Linking transdisciplinary research projects with science and practice at large: Introducing insights from knowledge utilization

Sabine Hoffmann[a], Julie Thompson Klein[b,c], Christian Pohl[b]

[a] Eawag: Swiss Federal Institute of Aquatic Science and Technology, Ueberlandstrasse 133, CH-8600 Duebendorf, Switzerland, sabine.hoffmann@eawag.ch

[b] TdLab, Department of Environmental Systems Science, ETH Zurich, Universitätstrasse 16, CH-8006 Zürich, Switzerland, christian.pohl@usys.ethz.ch

[c] Wayne State University, 42 W Warren Ave, Detroit, MI 48202, USA, julietklein@comcast.net

Abstract

Recent empirical studies show a persistent gap between 'socially robust' knowledge produced by transdisciplinary research projects and its ability to promote change on a large scale. Current discourses about the 'project-to-science-and-practice-at-large gap' have focused mainly on exploring various conditions that need to be fulfilled to produce 'socially robust' knowledge. Yet, those discourses have rarely built on the broader literature of knowledge utilization, which Greenhalgh and Wieringa (2011) emphasize acknowledges 'the fundamentally social ways in which knowledge emerges, circulates, and gets applied in practice.' Their insights are helpful in advancing our understanding of why transdisciplinary research projects do or do not contribute to sustainability on a large scale. Expanding Jahn et al. (2012) model of transdisciplinary research, we present a revised conceptual model of an ideal-typical, interactive, and iterative transdisciplinary research process that adds two new phases from the field of knowledge utilization to their original three-phase model and accounts for the social and relational nature of knowledge utilization. The revised model includes five phases through which transdisciplinary projects operate in different order: (i) defining sustainability problems, (ii) producing new knowledge, (iii) assessing new knowledge, (iv) disseminating new knowledge in realms of both science and practice, and (v) using new knowledge in both realms.

Keywords

transdisciplinary research; socially robust knowledge; knowledge dissemination; knowledge utilization; conceptual model; sustainability

1. Introduction

Transdisciplinary sustainability research is often expected to contribute to both societal and scientific progress (Jahn et al., 2012). The underlying assumption in this positive relationship is that fruitful collaboration among scientific and societal actors in a particular context, combined with 'constructive combination or integration' (O'Rourke et al., 2016) of different perspectives being brought together, produce 'socially robust knowledge' (Nowotny, 1999) that contributes to solving sustainability problems (Polk, 2014).

Current conceptual models of transdisciplinarity build on this underlying assumption including those of Jahn et al. (2012) and Lang et al. (2012). Jahn et al. (2012)'s model is one of the most cited ones. It differentiates three phases of an ideal-typical transdisciplinary research process: (i) forming a common research object, (ii) producing new knowledge, and (iii) evaluating new knowledge for its contribution to both societal and scientific progress. This model, though, assumes that once new 'socially robust' knowledge is assessed for relevance to science and society, transdisciplinarity intervenes in both discourses about a given sustainability problem. It does so, they assert, *"by means of targeted or non-targeted knowledge transfer by both scientists and societal actors"* (Jahn et al., 2012, p. 7). The impacts of such transfer–which involve implementing new strategies, amending current legislation, or applying innovative technologies–might trigger new transdisciplinary research processes starting from an altered understanding or framing of an initial problem.

Jahn et al. (2012)'s model of transdisciplinarity, however, does not conceptualize the link between new 'socially robust' knowledge and societal and scientific progress in a detailed way, raising a number of research questions. For instance, what constitutes knowledge and how does it impact on science and practice beyond particular contexts in which transdisciplinary research processes are embedded? How does transdisciplinarity intervene in scientific and societal discourses about a given sustainability problem, and how does it enhance knowledge utilization by intended target groups in science and practice at large?

In the present article, we address this gap–which we call the 'project-to-science-and-practice-at-large-gap'–by building on valuable insights from the literature on knowledge utilization. These insights are helpful in advancing our theoretical understanding why transdisciplinary research projects, which produce 'socially robust' knowledge, do or do not promote change in science and practice at large. In introducing the wider knowledge utilisation literature to the transdisciplinary research community, we draw particularly on Landry et al. (2001a), Belkhodja et al. (2007), Ward et al. (2009), Greenhalgh and Wieringa (2011), and Heinsch et al. (2016). In particular, we conceptualize the link between transdisciplinary research projects and science and practice at large while building on emerging models of knowledge utilization that acknowledge *"the fundamentally social ways in which knowledge emerges, circulates, and gets applied in practice"* (Greenhalgh and Wieringa, 2011, p.

