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Futures 37 (2005) 1159–1178
FUTURES
www.elsevier.com/locate/futures

Transdisciplinary collaboration in environmental research

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Available online 16 June 2005

Abstract

One aim of transdisciplinary research is to get natural and social scientists to collaborate, so as to achieve an integrated view of a subject that goes beyond the viewpoints offered by any particular discipline. The question of how transdisciplinary approaches can be practised remains a challenge, however, if the quantitative and the qualitative sciences are both to be included. To explore this question, a series of qualitative interviews was conducted with researchers involved in two recent Swiss and Swedish research programmes. In both these programmes natural and social scientists had to collaborate in problem-driven environmental research. Three findings from these interviews are discussed in this paper: (a) that the researchers have more reasons to offer for non-collaboration than for collaboration, and that most of the thinking about transdisciplinary collaboration takes place at the level of programme management, (b) that the researchers should be classified as Detached Specialists or Engaged Problem Solvers rather than as natural and social scientists, and (c) that if collaboration evolves in a problem-driven research environment it tends to take the form of division of labour. The conclusion this paper draws for problem-driven research is that, paradoxically, the pressure to produce usable results should be reduced if collaboration is to emerge.

1. Introduction

In Transdisciplinary Research (TR) issues are addressed from more than one viewpoint simultaneously. Two aims which motivate researchers to strive for

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doi:10.1016/j.futures.2005.02.009

transdisciplinarity can be distinguished: first, it is epistemologically challenging to search for a viewpoint that lies between, or beyond, disciplines [17,38,40], and, second, it is socially responsible to take knowledge which is produced and organised in accordance with a particular discipline and rearrange it so as to make it useful and meaningful for socially relevant issues [16,25,28,37]. Both of these aims can be found in Jantsch's definition of transdisciplinarity, in what is often referred to as the seminal work in this field.[1]

It is with regard to the second aim that Brewer quotes the well-known statement that '[t]he world has problems, but universities have departments' [5]. TR then is a means to complement the ongoing specialisation of science in order to address large societal challenges. These challenges are further characterised by Lawrence and Després, in a recent special issue of *Futures* on transdisciplinarity, as follows: 'Our incapacity to deal with the above-mentioned problems [climate change, health, land-use, forestry management, renewable and non-renewable resources, housing, poverty and urban planning] is related to their complexity, to the compartmentalisation of scientific and professional knowledge, to the sectoral division of responsibilities in contemporary society, and to the increasingly diverse nature of the societal contexts in which people live' [32].

TR accordingly has to be framed in such a way that it can handle these challenges. If the challenges are slightly reformulated, TR can be *defined* as research

(a) that takes into account the complexity of an issue—meaning the complex system of factors that together explain the issue's current state and its dynamic,
(b) that addresses both science's and society's diverse perceptions of an issue, and
(c) that sets aside the idealised context of science in order to produce practically relevant knowledge.

[1] 'In a purposive system, or human action model, however, *interdisciplinarity* constitutes an *organisational principle* for a two-level co-ordination of terms, concepts and disciplinary configurations which is characteristic of a *two-level multi-goal system*. The important notion here is that with the introduction of interdisciplinary links between organisational levels, the scientific disciplines defined at these levels change their concepts, structures, and aims. They become co-ordinated through common axiomatics—a common viewpoint or purpose. […] The ultimate degree of co-ordination in the education/innovation system, finally, which may be called *transdisciplinarity*, would not only depend on a common axiomatics—derived from a co-ordination towards an 'overall system purpose'—but also on the mutual enhancement of the epistemologies in certain areas, what Ozbekhan calls 'synepistemic' co-operation. With transdisciplinarity, the whole education/innovation system would be co-ordinated in a *multi-level*, *multi-goal system*, embracing a multitude of co-ordinated interdisciplinary two-level systems, which, of course, will be modified in the transdisciplinary framework. Transdisciplinary concepts and principles for the whole system change significantly with changes in the 'overall system purpose' […]. For example, adopting a notion of 'progress' (as inherent in Christian Thought) at this top level would imply a totally different education/innovation system from one for which 'ecological balance', or a notion of cyclical development (as inherent Hinduism and Buddhism), were adopted' [24].

If the motivation for TR is further based on the social responsibility of research, a fourth element of the definition is that TR is research

(d) that deals with the issues and possible improvements of the status quo that are involved in balancing the diverse interests and inputs of individual stakeholders and disciplines. Borrowing an expression from the field of Policy Science, it may be said that such research is oriented towards the common interest [8].[2]

These four features of TR (a–d) are mirrored in the design of transdisciplinary research processes.[3] To adequately address (a) the complexity and (b) the diversity of perceptions of an issue, various parties have to be involved: members of scientific disciplines such as the natural sciences, the social sciences, the humanities, medicine and engineering, as well as non-scientists, including stakeholders, users, so-called problem-owners and laypersons generally. Research is seen as a process (as opposed to a rigid methodology) that may be influenced by a particular discipline's or non-scientist's input. TR is accordingly characterised as a process of mutual learning [25].

The various parties must guarantee not only that the complexity and the diversity of perceptions will be addressed, but also (c) that the idealised context of science will be set aside in order to produce practically relevant knowledge. The non-scientists, by formulating their interests and bringing their input to the research process, must ensure the usefulness of, as well as their commitment to, the resulting ideas and proposed measures [1]. The involvement of natural and social scientists and engineers and health professionals is another way the competencies of analysis and synthesis can be balanced so as to get usable results [9]. To ascertain the usability of such results, a kind of reality check may be carried out to complement the traditional way of assessing scientific work (such as peer review). For this purpose—and also to detect possible negative side effects and therefore to address once again (a) the complexity—Guston and Sarewitz as well as Gross et al. propose to perform such research as a (recursive) learning process [20,21]. Finally, to deal with point (d), some researchers will have to take responsibility for orienting the research process towards the common interest, in order to avoid favouring a particular discipline or particular users' knowledge and interests [7].

The features of TR that ought to be realised by the research process sketched above suggest that TR is to some extent a 'megalomaniac' endeavour. Accordingly, raising interest in and funds for TR in a field of research is normally accompanied by a growing secondary literature on TR, its particularities, its management and its evaluation [3,4,7,11,12,23,30,33,36,43,45]. The following analysis belongs to this literature. Emphasis has been placed on *one* of the measures for fulfilling criteria (a) and (b)—the collaboration between natural and social sciences—in the context of environmental research. Section 2 below

[2] 'Interests […] are 'a pattern of demand and its supporting expectations'. Common interests are those that are widely shared within a community and demanded on behalf of the whole community. Safe drinking water, for instance, is a demand made by nearly all communities and supported by their expectation that they are entitled to a safe, healthy environment' [8].

