4

Transdisciplinary For and Against

Introduction

While it has been successful for a long time, reductionist, disciplinary, "linear" science is increasingly being confronted with highly complex problems that it cannot usually solve. This is partly because of the increasing fragmentation of the intellectual/scientific landscape into narrower and narrower disciplinary communities, following the institutionalization of science that I referred to in Chapter 3. This has hugely increased our understanding in certain areas, but at the same time it has left large, unmapped, and unexplored gaps in our understanding.

Another important contributing factor to this situation is the accumulation of unintended and unexpected consequences of earlier societal actions, which I will be discussing at length later in this book (Chapter 10; van der Leeuw 2012). Unobserved for a long time, owing to the acceleration of innovation since the Industrial Revolution, these consequences are becoming noticeable in many domains, revealing the underlying complexity of the systems we are dealing with.

Hence a more diverse and multidimensional science is emerging, better at taking contexts into account, and exploring the domains that disciplinary sciences have not.

To place this development in context, I must go back to the emergence of modern universities and the concomitant structuring of academic disciplines into departments and faculties. As previously mentioned, this led to the fragmentation of our scientific worldview and to the tangled hierarchy of the sciences, the social sciences, and the humanities that is still a dominant feature of academia and the global research community.

Tangled hierarchies like this exist in principle between any two disciplines, because once a scientist is brought up within the constraints of a particular discipline, all other disciplines are "others," and therefore themselves subject to the social, organizational, and administrative dynamics that distinguish it from any others. Insiders will thus value "their" discipline higher than outsiders, and outsiders will value theirs higher.

How can we disentangle such hierarchies? There are not many methods (van der Leeuw 1995, 31–32). We have seen that for Dupuy (1990) disentanglement consists of a double reversal of the hierarchies entangled within themselves (Figure 3.3b), so that where nature was first, culture becomes first, and where culture was first, nature becomes first. But as I mentioned in Chapter 3, this would merely twist the tangle the other way around – responding to one of Jonas' points (1982, 17): "if humanity is just a part of nature, then what sense does it make to suppose that nature may not have properties similar to our own?" Jonas's point has led to many developments in ethology, eroding boundaries between humans and nature; dolphins seem to have names, chimpanzees cultures, orang-utans dialects, etc. The fundamental question in all these cases is whether or not – and if so, how far – we project our own human characteristics onto the species concerned. After all, our understanding of the outside world passes through, and is constrained by, our human cognitive system.

One could also try to impose a sort of arbiter, as Aldo Leopold does with his "land ethic" (1949). Central to Leopold's philosophy is the assertion to "quit thinking about decent land use as solely an economic problem." While recognizing the influence economics has on decisions, Leopold understood that, ultimately, our economic wellbeing cannot be separated from the wellbeing of our environment. It was therefore critical for him that people have a close personal connection to the land. "We can be ethical only in relation to something we can see, feel, understand, love, or otherwise have faith in." Such a "land ethic changes the role of *Homo sapiens* from conqueror of the land community to plain member and citizen of it … it implies respect for his [non-human] fellow-members, and also respect for the community as such" (Leopold, 1949, 239).

But the problem with this is that humans cannot (and should not) devise the ethic for other beings, as we cannot experience them other than as "the Other" – i.e. without understanding or feeling or any other form of real contact. Thus, this option would lead to an acceptance of a natural chaos, in which for each living being, each aspect of nature, we