502). By integrating insights from the knowledge utilization literature and Jahn's model of transdisciplinary research, we then introduce a revised conceptual model of an ideal-typical, interactive, and iterative transdisciplinary research process that goes beyond evaluation of new knowledge into knowledge adaptation, dissemination and utilization. It distinguishes among five phases: (i) defining sustainability problems, (ii) producing new knowledge, (iii) assessing it, (iv) disseminating it in the realms of both science and practice, (v) and finally using new knowledge, again, in both realms. The article closes by discussing overlaps between the fields of knowledge utilization and transdisciplinary research.

2. Linking transdisciplinary research projects with science and practice at large

Despite recent efforts to conceptualize the link between transdisciplinary research processes and how different types of effects may (or may not) unfold in science and practice (current Special Issue, Hansson and Polk (2018)), studies show a persistent gap between 'socially robust' knowledge produced by transdisciplinary sustainability research and its ability to promote change at a larger scale (Cornell et al., 2013; Polk, 2014; Technopolis Group, 2018). Discourses about the 'project-to-science-and-practice-at-large gap' in transdisciplinary sustainability research have tended to mainly focus on various conditions that need to be fulfilled to produce 'socially robust' knowledge that then contributes to solving sustainability problems (Polk, 2014). These conditions include (i) participation of a variety of actors from both science and practice in transdisciplinary research and (ii) integration of knowledge from both science and practice. However, as Polk (2014) pointed out fulfillment of both conditions *"presumes the fulfillment of the third, which has two main interrelated parts, namely the creation of a specific type of knowledge and the consequent effectiveness of that knowledge"* (Polk, 2014, p. 442). Moreover, she added, it condenses underlying assumptions in the following claim: "*In transdisciplinary research, in-depth participation of stakeholders and the integration of relevant knowledge from both practice and research in real-world problem contexts produce socially robust results that contribute to solving sustainability-related problems"* (Polk, 2014, p. 442).

Exploring how this claim is fulfilled in five case studies, Polk (2014, p. 447) concluded that "*there are a number of practical barriers between socially robust knowledge and the ability to contribute to social change that persist even when these conditions are fulfilled."* By focusing on the various conditions needing to be fulfilled to produce 'socially robust' knowledge that then somehow 'miraculously' contributes to solving sustainability-related problems on a larger scale, discourses have rarely built on the broader literature of knowledge utilization. This literature, however, offers important insights on the inherently social process of knowledge utilization, which incorporates different forms of knowledge from both science and practice and takes place within a complex system of dynamic interactions between researchers and potential users (Ward et al., 2012). Such insights suggest that the ‘project-to-science-and-practice-at-large gap’ in transdisciplinary research might better be conceived as being a problem of knowledge utilization, rather than solely a problem of ‘socially robust’ knowledge production.

In this article, we treat knowledge utilization as a complex interactive and iterative process in which different forms of knowledge emerge, circulate, and are applied in practice. In a recent literature review of knowledge utilization, Heinsch et al. (2016) identified a wide range of terms that describe all or part of this complex process, including transfer, exchange, translation, diffusion, transmission, absorption, implementation, and dissemination. Although these terms all address the knowledge utilization process, Heinsch et al. (2016) found they often underpin different assumptions about knowledge utilization. They also revealed that sometimes different disciplines used different terms to refer to the same phenomenon; yet, at other times, the same term referred to different phenomena. For some, knowledge utilization was a process rather than a discrete event that took place at a certain time (Pregernig, 2006), while for others it involved multiple stages that occurred sequentially and sometimes iteratively, ranging from reception, cognition, reference, effort, influence to application (Landry et al., 2001a; Landry et al., 2003). Further, for others, knowledge utilization was one stage within a larger process including, for instance, ‘knowledge generation, exchange, and utilisation’ (cf. Beal et al. (1986) cited originally in Estabrooks et al. (2008). Based on their review, Heinsch et al. (2016, p. 100) concluded that*“the lack of definitional and conceptual clarity in the knowledge utilisation field might be an obstacle to its capacity to inform changes in practice.”*