[3] Some of these particularities of the research process—such as the collaborating disciplines or the stakeholder involvement—are so characteristic of TR that they are used to define it [26,28,31].

briefly discusses this context, and Sections 3 – 7 describe the methodology and present and discuss the results of a series of qualitative interviews that were conducted with researchers from two recent Swiss and Swedish environmental research programmes.

2. Natural and social sciences in environmental research

In environmental research the collaboration between the natural and social sciences does not evolve in a context-free space but in relation to a particular environmental problem that research is required to address. To carry out problem-driven research means to study the structure and dynamic of a particular environmental problem in order to (help to) solve or mitigate it. Both the natural and the social sciences ought to be included, since such problems expand into the realm of nature as well as the realm of society. TR is therefore not an end in itself but a corollary of the need to carry out problem-driven research that includes both the natural and the social dimensions of a phenomenon.

In some cases the natural and the social scientific views of a problem may be seen as two perspectives that can simply be added to each other. This *additive collaboration* occurs for example between disciplines where quantification is the standard means of describing phenomena. Schellnhuber's Earth System Analysis may serve as a sophisticated example. The earth system—more precisely the parts of it that are seen as archetypes of global problems[4]—are modelled in quantitative system analytical terms (levels, fluxes, sources, sinks, constants) as they were introduced by the Club of Rome in its world-model [35]. The aim of this approach is to understand the earth system in order to manage it [39,44]. Quantitative modelling is used as the unifying language in terms of which problems are described and the relevant steering units detected.

In other cases the natural and the social scientific perspectives on a phenomenon cannot be added to each other, because they are qualitatively different. Harriss's call [22] for a more sensitive approach by (quantitative) economics towards qualitative anthropological contributions addresses this duality. Similarly, Rayner and Malone identify two styles of social science, descriptive and interpretative, in a recent summary report on the role of the social sciences in climate change research: 'We use the descriptive paradigm to refer to research that analyses social systems in terms of natural science metaphors, e.g. in terms of mass balance, thermodynamics, or stocks and flows. In contrast, the interpretative approach refers to the analysis of the values, meaning, and motivation of human agents' [41]. Their distinction mainly aims at introducing and legitimising interpretative social sciences as an 'ordinary' way of doing social science that has not been satisfactorily incorporated so far into climate change research.[5]

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[4] Examples are the Sahel syndrome, standing for overexploitation of soil followed by soil degradation, the Aral Sea syndrome, representing an overuse of water-inflow that results in the sea nearly disappearing and an acidification of soil, or the Disaster Syndrome (Havarie-Syndrom), that stands for ecological catastrophes like Seveso, Chernobyl, Exxon Valdez or Bophal [49].

[5] Under the heading 'topic' Rayner and Malone explain why social scientific research on climate change may not even use the word 'climate change', since it does not address climate change as the problem but rather the social settings that invite people to cause it [42]. The need is felt to portray and justify its own perspective to a potential collaborator.

If the two perspectives cannot be added, another procedure has to be found for collaboration. Giri proposes, in regard to the diverse perspectives that have to be negotiated in TR, that '[i]n transdisciplinary striving, relationship rather than our separate disciplinary Being is the ground of our identity' [18]. For the descriptive and interpretative approach this means that TR starts as soon as both approaches are related to each other (which is not the case as long as the interpretative has to be legitimised); TR is the *outcome* of such a process, whereas the main *goal* is always to adequately address the particular environmental problem. This second procedure may be labelled *interrelating collaboration*. Like additive collaboration, it may be simple or sophisticated: it can range from debating different positions to developing new joint concepts. The main point is that perspectives interact.[6]

The two styles which cannot be added but have to be interrelated are not a new phenomenon. It was Snow who first drew attention to them, when he developed his famous distinction between the 'two cultures' 40 years ago. Snow juxtaposed the problem-driven, action-oriented nuclear physicist with the discussion-driven, contemplation-oriented literary intellectual. The lack of communication between the two 'is making it difficult or impossible for us to take good action' [48]. By 'good action' Snow meant solving the problem of unequally distributed wealth and goods on earth and his motivation for stressing the difference between the two cultures was to show that it hindered effective problem-driven research.[7]

Although Snow did distinguish two 'archetypes' of science that prevail, for example in the two styles distinguished by Rayner and Malone [41], his distinction may seem too general today. Other concepts or models of disciplines have emerged that describe the characteristics of the two in a much more comprehensive and elaborated way, such as Kuhn's paradigms [29], or Denkstile [13], or academic tribes and cultures [2,15,27]. In these examples disciplines (but also smaller or larger entities of science) are conceived of as communities of researchers that share a particular world view, including for example axiomatic settings, specific methods, theories and common relevant problems, but also common wordings, journals, conferences and mailing lists. And there are not just two of them but many.

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[6] A recent study finds interrelating collaboration to be highly relevant for successful TR: 'It was one of the most interesting and useful outcomes of this study, that team performance is not at all necessarily combined with a high degree of accordance amongst team members but that it rather seems closely connected to the consciousness of team heterogeneity and to a very open and down-to-earth analysis of divergences. A most striking result of the monitoring study was the observation that a number of projects that had been merged by the programme management and that consequently passed through an extremely difficult start phase of team building performed very well in the end: these merged teams soon enjoyed and cultivated the very direct style of discussion they had developed during the hot kick-off periods of the projects, and they felt more satisfied with their scientific results than many of the other teams that had started off in harmony and that later had great difficulties to establish a culture of open confrontation of contradictory views—inevitably linked to temporary experiences of disunity and conflict' [34].

[7] In a critical comment some years after the publication of his famous Rede Lecture, Snow complained that the 'two cultures' was what the lecture was mainly cited for, and commented: 'Before I wrote the lecture I thought of calling it 'The Rich and The Poor', and I rather wish I hadn't changed my mind' [47].