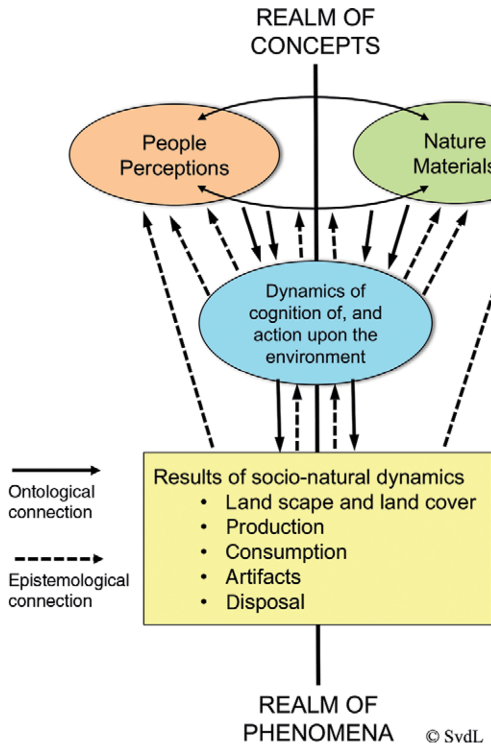

FIGURE 4.1 Doing away with the natural and the societal subsystems. (Source: van der Leeuw)

would impose the same total and absolute freedom as Hinduism allows for cows in India.

Evernden (1992, 94) proposes to radically admit the fictional nature of the opposition (see Figure 4.1). That is, if we want to prevent the realms of humanity or history from becoming subcategories of nature, we will have to admit to ourselves that nature is in fact a subcategory of culture – that we are, after all, the authors of the system we call nature. And moreover, that we are the authors of the dualism that facilitates the existence of humans and nature as separate and qualitatively distinct entities. We will have to admit our own role in the constitution of reality, which in turn means admitting something quite fundamental about the nature of our knowing (see Luhmann 1989; van der Leeuw 1998 for two other lines of argument that come to the same conclusion), i.e. that it is self-referentially construed by society on the basis of its very limited perception of extremely complex phenomena. Then one would bring all

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disciplines to bear on the study of socioenvironmental dynamics, acknowledging that there is no social subsystem nor an environmental one, but that there are only human perceptions of, and actions on, the social and natural environment that are directed by the human cognitive system (McGlade 1995). This would necessarily mobilize the full range of disciplines and scholarship in an attempt to improve understanding of the complexities involved.

This seems in many ways the cleanest solution, but it raises an important question: "How would one realize such a reintegration of nature within the realm of culture, while acknowledging that we cannot go back to a state of innocence or naiveté in which vitalism is reinstated as the dominant doctrine?" Many scientists in different (combinations of) disciplines have tackled this issue over the last century or so, attempting to get to the point at which the implied integration of many disciplines into a holistic perspective is successfully completed.

Those attempts have gone through a number of phases, from interdisciplinary to multidisciplinary' to transdisciplinary and most recently proposals for undisciplined research. It is the goal of this chapter to discuss some of the challenges that transdisciplinary science has to deal with if it is to live up to its promises. But I will begin with a brief description of how I understand these concepts in order to clarify how they will be used in the remainder of this book.

Interdisciplinarity

The term interdisciplinary implies the use of methods and insights of several established disciplines or traditional fields of study, with a focus on questions that are not raised in the scientific disciplines themselves. Although eclipsed in the last two centuries by the disciplinary organization of scientific research that was brought about by university organization, interdisciplinary research has a long history, according to some going back to the ancient Greek philosophers (Gunn 1992).

Interdisciplinary research is about creating new ideas and approaches by crossing boundaries, thinking across them to connect and combine different academic schools of thought, professions, or technologies in the pursuit of a common task (such as investigating sustainability issues). Interdisciplinary strategies are often applied when a subject seems to have been neglected or even misrepresented in the traditional disciplinary structure of research institutions, creating gaps in our intellectual map. In other instances, interdisciplinary approaches are applied when the topics involved are too complex to be dealt with within single traditional disciplines (among them the so-called wicked or hairy problems mentioned in Chapter 2).

The main intellectual challenge in interdisciplinary research is that the different disciplines involved have their own specific perspectives, questions, methods, epistemologies, and sources of information. Combining these in a fruitful way requires proficiency in, and deep understanding of, the disciplines involved, and is therefore far from easy to attain. As long as the number of disciplines involved is limited, a single individual may be able to achieve this; but as we will see in the next section, it is much more difficult to achieve if it involves teams of scientists trained in different disciplines.

