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SPECIAL FEATURE: EDITORIAL

Transdisciplinarity at the crossroads

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To what parts of science development does transdisciplinarity contribute?

Twentieth century science has seen an increasingly rapid development of the differentiation of science at large by building new disciplines and specialized or interdisciplinary sub-disciplines; this has been labeled fractalization and *chaos of disciplines* (Abbott 2001). This increasing fragmentation of the body of sciences, with different types of qualitative and quantitative methods, forms, and norms of validation such as deductive and inductive reasoning, probabilistic and deterministic models, or even different forms of reasoning (for instance, in mathematics certain schools do not consider an indirect proof as valid or acceptable; Gonzalez 1991) call for integrating meta-levels from an inner-science perspective (Gödel 1931). The construction of proper meta-levels of reflection, validation, and integration may play an important role in the future development of sciences.

Science has long subscribed to a Humboldtian or Newtonian world view that has been strongly shaped by a physical rationale and was lacking an integrating, coherent system of knowledge for the investigation of human–environment interactions. Understanding of the *unity of nature* was perceived as the ultimate reference (von Weizsäcker 1980/1971; Wilson 1999). Consilience and consistency of reasoning (Bunge 1967a, b) and a strong belief in rationality (Carnap 1991; Oppenheim and Putnam 1958) were dominant. In addition, attempts at the integration of knowledge, such as the search for a general system theory (von Bertalanffy 1951), were shaped by the thinking of natural science for a long time. The search for a unifying level or entity, or a framing of the meta-level (Gödel 1931) or total transdisciplinarity, can be considered Mode 1 transdisciplinarity (Piaget 1972), which sometimes leads to the assumption of spirituality and the idea of transcendence (Nicolescu 2014). However, the challenge of integration and consistency and dealing with a complexity of systems and integrated reasoning can also be approached from a realist stance (Bunge 2003; Klein 2003; Mitchell 2003; Scholz 2011).

Today, the scientific challenge has become even more complex. In the age of the Anthropocene (Crutzen 2002), instead of a "unity of nature" we are looking at the "resilience of inextricably coupled human–environment systems" (Scholz 2011) and their ontology, dynamics, and governance as a basis of sustainability science (Kates 2012). This is precisely where transdisciplinarity of the Mode 2 type (Scholz and Steiner 2015a; Gibbons et al. 1994) and the turn *From a science for society to a science with society* (Scholz and Stauffacher 2009; Seidl et al. 2013) serve to overcome the reductionist view of science.

Transdisciplinarity requires theory and practice. Much has been written about how transdisciplinarity is conceived. However, as we discovered over the course of preparing this special feature, very few scientific papers in peer-reviewed journals document the social and scientific outcomes and benefits of transdisciplinary processes. When

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reflecting on the prerequisites for—and the obstacles to—transdisciplinary processes, we get the impression that the community of transdisciplinarians is traveling in complex and widely unknown territory. There are a couple of epistemic, methodological, and practical challenges to overcome in order to determine the right path at each crossroad, junction, and complex roundabout as well as several multi-level, nodal points of communication. Here, the community faces the problem of possibly ending up at dead-end roads, impasses, or unnavigable terrain all together. In order to construct an effective roadmap that will take us where we want to go, let us identify a few of the decisions that transdisciplinarians face.

Transdisciplinarity extends beyond interdisciplinarity, applied research, and participatory research

The future of transdisciplinary processes and research is endangered by the risk of it becoming a buzzword with incoherent notions. One often encounters statements such as transdisciplinarity means being very interdisciplinary or transdisciplinarity means involving stakeholders. We can see that these statements refer to aspects of Mode 1 and Mode 2 transdisciplinarity. Yet, it is somewhat surprising that researchers often "adhere to interdisciplinarity or transdisciplinarity without debating what these terms mean" (Lawrence, 2015, p. 6).

Labels that we apply in the following section, like traffic signs or guideposts, must have unambiguous and explicit meanings in order to be useful. Otherwise, we may not find our way out of a roundabout. Thus, we suggest distinguishing between Mode 1 and Mode 2 transdisciplinarity, which both focus on relating or integrating knowledge from a meta-perspective. Transdisciplinary processes of the Mode 2 type include applied research; they emerge from and are directed toward real-world problems (not only to topic- or theme-centered interaction); they also include stakeholder participation. But scientists and practitioners are participating in transdisciplinary processes because they want to build capacity and consensus (for example, consensus regarding which problems are the most pressing) by mutual learning processes. Transdisciplinarity is fundamentally different from (most forms) of action research, consulting, university-industry-government collaboration according to the triple-helix model, and other forms of science–practice relationships.