3. Materials and methods

To explore the collaboration between natural and social sciences, two recent environmental research programmes were studied—the Swiss Priority Programme Environment SPPE (1992–1999) and the Swedish Foundation for Strategic Environmental Research MISTRA (incepted in 1994).[8] Both programmes were chosen because TR and the collaboration between natural and social sciences were considered highly relevant by the programme management. In the case of the SPPE it was during the first meeting of the steering committee that a member who represented the Swiss Agency for Environment, Forest and Landscape (Bundesamt für Umwelt Wald und Landschaft, BUWAL) stated that as research had produced a fair amount of knowledge about environmental problems, the time was now ripe for research on problem solving. The SPPE finally closed with an international conference on transdisciplinarity in 2000, signalling that 'different academic disciplines working jointly with practitioners to solve a real-world problem' [26] should be the lasting result of this programme. MISTRA was engaged in a conference on 'interdisciplinary and problem-oriented research and practice' in 1998 [6]. Additionally—and in alignment with feature (c) of the definition of TR given above—MISTRA states on its homepage that its programme 'is a meeting place between two worlds. One is the research community, which is driven by the need to constantly be at the cutting edge of knowledge. The other one is the world of real action, which is driven by the need to solve environmental problems'.[9]

The analysis of the collaboration between natural and social sciences—the collaboration case study—was carried out as one of four case studies in the research project 'The production of socially robust knowledge', which was funded by the Swiss National Science Foundation [19]. The aim of the research project was to explore knowledge production in areas where scientific knowledge and interests meet those of other societal actors and its research design was qualitative. Creswell [10] lists six characteristics of such research, according to which qualitative researchers (1) are concerned primarily with processes, rather than outcomes or products, (2) are interested in meanings, rather than facts which might seem to speak for themselves, (3) are the primary instrument for data collection and analysis themselves, (4) do fieldwork, (5) work descriptively and (6) are inductive, in that they build abstractions, concepts, hypothesis, and theories from details.

Characteristic (1) is clear from the focus of the collaboration case study: the process of collaboration between the natural and social sciences, while characteristics (2), (3), (5) and (6) become transparent in the presentation and discussion of results in Section 4. For the fieldwork (4) in the collaboration case study a partly standardised interview method was chosen: the problem-centred interview [14], in which the interviewer provides only marginal thematic orientations to stimulate the interviewee to formulate and conceptualise the issues of concern. This is because—as in narrative interviews—the qualitative

[8] For further information about each programme see www.sppe.ch and www.mistra-research.se.
[9] http://www.mistra.org/eng/ 10 November 2004.

researcher is as much interested in *what* is stated as in *how* it is stated: the content of the answers and the way of answering are the two main sources of evidence.

Twenty-seven problem-centred interviews were conducted during the years 2000–2002 with researchers involved in either the SPPE or MISTRA. Research in both programmes was structured in a similar way: sub-units were formed, grouping 10–20 individual research projects around one particular issue, such as coastal management, sustainable nutrition, transboundary air pollution, biodiversity or waste, and collaboration between the natural and social sciences was to take place within these modules. In the SPPE, researchers in the five modules funded in the second period of SPPE (1996–1999) were interviewed. In MISTRA, researchers from those five modules which stated on the homepage that collaboration was a relevant issue were interviewed. Two interviews were conducted within each module.

To find the interview partners, an e-mail was send to the head of each module stating the theme and aim of the study and asking for suitable researchers—one from the natural and one from the social sciences. It was left to the module coordinators to decide what would constitute a representative natural or social scientist within a module. The categories of natural and social scientist to be interviewed, however, became rather fuzzy; it was sometimes difficult to distinguish separate disciplines. Among the natural scientists, there were natural scientists and engineers, and mixtures of both; among the social scientists, there were 'real' social scientists, natural scientists who had a second degree in social sciences, and also some natural scientists who worked in the field of social sciences. For the analysis, however, the classification given by the coordinators was used. In addition to the researchers, the managers of both programmes were also interviewed to get their views on collaboration and the other dimensions of problem-driven research.[10]

The interviewees were invited to report on their experiences in and opinions on collaborating with 'the others'. Besides this main question, further dimensions of problem-driven environmental research were addressed (synthesis, usability of results, inclusion of the users, normative commitment) in order to attain a more comprehensive picture of the significance of the collaboration between disciplines in relation to other requirements that had to be fulfilled.

The interviews were transcribed and coded thematically. For the present analysis only those passages dealing with the issue of collaboration and giving answers to the three working hypotheses have been considered.

4. Results and discussion

In Section 1, TR was defined according to four features, and the collaboration between the natural and social sciences was introduced as a measure to take into account two of them: (a) the complexity of an issue and (b) the diverse ways it is perceived by science

[10] At the beginning of every interview the interviewees were assured that they would not be recognisable from a publication. For this reason no further information has been given about the interviewees and the modules: the quotes indicate only whether the passage is taken from an interview with a natural or a social scientist.

and society. In Section 2, two types of collaboration between the natural and social sciences in environmental research were distinguished: *additive* and *interrelating*. In interrelating collaboration, qualitative and quantitative research could cooperate with each other, which would be something like collaboration between proponents of Snow's famous two cultures.

For the analysis of the interviews three working hypotheses were derived from what has been stated so far: first on the status of TR in the studied programmes; second on the roles of the natural and social sciences; third on the content of research. These hypotheses are:

1. Collaboration between the natural and social sciences takes place as a means to handle the complexity of an issue and the diverse ways it is perceived by science and society.
2. There are specific roles for the natural and social sciences that correspond to Snow's two cultures.
3. Collaborating natural and social scientists develop new concepts, which allow them to address the natural as well as the social dimensions of an issue.

In the following, certain sequences from the interviews will be presented. This being a qualitative analysis, the author has selected passages—in his role as research instrument—that articulate a particular point of interest. The presentation and discussion of these passages is descriptive, inductive and concerned with meaning: descriptive since what is presented and discussed is the actual state of TR in these programmes rather than how TR should be carried out; inductive and concerned with meaning since it interprets selected passages by proposing a broader framework, which gives a particular sense to the passages.

5. Working Thesis 1. Collaboration between the natural and social sciences takes place as a means to handle the complexity of an issue and the diverse ways it is perceived by science and society

Working Thesis 1 would be proven if the collaboration in both environmental research programmes were perceived as a means to an end. The interviews did not provide much evidence to support this thesis. A noteworthy difference, however, can be found between the researchers' and the programme management's answers.