This conclusion from the literature review notwithstanding, the field of knowledge utilization offers important insights that are helpful for conceptualising the link between transdisciplinary research projects and science and practice at large. In recent years, scholars in this field have moved away from the *science-push* or *demand-pull model* of knowledge utilization elaborated in section 3, which emphasizes the technical quality of research results (i.e. their validity, reliability, accuracy, etc.) as crucial for knowledge utilization to the *interaction model* (Heinsch et al., 2016). This model emphasizes relationships and interactions between researchers and potential users at different stages of knowledge production, dissemination, and utilisation as essential for research results to be taken up in practice. In addition, some scholars have even moved beyond the *‘two communities perspective’* (Heinsch et al., 2016), which considers science and practice as two separate spheres or systems and scientific and practical knowledge as two essentially different entities. Gredig and Sommerfeld (2007, p. 2) explained,*“scientific knowledge is the result of abstraction and generalization. The standard it seeks to satisfy is validity or truth. Practical knowledge is concrete, case based, and situational. The standard it seeks to satisfy is that of appropriateness or adequacy. The dividing line between science and practice can be transcended in the form of a transfer.”* In critiquing the model of knowledge transfer, the authors supported a *hybrid one* in which different forms of knowledge combine and relate to one another to produce what Dewe (2005, p. 368), cited in Gredig and Sommerfeld (2007, p. 36).

termed a*“’third’ sphere of knowledge in its own right”* resulting from encounters between scientific knowledge and practical knowledge. Commenting on this notion, Heinsch et al. (2016, p. 101) called it “*an endless cycle of knowledge production and utilization (that) ensues as the process of using research leads to the creation of new knowledge, and so on.*” In the same vein, they also cited Davies and Nutley (2008) definition of knowledge utilization as a ‘transformation process’ rather than the simple transfer of prepackaged research results to passive users. This recent conceptualization in the field of knowledge utilization offers an opportunity for enhancing understanding of the social and relational nature of knowledge and its use in practice while acknowledging*“the blurring, and even dissolving, of boundaries between research and practice”* (Heinsch et al., 2016, p. 98).

3. Models of knowledge utilization

The field of knowledge utilization evolved in the 1940s with a core set of scholars from different disciplines ranging from rural sociology to anthropology, geography, social and organizational psychology, communication and information (Estabrooks et al., 2008). Though different disciplines were subsumed within the field, scholars had a strong common interest in exploring knowledge utilization proper, i.e. what knowledge is, often in the form of scientific research, and how it impacts practice. In the mid-1980s the field of evidence-based practice (EBP) subsequently emerged in medical sciences, drawing more widely from the fields of technology transfer, knowledge utilization, and innovation diffusion (Estabrooks et al., 2008). Heinsch, et al’s (2016) review of the literature showed that EBP and knowledge utilization are often considered synonymous since both are essentially concerned with linking scientific research with practice. Yet, they identified both similarities and differences between knowledge utilization and EBP, while Hering (2018) explored EBP for environmental sciences. For a review of the intellectual structure and substance of the knowledge utilization field see Estabrooks et al. (2008).

In recent years, scholars in the field of knowledge utilization have developed a range of different models to explain the link between research projects and practice at large. The various models can be arranged into four categories which differ with regard to main determinants of knowledge utilization (Landry et al., 2001b): *science push*, *demand pull*, *dissemination*, and *interaction*. The models were developed during a period when the relationship between production and utilization of knowledge was reconsidered from different angles. Stokes (1997, p. 10) for instance, criticized as too simplistic *“[t]he belief that scientific advances are converted to practical use by a dynamic flow from science to technology (…).”* He coined the term ‘use-inspired basic research’ to highlight basic research that has a specific use in mind. Another criticism originated in discussion of public understanding of science. Lewenstein (2002) introduced the term ‘deficit model’ to express a overly simplistic idea of lay people. According to the deficit model lay people are eager to be informed by experts, while assuming *“that better understanding leads to greater support”* (Lewenstein, 2002, p. 2).

The distinction of two modes of knowledge production is a third influential discussion (Gibbons, 1994; Klein, 1990, 1996; Nowotny et al., 2001): ‘Mode 1’ knowledge production is located in scientific institutions and structured by scientific disciplines. Problem-definition, problem-solution, and peer review take place inside the academic context with the aim to provide reliable, universal and context free knowledge. In ‘Mode 2’, knowledge is produced and assessed by heterogeneous teams in transdisciplinary collaborations among research, policy and practice. Whereas ‘Mode 1’ knowledge needs to be ‘translated’ to be applied in practice, ‘Mode 2’ knowledge is produced in the context of application and considered contextualized and ‘socially robust’ (Gibbons, 1994; Greenhalgh and Wieringa, 2011; Van de Ven and Johnson, 2006). Though the notion of ‘Mode 2’ knowledge production has raised considerable criticism (Hessels and van Lente, 2008), the four models can be located between these two extremes with the *science push model* on one extreme (‘Mode 1’) and the *interactive model* on the other (‘Mode 2’) and the *demand pull* and *dissemination model* in-between.

