and ethics has to be guaranteed. This possibility seems to be challenged in the field of advanced synthetic biology. A novel concept of this kind has been explicitly developed by Christoph Hubig (2015).

In essence, ProTA can be viewed as a paradigm of a critical-reflexive interdisciplinary practice—it is instrumentalist on a deeper and more fundamental level than what has been labelled instrumentalist-strategic interdisciplinarity. As such, it is an extension of well-established TA concepts but does not replace them. David Collingridge’s (1980, 16) central questions “How can we get the technology we want [...], and how can we avoid technologies which we do not want to have?” could be reworded as follows: How can scientists and societal actors conceptualize, understand, and shape the technosciences and technoscientific knowledge in the way we want during the early phases of research and development processes?

ProTA advances an anticipatory approach to deal with these urgent challenges. Since it puts a critical and reflexive mindset at the very centre of technoscience-based knowledge production, it can be deemed to truly epitomize the concept of critical-reflexive interdisciplinarity.

## Notes

- 1 Besides Prospective Technology Assessment (as first conceptualized in Liebert and Schmidt 2010), there are cognate concepts with similar perspectives, such as vision assessment (Grin and Grunwald 2000), real-time TA (Guston and Sarewitz 2002), constructive TA (Schot and Rip 1996), technology characterization (Gleich 2004), hermeneutical TA (Grunwald 2016), science assessment (Gill 1994), early-stage technology analysis (Zweck 2002), and, more generally, innovation and technology analysis; see also the introduction to TA in general: Grunwald (2019).
- 2 See, for instance, Fagerberg et al. (2005).
- 3 This fact is condensed in the diagnosis of the regime of technoscience, see Chapter 4 of this book.
- 4 See Chapter 6 in this book.
- 5 In applying the four orientations, ProTA complements the broad variety of existing TA (and related) studies on synthetic biology; to mention just a few: European Commission (2005), Miller and Selgelid (2006), Vriend (2006), Royal Academy of Engineering (2009), European Technology Assessment Group (2009), Schmidt (2009), and Giese et al. (2015).
- 6 On the one hand, “synthetic biology” seems to be a fairly young term. It was (re-)introduced and presented by Eric Kool in 2000 at the annual meeting of the American Chemical Society. Since then, the term has enjoyed a remarkable career and general circulation in the scientific communities as well as in science, technology, and innovation politics. On the other hand, the notion of synthetic biology emerged about 100 years ago—but it was rarely mentioned until the year 2000.
- 7 The European Technology Assessment Group (2009, 14) uses the term “paradigm” and states that synthetic biology can be considered a “new research paradigm.” See also Schmidt and de Lorenzo (2012).
- 8 Nersessian and Patton (2009) and Nersessian (2012) have investigated the role of engineering concepts in biology, focusing in particular on the process of concept formation, sense making, and model-based reasoning.
- 9 Similar expressions can be found in Nolfi and Floreano (2000) and Schwille (2011).
- 10 The European Technology Assessment Group (2009, 25) goes on to stress: “Central in their ideas is the concept of self-regulation, self-organization and feedback as essential characteristics of cognitive systems since continuous adaptation to the environment is the only way for living systems to survive.”
- 11 My translation of the German version (J.C.S.).
- 12 My translation (J.C.S.). The term “structural science” is exemplified in Schmidt (2008a).
- 13 See, for example, Schmidt (2008a, 2011a, 2015).
- 14 See the previous chapter.
- 15 One could say, in a more provocative manner, that the *more* late-modern societies, facilitated by (the ideals of) synthetic biologists, seem to control the material world, the *more* they lose their ability to control it. A control dialectic emerges, as shown in Kastenhofer and Schmidt (2011) and Schmidt (2015a).



- 16 Jonas did so explicitly in a book chapter (“Lasst uns einen Menschen klonieren: Von der Eugenik zur Gentechnologie,” in “Technik, Medizin und Ethik,” Jonas 1987) published in German only.
- 17 My translation (J.C.S.).
- 18 My translation (J.C.S.). The new “collaborative kind of technology” seems to be closer to humans and their actions and self-perceptions; it is not alien to humans like the mechanical type of technology of classic-modern engineering. From the same perspective, and a few decades earlier in the late 1950s, Ernst Bloch coined the term “alliance technology” to underline the difference between mechanical-engineering and biology-based technology (Bloch 1995). According to Bloch, we may apply that term to a technology based on self-organization. Today, we need to go beyond the thinking of Bloch and consider also the ambivalence of this type of technology.
- 19 My translation (J.C.S.).
- 20 The famous physicist Richard Feynman is quoted as saying: “What I cannot create, I do not understand” (cp. Schwille and Diez 2009, 223).
- 21 In line with these concerns, Joy (2000) warns about the dangers of the well-known and highly disputed dystopia: the “gray goo.”
- 22 Questions of this kind are posed by Gleich et al. (2012), Marliere (2009, 77f), and Schmidt and de Lorenzo (2013, 2201f).
- 23 This is in line with Nordmann’s concerns as to whether we can cope with this kind of technology. His objections are far-reaching: “This is a critique no longer of what we do to nature in the name of social and economic control. Instead it is a critique of what we do to ourselves as we surrender control to pervasive technical systems” (Nordmann 2008b, 182).
- 24 My translation (J.C.S.).