5.1. The researchers' report

On being asked whether he would like to add anything, a social scientist studying how natural scientific concepts could most effectively be transferred to the area of politics gave a clear statement concerning collaboration:

> Before you arrived here, I made up my mind and one question rose in my head, saying that you should ask how I collaborate with natural scientists. And if you should ask me that question I thought that I should answer that I don't collaborate at all with natural scientists, […] if you take collaboration in a bit deeper sense,

> as 'carrying out your own research, to collaborate with other sub-programmes and the people from the natural sciences'. And then the answer is: 'I don't do that'. I think it's very useful […] to be part of the programme. Because to us it's important to—in some way—understand what the natural scientists do, and we can ask them, we can talk to them in a very informal way and be up to date about what is going on. […] But we don't collaborate, we don't do studies together. (Social scientist)

A natural scientist working within a systems analysis framework—and therefore in an additive collaboration—was afraid that the scientist from the other culture (here an imagined philosopher) would probably not accept the framework and instead would criticise it:

> Q: Would you say it is difficult to collaborate with the social sciences because they're not quantifying?
>
> A: Well, I think it is, I don't think that's the main problem. I think the main problem is that some of them are just philosophers. They don't think in terms of solutions or knowledge that could be useful for action. They just think and walk around. I like philosophy, very much, personally. But it is not a good use when I want to produce solutions. (Natural scientist.)

A further natural scientist, engaged in residual waste cleaning technologies, questioned the relevance of collaboration between the natural and social sciences by suggesting that engineers could eventually produce a much more fruitful collaboration among disciplines. Finally, a social scientist claimed that she had too many tasks to fulfil—synthesis of part-results, implementation and communication of results, and finally her own studies—which meant that 'collaboration' in this particular project group was delegated to one person who, apart from having to assume responsibility for this delicate issue, also had to complete her doctoral thesis.

The researchers knew they ought to achieve transdisciplinary research (or at least they remembered about it when asked to give an interview on the topic). They also realised when they had not fulfilled this obligation and were able to explain why. However, the admission of non-collaboration, the reasoning about its impossibility or uselessness, the critical remarks about its relevance and the finding that the responsibility for collaboration was delegated to particular researchers—all this indicates that collaboration between the natural and social sciences was not perceived as a sine qua non of problem-driven research but rather as just one more demand on the part of the programme management that had to be met to get funded.

5.2. The management's view

Unlike the researchers, the programme managers, when asked about collaboration, not only did not question the relevance of the issue but also provided further insights into it. One of these managers described the changing relationship between the natural and social sciences over the previous years—in congruence with Rayner and Malone [41]—as an emancipation of the social sciences from the natural sciences. Whereas the social scientists were perceived in a socio-technological role at the beginning of the programme—as those

who help change society in order to fulfil the requirements of, for example, the substance fluxes defined by the natural sciences—they gained increasing respect during the course of the programme as practitioners of a science with a realm, questions and methods of its own. A second programme manager reported a parallel development in the way problems were addressed:

> I think that the whole tradition of environmental research […] has been over the decades very much natural science oriented in the sense that it started […] in 1960 essentially when natural science defined problems, concentration of DDT or […] acid rain or whatever […]. And that gave input to policy makers who then proposed legislation, who then proposed…and so on, and so on. And that has been very successful, so it has been an engineering type of approach [and] environmental sciences then came up with the solution and someone picks up the ball, runs with it and does something to it that hopefully solves the problem, and perhaps the whole thing takes yet another round […]. My theory is that most of the problems that we have…most of the easy problems have been solved in the area of environment…the tricky ones remain […].
>
> I think that the whole area of environment is […] defined in terms of natural science, but not defined in terms of social science […] and everything somehow starts and ends in natural science, it is seen to start and end with natural science. But when you sort of scratch on the surface of a natural science defined programme you come up with issues like biological diversity which is of course […]. On the surface it may be natural science but […] very close to the surface it's not at all natural science, actually it's social construction […]. (Natural scientist.)[11]

This programme manager describes a shifting way of looking at environmental problems and suggests an intrinsic reason for this: the environmental problems that were addressed successfully in the past were those which could be solved by technical measures. Such measures were, for example, to replace ozone-depleting substances with substitutes, to optimise burning processes (low-NO_x), to adopt catalytic converters in cars or to produce heating oil with a low sulphur content. The 'tricky' problems that remain are the ones that cannot be solved immediately by way of technology and instead concern human behaviour and routines. Global climate change is a paradigmatic example of a tricky problem connected to the ever more intensive use of fossil fuels. Biodiversity loss, which is interrelated with the intensive agricultural use of land and the overfishing of water areas, would be a second example. Thus, from this manager's point of view, the growing importance of the social sciences in relation to the natural sciences is not only a question of emancipation but also a logical next step towards dealing adequately with the prevailing environmental problems. In this sense the collaboration between the natural and social scientists receives support from the (prevailing) problems themselves.

To reflect on the roles of the natural and social sciences in TR and even on changes in their relationship over time seems to be part of the programme management's daily

[11] From the interview it is not clear whether 'socially constructed' means that the problems are the consequence of routine behaviour of society or that they do not exist as such in nature and are a conceptual construct.

business. For the researchers, on the other hand, collaboration seems to be just one demand among many, instead of, as Working Thesis 1 assumes, a self-evident means of carrying out TR. The discussion of Thesis 1 thus reveals a discrepancy between the programme's overall planning and its realisation by individual researchers: collaboration between the natural and social sciences as a means of TR exists mostly at the level of the overall programme but is almost non-existent at the level of joint projects. For the researchers, the most burning questions are still of a more basic kind: 'As a sociologist to collaborate intimately with a biologist. What should we write about? I don't know!' (Social scientist).

6. Working Thesis 2. There are specific roles for the natural and social sciences that correspond to Snow's two cultures

The idea of interviewing the researcher about the collaboration between the natural and social sciences implicitly assumes that this distinction is a relevant issue in problem-driven research. A deeper analysis of the interviews, however, shows that some of the interview partners in fact refused to discuss this issue as expected.

Two researchers engaged in a project on sustainable food production addressed the collaboration between natural and social sciences at three different places in the interview. They reflected on natural science, social sciences *and* systems analysis; on natural sciences, social sciences *and* implementation; and on natural sciences, social sciences *and* participation. Both were willing to consider the issue of collaboration only in a given problem context.