In Table 4.1, I point to some of the differences between the natural and social sciences, and a possible way in which we can look at them in an integrated manner.

Clearly, Table 4.1 covers only a very limited number of the differences, and the solutions proposed are very tentative. It merely aims to give a general idea of the complexity of what is required to truly integrate these two kinds of approaches.

Moreover, in an overwhelming majority of institutions there are numerous administrative and organizational barriers to such interdisciplinary work, but as these also hold for both multidisciplinary and transdisciplinary research they will be dealt with later in this chapter.

Multidisciplinarity Results in a Bee's Eye View

Let us now look at the perspective that is gained by attempting to tightly bundle together the results of a much wider range of disciplines. Wikipedia (April 25, 2016) defines a multidisciplinary approach in much the same way as an interdisciplinary one: "drawing appropriately from multiple disciplines to redefine problems outside normal boundaries and reach solutions based on a new understanding of complex situations." The difference seems to be in the number of disciplines involved and the difficulty of integrating them.

One widely used application of this approach is in health care, where people are often looked after by a multidisciplinary team that aims to address their complex clinical and nursing needs. In such situations, every person involved (except the patient) has expertise and a task of his or her own. The collaboration is effective because all tasks are devoted to getting parts of the patient better, and the patient's body integrates the efforts

Table 4.1 Differences between natural history and human history as an example of the differences between natural and humanistic approaches to environmental research, and suggestions toward creating an encompassing integrated approach to socioenvironmental dynamics.

	Natural history	*Human history*	*Integrated history for the anthropocene*
Domain	Nature	Society	Environment (socioecological interactions)
Time scale	Longer timescales	Shorter timescales	Integrated timescales
Focus	Causality	Human agency and contingency	Causality and agency interacting; envelope of contingency
Goal	Interpreting the past from the present; looking for origins in terms of natural laws	Interpreting the present from the past; looking for origins in terms of causal chains	Looking for emergence (in the systems sense) to understand the present and generate a better future
Process	Observation, description, and experimentation lead to explanation	Description, critique, analysis, and interpretation lead to insight and understanding	Description is the basis for modeling and understanding dynamics of the socioecological system
Tools	Natural science discourse Paleoenvironmental sciences Prehistoric archaeology Conceptual frameworks	Narrative and statistical discourse Classical and historical archaeology Documentary history Case studies as unique trajectories	Multiple discourses Integrated history of people and the environment Use case studies embedded within conceptual frameworks to generalize

Source: van der Leeuw et al. (2011).

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into a synthetic one. This is also the case with sustainability, the study of the health of the planet, which involves a very large number of disciplines that each have (at best) a positive effect, while the synergy between the approaches is provided by the socioenvironmental system. In neither case is there intellectual fusion between the expert scientists involved.

Historically, the first practical use of the multidisciplinary approach was during World War II, when the Lockheed Aircraft Company set up its own special projects operation – famously nicknamed the Skunk Works – in 1943 to develop the XP-80 jet fighter in just 143 days. During the 1960s and 1970s, the multidisciplinary approach spread across the academic world, initially among disciplines with a practical purpose, an example being to architects, engineers, and quantity surveyors who worked together on major public-sector construction projects with planners, sociologists, geographers, and economists. Somewhat later, spearheaded by fields such as geography and archaeology that were defined by either space or time rather than by a particular approach or set of questions, multidisciplinary approaches quickly spread to many other scientific domains.

Each of the disciplines involved presents the observer with a (sometimes only slightly) different view of the subject of study because it brings to bear slightly different questions, as well as different methods and techniques. The information gained by each discipline is therefore in itself coherent, valuable, and focused on a specific question or topic, but it is couched in terms designed by the communities that are responsible for the different disciplines and is therefore not easily fused with information gathered by other disciplines. Bringing the results of such efforts together in a single perspective often has difficulty transcending the lowest common denominator, and tends to be more simplistic (and often functionalist) than one could wish for.