However, if we focus on Mode 2 transdisciplinarity, this does not call for purely theoretical research. Yet there is a significant body of theoretical and accompanying research about and "beyond" transdisciplinarity, whereas there are only a relatively few comprehensive reports about "real transdisciplinary processes". The present volume attempts to fill this gap. All papers in addition to the one on "theoretical foundations" (Scholz and Steiner 2015a) provide insights into one or more transdisciplinary processes. Several of them (Miah et al. 2015; Schodl et al. 2015; Vilsmaier et al. 2015) also deal with transdisciplinary processes that included industry representatives as partners or co-leaders. It is our belief that that transdisciplinary research ought to explore the precarious roads of practice. Science–practice complementarity is not just a theoretical construct. Transdisciplinary research needs practice (and this is a reality of transdisciplinary processes) just as much as empirical research needs experiments, surveys, and data. Reflection and theory development have to be built on the practice of transdisciplinary processes.

Outcomes must be of interest for both practice and science

Practitioners and scientists have diverging interests. Practitioners' goals are to improve their business or to more successfully cope with tangible problems. By contrast, scientists tend to aspire the generation of theoretical knowledge (and to write papers) that contribute to a better understanding of the real world. Thus, if we consider socially robust orientations as a primary output of transdisciplinary processes (Gibbons and Nowotny 2001), these processes must have a 'double-bind' character so that both practice and science can benefit. Scientists can benefit from a reframing of scientific subjects or disciplinary research subjects in a broader frame; they may also develop methods and theories describing how knowledge from theory or practice can be related or how disciplinary knowledge integration may work. The contributions of Njoroge et al. (2015), Vilsmaier et al. (2015), and Miah et al. (2015) deal with all of these aspects. In the frame of the traffic metaphor, science may be considered as an experimental or racing car laboratory that serves as a hub for exploring new settings and technologies from which the practice of producing utilitarian cars can benefit.

Going beyond science and utilizing different epistemics for coping with complex real-world problems

Disciplinary knowledge may certainly provide information about how stock markets function, how natural and anthropogenic material flows work, how morality and social justice develop, or what role digitally stored information plays in the wealth of a society. However, all of these systems are of an inextricably coupled human–environment type (Scholz 2011); there are dozens of natural, social, engineering, and humanity sciences that can describe single aspects of the comprehensive system. We argue that—if we approach knowledge integration from a science–practice perspective—we have to address a threefold knowledge-integration problem: (1) we have an interdisciplinary, inner-science challenge of integrating knowledge; (2) there is the necessity to integrate interests and types and qualities of knowledge from different practitioners/stakeholders; and (3) the different types of epistemics (i.e., ways of knowing) from practice and science have to be functionally related to efficiently produce socially robust knowledge (see Figure 1 in Scholz and Steiner 2015a).

There is evidence that transdisciplinarity is strongly welcomed by practitioners. But there seems to be some reluctance on the part of scientists and scientific institutions to turn onto the potentially bumpy road of transdisciplinarity that may present scientists with new and unfamiliar problems to confront. Scientists are, in part, losing control about where to drive, and they may be confronted unexpectedly with questions that they are not required to answer in their core domains. Knowledge from practice and science has to be properly acquired, related, valuated, and utilized. This holds true not only for the big problems presented above, but also for many pressing problems. In a world of globalized challenges such as pollution, social injustice, migration, and resource use, sustainable transitioning is a multidimensional and multiscale issue. Mastering these challenges calls for including experiential knowledge from multiple scales such as disciplinary knowledge related to a specific challenge. This has been done in a project on global phosphorus management (Scholz, Roy, Brand, Hellums, and Ulrich 2014). The paper by Njoroge et al. (2015) shows how African smallholder farmers can approach these problems through transdisciplinary processes. And the paper by Vilsmaier et al. (2015) introduces a new method of case-based mutual learning sessions (*cb*MLS) that relate the epistemics of science and practice on different scales.