A second, more explicit observation of the same phenomenon was provided by a researcher who was also engaged as an expert in international environmental politics. When discussing the different 'hats' worn in the fields of science and politics, the interviewer (the author of this paper) suggested that the uncertainty of scientific findings might be common ground for collaboration:

> Q: […] To come back once more to the uncertainty. In my eyes there is […] a big problem in what to do with the scientific uncertainty in this area […] Did you ever think to go further into this aspect [by including] social scientists to look at it? […]
>
> A: To be honest I haven't thought of uncertainty as really a social scientific issue. But it is, of course, it is. It is really. […]
>
> I want to turn the whole issue around, if you look into what is important for a policy maker when he discussed this area. And of course you have environmental goals […] in terms of diminishing acidifications in Europe. And the first question is: is the goals right? […] Are we over doing or are we doing too little? […]
>
> The second problem is that the problem […] we're talking about transboundary air pollution […] is a problem of several environmental effects and several components. And there is of course [the] question: Do we have enough knowledge to give the right priority to the compounds? […] Do we give the right priority between ammonium and nitrogen oxides when we're talking about nutrification? […]

> Then you have a third question. […] Is the share of control margins between countries right? Since that's what you calculate […]. You look at the cost and you come up with different requirements for Denmark or Finland or whatever it is. Switzerland. Or […] if you look in the sectors: is division between sectors right? Do you put the right pressure on energy sector compared to the transportation sector? Or compared to agriculture? […]
>
> And […] if you realise that there is a problem—we have a problem of acidification, we have a problem of health effects from particles and so on—these three questions are to me the main questions. […] Uncertainty should be put in relation to such types of questions. And then you can do whatever uncertainty calculations you want. Since you […] easily get lost in uncertainties. And that is what I call robustness instead. […] How much error can we have in the cost estimates before we turn our […] control requirement from Austria to Switzerland? That is much more interesting […] that's my thinking. I think this is perhaps more social science than natural science. (Natural scientist.)

When the interviewer explicitly tried to introduce the issue of uncertainty as an abstract concept to help discuss collaboration between natural and social sciences the researcher did not cooperate but instead turned the whole issue around so as to approach it from the point of view of the problem that had to be tackled. In addition he closed his remarks with the comment that his approach probably did not really fit the natural/social sciences dichotomy.

Based on these observations and triggered by a further comment by a natural scientific researcher, who claimed that the social scientist had not truly engaged with the problem, it was decided that it would be more appropriate to group the researchers according to the way they related themselves to environmental problems rather than to collaborators from the other 'culture'. Two groups can be distinguished in this way: one engaged in solving environmental problems, the other in providing expertise to those who are dealing with the problems. The two groups are referred to hereafter as *Engaged Problem Solvers* and *Detached Specialists*, respectively. One of the Engaged Problem Solver's core characteristics is that he or she refuses to discuss a topic in an abstract way, and so is willing or able to think and debate issues only in a given problem context. This distinguishes him or her from the Detached Specialist, who is willing and able to discuss things in a much more abstract, generalised and context-free manner.

The distinction between Engaged Problem Solvers and Detached Specialists is not the same as the one between the natural and the social scientist. In a project on climate change, a natural scientist emphasised that his main interest in the programme was to perform sophisticated climate research into a unique climatic situation in the Swiss Alps. He was, as a Detached Specialist, primary interested in the mechanisms of climate and only secondarily in climate change as an environmental problem of high priority. In contrast, an Engaged Problem Solver was in charge of the joint social scientific project, whose object was, by means of focus groups, to make lay people familiar with the natural scientific findings about climate change, as a first step towards encouraging them to make political statements requesting a more rigorous climate policy. By using different kinds of focus

groups in different settings, various ways of informing lay people were tested, in order to determine the most effective means of knowledge transfer. The problem was perceived as being how to inform people most effectively about natural scientific findings on climate change, with climate scientists providing the relevant knowledge. A Swedish project on air pollution was organised the other way around: here the natural scientist was engaged not only as a researcher but also as an expert in international negotiations to regulate air pollution. The collaborating social scientist perceived himself in the role of the Detached Specialist in knowledge transfer between natural science and international politics. In this role he advised the natural scientist on how to situate his ideas most successfully in the realm of politics.

In both the climate project and the air pollution project the problem was how to introduce an idea into a particular sector of society. Typically, the social scientist consults the natural scientist about *what* to implement and the natural scientist consults the social scientist about *how* to implement. But the natural scientist is not necessarily a Detached Specialist and the social scientist is not necessarily an Engaged Problem Solver: either may be a person who implements or a person who advices the implementers. The two roles are interchangeable and not mutually exclusive.

Thesis 2 is asserted insofar as Snow's two cultures can be equated with the Engaged Problem Solvers and the Detached Specialists: the former—like Snow's physicists—are keen on (active) problem solving, whereas the latter—like Snow's literary intellectuals—are keen on providing expertise in the form of letters. But, contrary to Snow's claim that the literary intellectuals do not engage at all with the world's most relevant problems [46], in the context of problem-driven environmental research both the Engaged Problem Solver and the Detached Specialist are indeed engaged. In this kind of research, within which both programmes being discussed here evolved, the researchers were forced to address environmental problems in order to be funded. The Engaged Problem Solver and the Detached Specialist can therefore be seen as adaptations of Snow's cultures to a particular context.

7. Working Thesis 3. Collaborating natural and social scientists develop new concepts, which allow them to address the natural as well as the social dimensions of an issue

As in the case of Working Thesis 1, the management and the researchers gave different answers.

7.1. The management's view on new concepts

Though the managers did not mention the new concepts explicitly, they were aware of a core challenge of such an endeavour. One programme manager accordingly said that at first glance the remaining tricky problems appeared to have natural causes, but that on further investigation they turned out to be socially constructed (see Working Thesis 1). Another interview partner from the programme management addressed the question of

how a social scientist would approach a problem when he or she portrayed the relation between social sciences and problem-driven research in a more general sense:

> It is quite right, as many researchers do, to emphasise that you cannot really—from the point of view of a social scientist—promote problem-solving in a very direct way, I mean it's not as direct as in engineering research […]—the decision makers are the ones who will be making the decisions [and] you produce knowledge or analysis, […] that are to be helpful to society in making decision.
>
> […] Most social scientists would start by thinking about how the problem is defined, who has defined it and so on—and often very rightly so. […] There are [insights] to be gained by more social science research on these issues. But […] you have to adapt also your way of looking at it. What are the problems? And what is the help that can be provided to arriving at solutions from social sciences? I mean […] it might be more […] perhaps providing a new perspective, or changing a perspective, or pointing at some rather neglected factors or factors that are not yet discussed. (Social scientist)

The point of 'thinking about how the problem is defined and who has defined it' is that (interpretative) social scientists are interested in redefining the problem in order to highlight the underlying social implications. It is evident that the programme management—or at least a part of it—was not only aware of the challenges of such concepts and their hybrid character, as naturally given and socially constructed, but also knew that such a development of new common concepts would require a re-examination and redefinition of the problem.