This is in part because the practitioners of such multidisciplinary research often have the wrong expectations. They expect "knowledge" and the possibility to seamlessly integrate results from different disciplines as if they were equivalent. In striving for clarity, such an approach loses sight of the fact that most complex phenomena are multifaceted and so rich in information that a single coherent picture of them is at best a very partial representation.

In my opinion all we can hope for is what could be called a "bee's eye view," a multifaceted picture that can provide some insights if one is prepared to accept the fracture lines between the facets and make a number of "leaps of faith" across them (van der Leeuw 1995, 2003).

Although that goes against our (culturally determined) tendency to insist on clarity and simplicity of explanation, such a bee's eye view is not necessarily a disadvantage in dealing with complex information: most insects that have faceted eyes manage very well with them. But it does require that the scholars involved are able to function while holding contrasting or opposing ideas in mind.

To distinguish the results of such an approach from the traditional and interdisciplinary ones, one might perhaps suggest that what we strive for is sufficient understanding (as opposed to knowledge) to be able to begin dealing with complex phenomena. This distinction is introduced to highlight the fact that multidisciplinary investigations do not aim for the same degree of coherence in their explanations as traditional disciplinary ones. Because we believe such coherence can only be achieved for very simple phenomena (if those exist), we hope to compensate for that by gains in the applicability of our understanding to the (inherently complex) real world.

Transdisciplinarity, Intellectual Fusion, and Linking Science and Practice

Transdisciplinary science is for the moment the latest acknowledged stage in this development, explicitly connoting a research strategy that crosses many disciplinary boundaries to create a holistic approach. Crow emphasizes that this requires "intellectual fusion" (2010).

Transdisciplinarity signifies a unity of knowledge beyond disciplines. Jean Piaget introduced the term in 1970, and in 1987 the Centre International pour la Recherche Transdisciplinaire (International Center for Transdisciplinary Research, CIRET) adopted the Charter of Transdisciplinarity at the First World Congress of Transdisciplinarity in Portugal.

As the prefix "trans" indicates, transdisciplinary science concerns that which is at once between the disciplines, across the different disciplines, and beyond each individual discipline. Its goal is the understanding of the present world, of which one of the imperatives is the overarching unity of knowledge. In its approach, transdisciplinary science is thus radically distinct from interdisciplinary and multidisciplinary science. These latter approaches concern the transfer of methods from one discipline to another, allowing research to spill over disciplinary boundaries but remaining within the framework of disciplinary research. Transdisciplinary science explicitly crosses these boundaries and strives for intellectual fusion among the ideas of practitioners of different disciplines and research and practice domains.

But it does more. Transdisciplinary approaches also attempt to cross the boundaries between the realms of ideas and phenomena, and between science and society, by including stakeholders from civil society in defining research objectives and strategies to better incorporate the diffusion of learning produced by the research. Collaboration with and between stakeholders is deemed essential – not merely at an academic or disciplinary level, but through active collaboration with people affected by the research and community-based stakeholders (Thompson-Klein et al. 2012). In this way, transdisciplinary collaboration is expected to become uniquely capable of engaging with different ways of knowing the world, generating new knowledge, and helping stakeholders understand and incorporate the results or lessons learned from the research.

This kind of transdisciplinary approach is the only one of the three that can even attempt to deal with the "hairy" or "wicked" problems introduced in Chapter 2. What are they? The concept was first introduced by Churchman in 1967, to distinguish between those problems that could be solved once and for all and those that could not. As Xiang defines them (pers. comm. 2015), "Wicked problems can be suppressed or even overcome, but cannot be eliminated, and will recur, often in different and more wicked forms. Many, if not most, problems in human activity systems in general, and in socio-ecological systems in particular, are wicked." Such wicked problems are highly multidimensional, and the various contributing dynamics are so unstable that there are no permanent solutions. They recur time and time again and are often the main staple for political decision-makers.