Co-leadership for mutual learning vs. participatory research

Much has been written about the co-construction of knowledge in Mode 2 transdisciplinarity. However, only a few papers describe how mutual learning really takes place and how to establish an authentic equal footing. When we take a critical look at what factually happens in projects whose results are published as academic papers under the label of transdisciplinarity (Zscheischler, Rogga, and Weith 2014), we can see that many projects do not go beyond forms of (structured or unstructured) interviews and participatory research. The paper by Binder et al. (2015) provides a "framework-based self-reflection from science and practice leaders" that usefully elaborates the constraints and incentives that are on the side of practice and the side of science.

We argue that equal footing, authentic collaboration, and securing benefits for both science and practice are most effectively ensured by "truly lived co-leadership" (Binder et al. 2015) from the very beginning of the project and, in particular, at the stage of problem definition and goal formation. Transdisciplinary processes require different expert drivers who can take the lead in the areas of practice and science. The organizational charts presented in the papers by Binder et al. (2015, Figure 3) and Njoroge et al. (2015, Figure 4) may be considered an operationalization of authentic collaboration by co-leadership. This leads to new forms of collaboration and legal framings such as access to data and the question of property rights, but in addition to the question of what responsibility science should take if a practitioner is negatively impacted or harmed by a transdisciplinary process.

Science as one stakeholder group among others vs. a public good that serves all stakeholder groups

Scientists take on new roles in Mode 2 transdisciplinary processes. They interact with practitioners in real-world cases. These interactions have the potential to change the real world. This has also been called transformative science (Schneidewind, 2013). Scholz and Steiner (2015a; see Box: Mode 2 Transdisciplinarity in a nutshell) suggest that socially robust orientations can be considered a main outcome of a transdisciplinary project. The reader may question why we do not use the terms recommendation or solution instead of orientation. This is because of the type of role a scientist may take on in a transdisciplinary process. Recommendations or solutions are typically the products of contract-based research; here, the scientist may take on the role of a consultant with all the legal liabilities that are bound to such a collaboration.

But even if we go beyond the legal liabilities, scientists may be exposed in a transdisciplinary process; to simplify this idea, we may distinguish between two extreme roles. One is that science is considered a public good that has to serve all stakeholders (as long as it meets human rights and constitutional rules). The other extreme is that science becomes a stakeholder and just one voice in the ensemble of stakeholders. The latter position is often related to an actionist perspective. There are many cases where scientists strongly push specific environmental goals in regard to nature conservation or other issues. Here, the following questions arise: in which ways are scientists transgressing their roles as scientists? In what ways are they democratically or societally legitimized if they promote a specific rule or solution? Should they act as facilitators who have to serve all stakeholders? We consider the rationales of science and practice rather as two systems, such as rail and road, that follow their own rationales and have different ownership. Nevertheless, both road and rail serve a related goal, which is to transport people and objects. Thus, there is a challenge involved in properly relating and integrating these systems.

It is important to acknowledge that, in the course of a transdisciplinary process, scientists may take on different roles. They may work as facilitators of the process, as subject specialists, as representatives of public universities, etc. With respect to these multiple roles, there are different papers of interest in this special feature. Miah et al. (2015) illuminate the role of a PhD student who is acting as a facilitator in developing a framework for a food industry plant's energy supply (Miah et al. 2014). The study demonstrates in what ways an interdisciplinary team of scientists can cooperate with a company's engineer in order to develop strategies for energy conservation. The study by Schodl et al. (2015) reveals how researchers' ideas about animal welfare in pig fattening may be conceived as normative ideas that might conflict with the interests of practitioners. And the papers by Njoroge et al. (2015) and Steelman et al. (2015)—both in an African context—present different forms of leadership and participation that scientists may take.

Rigorous disciplinary and interdisciplinary work as one pillar of transdisciplinarity vs. agglomerative knowledge acquisition

"Mode 2 transdisciplinarity (Td) has become a third way of utilizing and doing science supplementing disciplinarity and interdisciplinarity" (Scholz and Steiner 2015a). In general, in the cycle of a transdisciplinary process, all three ways (i.e., disciplinary, interdisciplinary, and transdisciplinary) alternate (see Binder et al. 2015, Figure 1), and experientially substantiated real-world system knowledge and abstracted, theoretical and/or modeling-based knowledge prevail (Stauffacher, Flüeler, Krütli, and Scholz 2008). Thus there is a vision of disciplined interdisciplinarity in transdisciplinary discourses.