7.2. The researchers' report on new concepts

The researchers were at a different point from the management. At the time of the interview, the projects had been running for at least three and as much as 6 years. Nevertheless, the general understanding of how the collaborator from the natural or social sciences conducts research and respect for the way in which he or she was looking at the problem could still not be taken for granted.

An Engaged Problem Solver described the slow learning process in the urban water project, which was supposed to develop and implement a new generation of sustainable urban water infrastructure. For example, urine separation would remove excrements and urine in the toilet in such a way as to process them individually and therefore more efficiently in two parallel wastewater systems. The first phase of the project, which is reported below, describes such a learning process as a development from a failed additive collaboration to an acknowledgment of the difference between the 'cultures'.

> …the main concept for our systems analysis is that first we develop criteria for sustainability. How many kilograms of phosphors can we allow to be discharged into the sea and so on. And then we develop a model to calculate how many kilos of phosphors are discharged and then we apply this to so-called model cities, real areas. And then we try to develop different—system structure we call it—physical structures or organisational structures and apply these criteria and these models to

> this alternative system. […] The next step is to develop scenarios, but we haven't come to that yet, we will in the next programme phase. […] We could do this for health and hygiene, we could do it for environmental impact, we could do it for use of natural […] resources and a couple of others. But when it came to social sciences it was much more difficult. […]
>
> An example: A model—what is a model? We don't use models! [Laughing] And then they imagined maybe some computerised mathematical model with input data and output data and that's it. And of course we have such models but […] a model is a picture of something, of reality. I was trying to explain but they couldn't buy that concept. They were not able to develop pictures of reality in the sense we wanted them to do. And they were not able to generalise the results. […] I have been trying to say, if you read that and that report […] and you give me a summary and make some conclusions and try to generalise it: What do people think? How do they act in a certain situation? How do they react to the urine-separating toilet for instance, or other devices? What are their environmental opinions to different systems? Do they protect nature or what are their driving forces to use the system—or misuse it? Now—she couldn't say. […] She said two things really. The first thing is, it happened there and then, in that area 1998, somebody says something in that area, you cannot generalise that to another area at another time. That's not possible. […] And then she said another thing: this evaluation at that first day was made by a sociologist—I'm not a sociologist. They have another theory, they look at it from another viewpoint with different methods, I cannot use that. Or: that was done by a pedagogical scientist, I cannot use it. […] When I say 'social science' I think that's defined, but it's not! [Laughing]. There are so many disciplines within social science that work differently and look at the human being differently. Can you manipulate that human being or is it…do we have a free will? Or do we have intentions or do we just react on what people tell us? So—interdisciplinary differences within social science, […] within behavioural sciences there was one […] they couldn't generalise these things. […] They want to understand why people do things, we want to control it [Laughing]. (Natural scientist.)

This interview was conducted at the end of the first phase of the research programme. The learning process, within which the additive collaboration was given up and the social scientist's approach was accepted, thus covered a period of about 3 years of collaboration.

In this case the Engaged Problem Solvers learned to know and respect the perspective of the social scientists during collaboration, which was not the case in every project. This project would thus be ready to develop interrelating collaboration. In the Swedish as well as in the Swiss research programme, however, the pressure to make use of what had been studied so far grew in proportion to the programme's running time. The demand to focus on implementation was therefore most intense at the end of the first 3-year period when the proposal for the second period had to be written. In the urban water project it was certain that the proposal for the second period would include the installation of new urban water systems in a number of communities, but the form of further collaboration between the natural and the social scientist in this project was still open. The social scientist proposed a division of labour in the implementation: the natural scientists and engineers would

evaluate the technical aspects and the impact on substance flows; the social scientist would study how people dealt, for example, with the urine-separating toilet and what routines they would develop to include the new device in their daily lives.

Thus, in the case of urban water, after 3 years of intensive efforts and the failure to synthesise knowledge from the natural and social sciences in additive collaboration and to learn about the other 'culture', the pressure for implementation and the acknowledgment of the difference between the 'cultures' gave rise to the idea of a division of labour: the natural scientific aspects of the implementation would be taken care of by the natural scientists and the social by the social scientists. In this case both can be designated Engaged Problem Solvers, each with their own particular viewpoint and responsibilities.

However, whereas in the urban water project a division of labour was a reasonable and practicable approach for implementation, it posed unexpected problems in a project on sustainable food consumption. A psychologist and an environmental engineer were to analyse consumer patterns so as to identify opportunities for and obstacles to sustainable food consumption. The first step was for a psychologist to study citizens' shopping habits. To know which variables should be collected she needed an ecological profile of food products. This was determined by an environmental engineer, using an environmental product analysis.[12] In line with the current state of the art, the most relevant variables were said to be the way the food is produced (organic or not), its packaging, and the way the consumer goes shopping (by car, by public transport, by bicycle or on foot). The psychologist classified consumer patterns in accordance with these variables: to go on foot to buy unpacked organic food was defined as ecologically sound behaviour. Based on this analysis, she looked for opportunities that helped or obstacles that hindered consumers in ecologically enhancing their consumer patterns.

Meanwhile, the environmental engineer studied aspects of products that had not so far been dealt with in depth and found that they were quantitatively more relevant than those used to classify consumers. According to his results, the really relevant variables were the distance that food was transported before it reached the shop, the means of transportation (ship, plane or road transport) and whether or not the products had to be cooled. The altered criteria for ecological profiling conflicted with the classification of ecological consumer patterns and therefore also with the analysis of opportunities and obstacles. Accordingly, in the interview the psychologist recorded her astonishment at the inherent uncertainty and variability of the natural scientific approach, which she had not been prepared for. Unlike the example of urine separation, in this project division of labour was conceived of in a more interdependent way. The results of the environmental product analysis were intended for use as a basis for the psychologist's work. What might have looked like a step forward in the direction of collaboration (in the form of division of labour) was challenged in this case by the nature of the research processes, where what seemed essential at the beginning of the project could become irrelevant by the end.