I will discuss the relationship between transdisciplinarity, complex adaptive systems approaches, and wicked problems further in Chapter 5, but for now I will move on to discuss some of the difficulties involved in transdisciplinary research.

Barriers to Practicing Transdisciplinary Science

Apart from the intellectual difficulties of overcoming tangled hierarchies and bringing the contributions of many disciplines together in an intellectual fusion, there are a number of other barriers to the practice of transdisciplinary science, which range from the cognitive to the psychological to the organizational. In the cognitive field, I have already referred to the limits of the human brain's short-term working memory to deal with more than seven or eight sources of information simultaneously (Read & van der Leeuw 2008), which makes it difficult, if not impossible, to deal with challenges that are of a much higher dimensionality. Moreover, our theories are underdetermined by our observations (Atlan 1992), so that our reactions to challenges are usually overdetermined by past experiences. Another issue here is the bias in category formation toward either similarity or dissimilarity that I refer to in Chapter 9, based on the work of Kahnemann, Tversky, and others (Tversky 1977; Tversky & Gati 1978; Kahnemann et al. 1982). At issue in the psychological field, for example, is the important debate about whether choices are primarily determined emotionally or rationally (Elster 2010). From an organizational perspective, one of the important issues is the structure of the team, and in particular the extent to which the structure of the team network is organized along vertical and horizontal lines of communication, and its degree of redundancy. All of these are currently important subjects of research that are aimed at reaching a better understanding of the underlying dynamics in transdisciplinary teams (see Stokols 2006; Gray 2008).

But there are also several issues that do not generally receive much attention. I will briefly point to some of these before moving on to a description of some of the qualities needed for true transdisciplinary research efforts and how we might promote these in higher education. In doing so I will begin with individual challenges, and then move toward organizational and administrative ones.

At the individual level, there are at least two major challenges. The first of these is a lack among many scientists of the skills that are necessary to effectively and efficiently implement transdisciplinarity. Education will help overcome this (van der Leeuw et al. 2012; Wiek et al. 2014; and many others). But there is an underlying problem that is at least as important that is not so often discussed: the challenge of changing identity.

Becoming a scientist is an important investment not only in time and money, but also in one's own human capital. For at least a decade, but often much longer, a scientist will have invested herself or himself in learning the tools of a particular discipline, practicing it, publishing in it, and getting to be known in an increasingly wide community of scholars who are more or less aligned with his or her ideas. In the process, the scientist, if she is competent, will have acquired the respect of that community for the knowledge, understanding, skills, or other talents that constitute the requirements for a scientific career. In effect, the effort has given the person involved a scientific identity that is closely related to the field and the

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community that is his or hers. Over time, unless the scientist changes careers or disciplines, that identity will become stronger and stronger, in the eyes of the scientist concerned as well as those of the community.

Transitioning to inter-, multi- or transdisciplinary research forces the scientist to give up part of that identity in order to, slowly but surely, assume a new one. This is very difficult for many people; not only because it takes another major investment, but also because until that new identity has solidified, the person does not have a firm and fixed context within which to operate. In such situations, many people are insecure. They do not know the unwritten rules of the new game, have not yet become part of the new like-minded intellectual community, let alone gained the respect that was theirs in the discipline in which they were originally trained. When one adds to this the fact that many of the epistemological differences between disciplines are not clear to their practitioners, because they are buried deep in the core of a discipline's thinking and are not explicitly acknowledged, it becomes easy to understand why many people are not very keen on wholeheartedly making this kind of transition. They will pay lip service to it, even be part of a transdisciplinary team, but have difficulty achieving the kind of intellectual fusion that is the goal of the operation.