Theories and methods for knowledge integration are needed for Mode 1 and Mode 2 transdisciplinarity vs. an 'everything goes' mentality

Transdisciplinarity will have a future only if the added value compared to other forms of theory–practice collaboration such as normal applied research, participatory research, action research, the triple-helix approach, university practice knowledge transfer, etc., can be proven. We think that there are three important points that may become unique selling points of transdisciplinarity.

First, there is a need to properly relate scientific reasoning to non-neighboring or seemingly unrelated disciplines, e.g., from ethics, quantitative epidemiology, and medical engineering. Sustainability science calls for developing strategies, methodologies, and theories of scientific approaches to meet this challenge. As different types of causation, rationales, and cosmologies become related, this may be considered a renewal of metaphysics (Toulmin 1982; Whitehead 1929). Hence, we believe that Mode 1 transdisciplinarity will be important as well from an applied perspective.

Second, there are different sophisticated forms and qualities of practice-based experiential knowledge (Dreyfus and Dreyfus 2005; Hogarth 2001; Scholz 1987), expertise (Bukach, Gauthier, and Tarr 2006), or wisdom (Ardelt 2004; Baltes and Staudinger, 2000) that are of interest for Mode 2 transdisciplinarity. Research on the validity and functionality of these types of experiential knowledge may become part of the transdisciplinary research agenda. And third, the relating of fragmented scientific knowledge with the potentially also segregated expertise from practice is another challenge. The theoretical side of this aspect is discussed in Scholz and Steiner (2015a). How this may be realized in transdisciplinary processes is—in a very first step—approached by Vilsmaier et al. (2015) who utilize *cases* as boundary objects to relate scales of concrete, geographical, administrative, or organizational units to scientists' conceptual, abstract, and cognitive levels of epistemics and representation.

Methods for evaluation are needed: are we moving in the right direction?

Numerous papers have been written about the methodology of transdisciplinarity. Some provide evaluations based on literature reviews that obviously include projects that do not meet the criteria for transdisciplinarity (Klein 2008; Zscheischler et al. 2014). There are only a few papers that address evaluations of real transdisciplinary processes such as Stokols (Stokols et al. 2003). One of the few (post hoc) quantitative evaluations has been provided by Walter et al. (2007), who used a statistical mediation model to identify the capacities that were developed in a transdisciplinary model. This special feature includes three papers that provide contributions to the issue of evaluation. First, Miah et al. (2015) extract a set of criteria offered in several papers on evaluation criteria and provide a (nominally scaled) self-evaluation. Second, Vilsmaier et al. (2015) provide a qualitative evaluation of eight stakeholder groups who participated in *cb*MLS applied in a transdisciplinary project for global phosphorus management. This evaluation was based on the content analysis of interviews of participants of *cb*MLS. Lastly, Njoroge et al. (2015) develop and apply an analysis of variance-based assessment of the effects of the transdisciplinary process on the yield of smallholder farmers who participated in a transdisciplinary process. We may consider this a groundbreaking innovation (which refers to experimental action research) in the evaluation of transdisciplinary processes; after all, the measurement of an effect of a transdisciplinary process on one main variable/outcome is embedded in a transdisciplinary study design.

Transdisciplinary processes as a tool for a societal didactics of sustainability learning

Although this special feature does not focus on university-level education explicitly, it is a highly promising didactic approach and instructional strategy at many educational levels. The 'science part' of most of the 41 studies presented in the supplementary information provided by Scholz and Steiner (2015b) was run in the context of graduate, postgraduate, or PhD programs. For instance, 17 studies were linked to the program for environmental system sciences at ETH Zurich, Switzerland, and 13 studies were linked to a similar program at Chalmers and Göteborg Universities. However, we think that experienced drivers may also need training, for instance, by participating in defensive driving courses, at least if the ground is slippery and visibility is critical. We observed that many mid-career practice partners of transdisciplinary processes filled high-ranking positions that call for strategic management (such as CEOs of federal or regional offices), and many of them conveyed that they benefitted as a result of their transdisciplinary experiences. Thus, we think that transdisciplinary processes and the founding of institutions such as "transdisciplinarity colleges" (Scholz and Marks 2001) at the PhD level or continuing education are a unique window of opportunity for universities to promote sustainability learning in industry, administration, non-governmental organizations, and society at large.

We hope that this special feature contributes to improve theoretical foundations and practice of transdisciplinary processes and helps to find a good route for the future development of transdisciplinarity.

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