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[12] The method was what is called Life Cycle Assessment (LCA), as it is for example extensively introduced, developed and discussed in the *International Journal of Life Cycle Assessment*. With an LCA the energy use and the substance flows which are caused during the life-cycle of a product, i.e. from the extraction of the corresponding raw materials to the depositing or incineration of the waste, are calculated.

Working Thesis 3—as with Working Thesis 1—points again to the discrepancy between the planning of the programme and its realisation in individual projects. Whereas the management seemed to be aware of the challenges of these new concepts, understood their hybrid character and knew that to develop joint concepts they would have to start by defining the problem, the researchers, even if they had already prepared a joint proposal originally, needed several years of collaboration to become acquainted with and develop respect for the other 'culture' before they could develop such concepts.

In both programmes after the first 3 years the pressure to make use of what had been studied so far became overriding and affected proposals for the second period. Some projects reacted to this pressure with a pragmatic division of labour: the natural scientists took care of the natural scientific or engineering aspects of implementation; the social scientists took care of the social aspects. In one such project, within which the results of two shared projects were interdependent, the division of labour conflicted with the knowledge produced in these projects.

8. Conclusions

The analysis of 27 interviews with researchers from the Swiss and the Swedish environmental research programmes produced the following insights, among others, into collaboration between the natural and social sciences in TR:

- The programme management has a highly developed understanding of collaboration as a means of TR. It is able to report on the changing relationship between the natural and social sciences in environmental research and is aware of some of the problems that the development of new joint concepts would pose.
- The researchers, on the other hand, perceive transdisciplinarity not as a sine qua non of problem-driven research but rather as just one additional demand on the part of the programme management.
- The researchers need several years of collaboration to become acquainted with and develop respect for the other 'culture' before they will be able to develop joint concepts. This is equivalent to the first funding period of a possible 6-year grant in both programmes.
- As the pressure to produce usable results grew during preparations for the second period, a division of labour approach was used in which each side took responsibility for either the natural or the social scientific aspects of implementation.

If it is assumed that interrelating collaboration could lead to new hybrid concepts, and if it is further maintained that such a collaboration between the natural and social sciences is an essential precondition for creative and effective problem-driven research, the following may be concluded: the pressure to produce usable results should be replaced by the more general pressure to rearrange a particular discipline's knowledge so as to make it useful and meaningful for socially relevant issues. And this pressure should not be mild at the beginning and intense in the middle of the programme but steadily present as a guiding force—and as the reason for aiming at collaboration between the natural and social

sciences—for the whole duration of the programme. But the challenge which remains is to provide appropriate incentives to attract the interest of the Engaged Problem Solvers and the Detached Specialists and for them to join forces in working in this direction.

Acknowledgements

My thanks go to the researchers who agreed to be interviewed and reported so many interesting things, to Helga Nowotny who enabled the project, to the Nils-Eric Svenson Scholarship of the Bank of Sweden's Tercentenary Foundation (Stiftelsen Riksbankens Jubileumsfond) and Aant Elzinga who made me go to Sweden, to Alexandra Hofmänner who discussed several older versions of this paper intensively with me, to the reviewer who made me revise the paper once again and to Di Kilpert for the helpful editing.

References

[1] E. Arias, H. Eden, G. Fischer, A. Gorman, E. Scharff, Transcending the individual human mind: creating shared understanding through collaborative design, ACM Transactions on Computer–Human Interactions 7 (1) (2000) 90.
[2] T. Becher, Academic Tribes and Territories—Intellectual Enquiry and the Cultures of Disciplines, The Society for Research into Higher Education [etc.], Stony Stratford, Milton Keynes, 1989.
[3] M. Bergmann, Indikatoren für eine diskursive evaluation transdisziplinärer forschung, TA-Datenbank-Nachrichten 1 (12) (2003) 65–75.
[4] V. Boix Mansilla, H. Gardner, Assessing Interdisciplinary Work at the Frontier: An Empirical Exploration of 'Symptoms of Quality', 2003, Interdisciplines, www.interdisciplinesorg/interdisciplinarity/paper/6.
[5] G.D. Brewer, The challenges of interdisciplinarity, Policy Science 32 (1999) 328.
[6] G.D. Brewer, K. Lövgren, The theory and practice of interdisciplinary work, Policy Science 32 (1999) 315–317.
[7] A. Bruce, C. Lyall, J. Tait, R. Williams, Interdisciplinary integration in Europe: the case of the Fifth Framework Programme, Futures 36 (2004) 457–470.
[8] T.W. Clark, The Policy Process: A Practical Guide for Natural Resource Professionals, Yale University Press, New Haven, 2002. p. 13.
[9] R. Costanza, A vision of the future of science: reintegrating the study of humans and the rest of nature, Futures 35 (2003) 654.
[10] J.W. Creswell, Research Design—Qualitative and Quantitative Approaches, Sage, Thousand Oaks, 1994. p. 145.
[11] R. Defila, A. Di Giulio, Transdisziplinarität evaluieren—aber wie? Panorama Sondernummer, in Panorama, 1999, Schwerpunktprogramm Umwelt Schweiz, p. 40.
[12] S.R. Epton, R.L. Payne, A.W. Pearson, Managing Interdisciplinary Research (Second International Conference on the Management of Interdisciplinary Research, Manchester, July 1981), Wiley, Chichester, 1983.
[13] L. Fleck, Genesis and Development of a Scientific Fact, The University of Chicago Press, Chicago, 1979. [1935].
[14] U. Flick, E. von Kardorff, H. Keupp, L. von Rosenstiel, S. Wolff, Handbuch Qualitative Sozialforschung, Psychologie Verlags Union, München, 1991. p. 178.
[15] P. Galison, Image and Logic—A Material Culture of Microphysics, The University of Chicago Press, Chicago, 1997.