All this is not made easier by the fact that over well-nigh two centuries, formal and informal scientific organizations, rules, and institutions have evolved that reinforce and constrain such disciplinary communities. These impose – often rather strict – rules in each discipline on topics that range from "Which questions can be broached and which are out of bounds?," "What is the correct format for reporting scientific experiments and results?," "Which are valid hypotheses, confirmations, or even proofs?," to "Where to publish in order to gain stature in the discipline?" (see for example Ingerson 1994).

One example that is of direct relevance to us, and in which such constraints have until recently confined the discipline very strongly within clear bounds, is (macro-) economics. As expressed by Gowdy et al. (2016, 325–328):

> ... its perceived scientific foundations focus generally on narrow concepts of representative agents or average behavior (vs. populations of diverse behaviors in evolutionary approaches), equilibrium (vs. innovation, surprise, and selection dynamics) and markets (neglecting social networks of nonmarket interactions between agents). Economists' research often focuses on efficiency in a static allocation framework, assuming that institutions, norms, and culture are outside the purview of economic analysis. By the middle of the twentieth century the

common definition of economics had become the science of the allocation of scarce resources among alternative ends (Robbins 1935). Issues of formation (i.e., how institutions, norms, and culture develop and how allocative mechanisms feed back onto them) received some consideration, but they were generally to be found at the margins rather than at the center of analysis. Their marginalization led to some quite spectacular shortcomings of economic models, such as their failure to consider, much less predict, the possibility of catastrophic financial crises. (Colander et al. 2009)

But the impact of such constraints is not limited to economics. Economics may be an extreme case, but similar constraints have to varying extents impacted most disciplines, including physics, climate science, ecology, sociology, and anthropology. Indeed, they have helped the alignment of disciplinary scientific communities by creating intellectual constraints around the domains they are involved in, and are thus in a sense tools that have helped create the disciplines and their identities.

Since World War II, and as part of the wave of rapid and huge expansion of scientific investment and effort in the developed countries that followed the war, which went along with a conviction that science could do just about anything, this dynamic has been reinforced by increasingly strict and formal top-down administrative rules, not only concerning the practice of scientific research, but also the funding of research, the career structures, and the evaluation of the scientists themselves. These were made necessary by the rapid upscaling of research effort, and therefore of the size of the research community, but they also strongly reinforced the existing management of disciplines and thus fundamentally changed the practice of science, particularly in many universities but also in research funding organizations.

The core of the structure that has been created is the 'peer review,' about which a great deal has already been written. I will therefore confine myself to a few short paragraphs. This ubiquitous institution on the one hand aims to, and generally does, ensure the quality of scientific work that gets funded or published, and the quality and productivity of scientists at different stages in their careers. However, it also severely constrains, in many cases, the range of scientific topics discussed, the questions raised, and the methods applied. As long as the principal aim of science was the maintenance of quality within disciplines, these constraints were reasonable and acceptable. However, in the development of a wider range of topics and collaborations between disciplines (whether inter- multi- or transdisciplinary), such peer reviews have to some extent hindered the development of novel ideas.

This is in part a generational problem. The people invited onto peer review committees are generally highly respected and senior scientists who do not participate in the scientific culture of the younger generations, the champions of scientific innovation and novelty. Moreover, reduced funding, competition between more and more journals and funders, as well as the increasing call for transparency and responsibility have added stresses to the system.

For many funding institutions, political oversight is limiting the kinds of science that they can fund. Moreover, especially if they fund research with public money, they have a tendency to avoid risk, and therefore to favor research of which they can, at least to some extent, predict the outcome. In the case of journals, the publication of longer papers has become difficult (this is in the process of changing owing to the rise of electronic publishing), while the topics, format, and language of papers have all been narrowed by editorial policies.

From the role of peer review in assessing the quality and productivity of researchers and university faculty, we move into the domain of administrative barriers to transdisciplinary research. I want to begin this section with the statement made by a well-known professor in sustainability science about his home institution. When confronted with a plan to open up such research and to implement new ways of organizing it, he answered: "I'd love to do this, but I cannot – my institution is perfect." Of course, he expressed not so much his own vision, but the image that his institution had of itself.