[16] M. Gibbons, C. Limoges, H. Nowotny, S. Schwartzman, P. Scott, M. Trow, The New Production of Knowledge—The Dynamics of Science and Research in Contemporary Societies, Sage, Thousand Oaks, 1994.
[17] A.K. Giri, The calling of a creative transdisciplinarity, Futures 34 (2002) 103–115.
[18] A.K. Giri, The calling of a creative transdisciplinarity, Futures 34 (2002) 106.
[19] P. Gisler, M. Guggenheim, A. Maranta, H. Nowotny, C. Pohl, Imaginierte Laien. Die Macht der Vorstellung in Wissenschaftlichen Expertisen, Velbrück Wissenschaft, Weilerswist, 2004.
[20] M. Gross, H. Hoffmann-Riem, W. Krohn, Realexperimente: Robustheit und Dynamik ökologischer Gestaltungen in der Wissensgesellschaft, Soziale Welt, 54, 2003, pp. 241–258.
[21] D.H. Guston, D. Sarewitz, Real-time technology assessment, Technology in Society 24 (2002) 93–109.
[22] J. Harriss, The case for cross-disciplinary approaches in international development, World Development 30 (3) (2002) 487–496.
[23] K. Hollaender, M.C. Loibl, A. Wilts, Management of transdisciplinary research in: G. Hirsch (Ed.), Unity of Knowledge in Transdisciplinary Research for Sustainability in Encyclopaedia of Life Support Systems, Eolss Publisher, Oxford, 2002.
[24] E. Jantsch, Towards Interdisciplinarity and Transdisciplinarity in Education and Innovation, in: Center for Educational Research and Innovation (CERI) OECD, Problems of Teaching and Research in Universities, 1972, p. 105f.
[25] J.T. Klein, W. Grossenbacher-Mansuy, R. Häberli, A. Bill, R.W. Scholz, M. Welti, Transdisciplinarity: Joint Problem Solving among Science, Technology, and Society, in Synthesebücher, Swiss Priority Programme Environment, Birkhäuser, Basel, 2001.
[26] J.T. Klein, W. Grossenbacher-Mansuy, R. Häberli, A. Bill, R.W. Scholz, M. Welti, Transdisciplinarity: Joint Problem Solving among Science, Technology, and society, in Synthesebücher, Swiss Priority Programme Environment, Editor, Birkhäuser, Basel, 2001. p. 4.
[27] K. Knorr Cetina, Epistemic Cultures—How the Sciences make Knowledge, Harvard University Press, Cambridge, MA, 1999.
[28] R. Kötter, P.W. Balsiger, Interdisciplinarity and transdisciplinarity: a constant challenge to the science, Issues in Integrative Studies 17 (1999) 87–120.
[29] T.S. Kuhn, The Structure of Scientific Revolutions, third ed., University of Chicago Press, Chicago, 1996. [1962].
[30] G. Laudel, Interdisziplinäre Forschungskooperation—Erfolgsbedingungen der Institution 'Sonderforschungsbereich', ed. Wissenschaftszentrum Berlin für Sozialforschung, Edition Sigma, Berlin, 1999.
[31] R.J. Lawrence, Housing and health: from interdisciplinary principles to transdisciplinary research and practice, Futures 36 (2004) 488.
[32] R.J. Lawrence, C. Després, Futures of transdisciplinarity, Futures 36 (2004) 398.
[33] M.C. Loibl, Empfehlungen zu Praxiseinbezug, Produktentwicklung und Ressourcenplanung, Begleitforschungsprojekt SU11 zur Österreichischen Kulturlandschaftsforschung und Internationale D-A-CH Kooperation, Wien, 2001, p. 28.
[34] M.C. Loibl, Integrating perspectives in the practice of transdisciplinary research, in: D. Bauknecht, R. Kemp, J.-P. Voß, (Eds.), Shaping Sustainable Transformation—Introducing Reflexivity to Processes of Socio-Ecological Change, (in preparation).
[35] D. Meadows, D. Meadows, E. Zahn, P. Milling, The Limits to Growth, Universe Books, New York, 1972.
[36] M. Mogalle, Management Transdisziplinärer Forschungsprozesse, Birkhäuser, Basel, 2001.
[37] J. Mittelstraß, Enzyklopädie Philosphie und Wissenschaftstheorie, Metzler, Stuttgart, 1996.
[38] B. Nicolescu, LA TRANSDISCIPLINARITÉ—Manifeste, Éditions du Rocher, Monaco, 1996.
[39] G. Petschel-Held, M.K.B. Lüdeke, F. Reusswig, Actors structures and environment—a comparative and transdisciplinary view on regional case studies of global environmental change, in: B. Lohnert, H. Geist (Eds.), Coping with Changing Environments, Ashgate, London, 1999, pp. 255–293.
[40] T. Ramadier, Transdisciplinarity and its challenges: the case of Urban studies, Futures 36 (2004) 423–439.
[41] S. Rayner, E.L. Malone, in: S. Rayner, E.L. Malone (Eds.), The Challenge of Climate Change to the Social Sciences Human Choice and Climate Change vol. 4 (1998), p. 37.
[42] S. Rayner, E.L. Malone, in: S. Rayner, E.L. Malone (Eds.), The Challenge of Climate Change to the Social Sciences Human Choice and Climate Change vol. 4, Battelle Press, Ohio, 1998, p. 51.

[43] M. Röbbecke, D. Simon, M. Lengwiler, C. Kraetsch, Inter-Disziplinieren: Erfolgsbedingungen von Forschungskooperationen, Wissenschaftszentrum Berlin für Sozialforschung, Edition Sigma, Berlin, 2004.
[44] H.J. Schellnhuber, 'Earth System' analysis and the second Copernican Revolution, Nature 402 (Suppl. 2) (1999) C19–C23.
[45] M. Schophaus, S. Schön, H.-L. Dienel, Transdisziplinäres Kooperationsmanagement, Ökom, München, 2004.
[46] C.P. Snow, The Two Cultures and the Scientific Revolution, Cambridge University Press, Cambridge, 1959.
[47] C.P. Snow, The Two Cultures and a Second Look—An Expanded Version of the Two Cultures and the Scientific Revolution, second ed., University Press, Cambridge, 1964, p. 79.
[48] C.P. Snow, The Two Cultures and a Second Look—An Expanded Version of the Two Cultures and the Scientific Revolution, second ed., University Press, Cambridge, 1964, p. 60.
[49] Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen. Umweltveränderungen, Welt im Wandel—Herausforderung für die deutsche Wissenschaft, Springer, Berlin, 1996, p. 111.