Such institutional self-images are maintained by rules and regulations, and by quality and performance assessments of junior faculty and students. These involve peer review based on predetermined criteria (number of publications, prestige of the journals involved, amount of research funding raised externally in competitions, patents, teaching performance judged by students, etc.). One difficulty with this system is that because the criteria are predetermined, people are increasingly focusing their activity on them, and a substantive reduction in the diversity of research can be the result. This has been one of the persistent problems with the UK's Research Assessment Exercises, for example (Strathern, 2003, pers. comm.). Once such a dynamic has been set in motion, and an increasing number of people have invested in it, the criteria are very difficult to adapt.

Another problem is that these evaluations are often undertaken by relatively small committees with three- or four-year mandates. Because of their size, there is a substantive possibility that they will be asked to pass judgment on domains or approaches that are at best marginal to their own interests and of which they do not have any intimate knowledge. Moreover, the members of such committees are themselves part of the communities they evaluate, so they have their own agendas. Although I do not in any way want to cast aspersions on the members of such committees, who no doubt make decisions honestly and seriously, I believe that the institutional context in which they work urgently needs review. The current situation is not only hindering the exploration of new research areas and topics, questions and methods, but is also beginning to undermine the value of some of the existing disciplinary research.

Competencies for Transdisciplinary Research

Wiek and colleagues at Arizona State University in the USA and Lange and colleagues at Leuphana University in Germany are among a growing number of leading young scholars in select universities (Maastricht University, Lund University, Stellenbosch University, Technical University of Catalonia, University of Tokyo) that are developing outstanding approaches to transdisciplinary education and training in sustainability. In this section, I will discuss some of their ideas about the qualities that are necessary for effective and creative transdisciplinary work.

Because sustainability problems and challenges have specific characteristics that differ from problems addressed in other fields, analyzing and solving sustainability problems requires a particular set of interlinked and interdependent key competencies. In the case of sustainability these qualities are in fact "functionally linked complex[es] of knowledge, skills, and attitudes that enable successful task performance and problem solving [...] with respect to real-world sustainability problems, challenges, and opportunities" (Wiek et al. 2011, 204). In practice, having these competencies means that people "are able to enact changes in economic, ecological and social behavior without such changes always being merely a reaction to pre-existing problems" (de Haan 2006, 22).

Wiek et al. (2011, 205) distinguish five different competencies (Figure 4.2): (1) systems thinking competency, (2) anticipatory competency, (3) normative competency, (4) strategic competency, and (5) interpersonal competency. Together, these are thought to enable the development of an integrated (transdisciplinary) research and problem-solving framework. The following example, drawn from the same paper, shows how these competencies can interact to create real-world results:

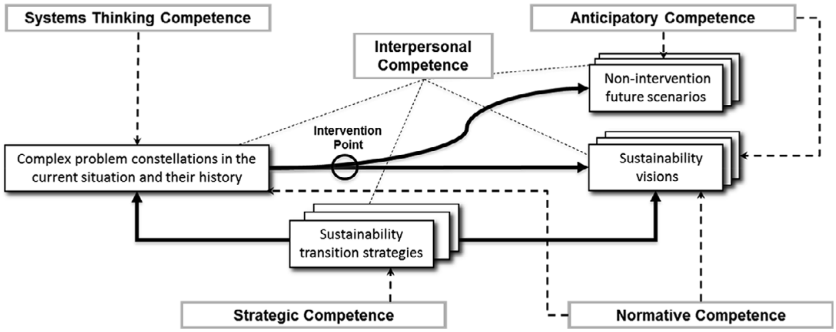

FIGURE 4.2 The five key competencies in sustainability (shaded in gray) as they are linked to a sustainability research and problem-solving framework. The dashed arrows indicate the relevance of individual competencies for one or more components of the research and problem-solving framework (e.g., normative competence is relevant for the sustainability assessment of the current situation as well as for the crafting of sustainability visions). (Source: Wiek et al. 2011, 206 By permission Springer)

Let us assume that the ultimate goal of a sustainability activity would be to develop, test and implement strategies for sustainable urban development. This calls for a well-founded *strategic competence*. These strategies are intended to redirect urban social-ecological systems from unsustainable trajectories toward a sustainable future state. To this end, the current state, past developments, as well as future trajectories of the city are analyzed systemically and key leverage or intervention points in the system are identified. This requires *systems-thinking competence*, and these points are assessed against sustainability criteria (to identify critical trajectories and consider trade-offs), which requires *normative competence*. Based on new knowledge and learning, the strategies are conceptualized as being continuously adapted in order to redirect path dependent future trajectories in the city toward visions of a sustainable future, which requires *anticipatory competence*. The collaboration among a suite of urban stakeholders, including scientists, policy-makers, managers, planners, and citizens is critical for understanding the system's complexity, exploring future alternatives, crafting sustainability visions, and developing robust strategies in ways that are scientifically credible, create shared ownership, and are conducive for action – all of which requires strong *interpersonal competence*. (Wiek et al. 2011, 205–206)

This is not the place to drill down into the ways in which the authors justify each competency in some detail, based on a wide survey of existing literature. For the purposes of this book, the above description must suffice, and the reader who is interested can find details in the paper itself. But there is one other important aspect of achieving transdisciplinary research and problem-solving that has not received enough attention –

how we foster these skills and build sufficient capacity to deal with sustainability challenges across the globe.

For that purpose, based on work done in the medical sciences and in sustainability science in European universities (notably Maastricht and Aalborg), we have at Arizona State University implemented problem- and project-based learning (PPBL) to practice such competencies in real-world situations – dealing with challenges that were encountered in business, and by governments, NGOs, etc. (Brundiers et al. 2013). The key features of this approach are that it promotes student-centered, self-directed, and collaborative learning that focuses on real-world issues and involves stakeholder engagement. It does so by confronting a group of students who have different disciplinary backgrounds with an issue communicated by another organization. The students then unpack the issue and analyze aspects and elements of it, communicate with the stakeholders and among themselves – practicing each of the five competencies outlined above – and ultimately try and find practicable solutions. In the process, faculty will counsel and help, but the work is directed and executed by the students. PPBL thus requires students to actively and self-responsibly develop knowledge, skills, and attitudes, while being supported in reflecting on and deepening their learning experience and strategies. Furthermore, the outcomes expand beyond rich learning experiences by engaging cognitive, procedural, and affective knowledge domains, and also include the writing of policy-relevant reports, intervention manuals, and project proposals for submission to funding organizations (Brundiers et al. 2013).

In this manner, students are also confronted with the fact that they need critical thinking – or, to put it more starkly, that there are accepted immutable facts on which sustainability thinking is based, but that the complex links between them are always part of a particular perspective, and that there are always other perspectives. Once that is understood, they will realize that there are always alternatives to any choice made by the researcher. Such alternatives will have to be evaluated against each other from the perspective of intended and unintended consequences in order to make responsible decisions.

I would expect that once such approaches were commonly taught and practiced, the scientific community could set a further urgent, and in my opinion absolutely fundamental, step – from transdisciplinary to nondisciplinary or undisciplined research. Such research would bring all domains of knowledge and skills, academic, applied, and nonacademic, to bear on the fundamental issues our society is facing, mobilizing all talent available, for example by crowdsourcing answers to vexing questions or solutions to acute problems.

This would further be favored if people who are the best suited for such studies were to be recruited, with commensurate salaries, by businesses and positioned in senior executive functions where nondisciplinarity is practiced every day. In economics, finance, technology, law, trade, markets, industry, and government, issues such as the environment, human resources, strategy, long term vs. short term are among the topics that a senior executive is permanently dealing with. And a business can only be successful over the long term if its senior executives are able to fully integrate these various aspects.

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