3.1. Science push model

The *science push model* emphasizes supply of research results as the major determinant of knowledge utilization. As Landry et al. (2001b, p. 334) noted, “*in this model, the researchers are the major source of ideas for directing research*, *and the users are simple receptables for research results.”* The model assumes a linear sequence from supply of research advances to utilization in practice and an alignment of knowledge utilization with the technical quality of research results. Previous studies have considered many dimensions of research results potentially impacting utilization, including (1) attributes of content, especially, efficiency, compatibility, complexity, observability, trialability, validity, reliability, divisibility, applicability and radicalness and (2) types of research: basic/applied, general/abstract, quantitative/qualitative and research domains and disciplines. However, as pointed Landry et al. (2001b, p. 334), “s*ome empirical studies have found no relation between the technical quality of research results and utilization.”* Given this lack of empirical evidence, they formulated two main criticisms of the science push model*: (1)* “*transfer of knowledge to users is not automatic in a context where no one assumes responsibility for this transfer, and (2) raw research information is not usable knowledge and there is a process for transforming it into one usable”* in practice (Landry et al., 2001b, p. 334).

3.2. Demand pull model

The *demand pull model* stresses demand of research results as the major determinant of knowledge utilization. In this model, Landry et al. (2001b) explained, users are the major source of ideas for directing research. Similar to the *science push model, demand pull* follows a linear sequence, which, in this case, starts with identification of a research problem by users. This model explains knowledge utilization by users' needs, i.e. research results are more likely to be used in practice when they address specific needs of users instead of focusing solely on research advances for science. However, Landry et al. (2001b) added, it falls short of considering that even research aimed at contributing to problem solving can be pushed aside because it may conflict with organizational (or political) interests of users. This criticism stimulated emergence of a variant of the *demand pull model*, that of *organizational interests* (Rich and Oh, 1993). It emphasizes organizational structures, rules, norms, procedures and routines as the major determinants of knowledge utilization and assumes that research results are more likely to be used in practice when they support interests and objectives of organizations. The *demand pull model* and its variant, however, is criticized for (1) focusing largely on the instrumental use of research results, (2) emphasizing essentially users' or organisations' interests, and (3) neglecting interactions between researchers and users (Landry et al., 2001b).

3.3. Dissemination model

The *dissemination model* emerged in response to criticisms that transfer of knowledge to potential users is not automatic, and that 'traditional' transfer mechanisms (e.g. scholarly publications) are not tailored to users' needs. As Landry et al. (2001b) explained, this model defines knowledge utilization in terms of two main determinants. The first is adaptation of research results, which includes according to Huberman and Thurler (1991) efforts to make written documents more readable, more appealing and easier to understand, to make conclusions and recommendations more specific and more operational, and to focus on variables amenable to interventions. The second is dissemination of research results to potential users. Taken together the two determinants of this model assume research results are more likely to be used in practice when researchers identify and select useful results; adapt results (and products) to particular user needs in terms of content, calendar, form, and mode of diffusion; and disseminate adapted results to potential users. However, as Landry et al. (2001b) highlighted, mere reception of research results by potential users does not imply their 'use' in practice. The main criticism of this model is that potential users are neither involved in identification and selection of useful results, nor in their production.

3.4. Interaction model

The *interaction model* surfaced in response to criticisms of the *science push*, *demand pull,* and *dissemination* models. It assumes that knowledge utilization depends on disorderly interactions between researchers and potential users at different stages of knowledge production, dissemination, and utilization rather than linear sequences starting solely with needs of researchers or needs of users. As Landry et al. (2001b) explained, the *interaction model* incorporates all determinants of knowledge utilization in previous models: research types and scientific disciplines, users' needs and organizational interests, and mechanisms of adaption and dissemination. Unlike previous models, however, it pays particular attention to formal and informal linkage mechanisms between researchers and users including informal personal contacts; participation in committees, seminars, workshops; and active transmission and discussion of results. Thus, this model draws a stronger connection between processes of knowledge production, dissemination, and utilization. It presumes the more sustained and intense interaction between researchers and potential users, the more likely knowledge utilization will occur. As noted earlier some scholars, notably Gredig and Sommerfeld (2007), have moved even beyond the *interaction model* with its focus on informal and formal linkage mechanisms to dissolve boundaries between science and practice altogether. They conceptualize an intermediary social sphere between science and practice in which knowledge that is intrinsically different in quality is generated in the process of combining different types from different sources. This recent shift in the field of knowledge utilization is mirrored in alternative metaphors for knowledge as 'created', 'embodied', 'performed', 'collectively negotiated,' 'socially constructed' (Greenhalgh and Wieringa, 2011), 'transformed' (Heinsch et al., 2016), and 'situated' (Suchman, 1991).

The shift in recent conceptualizations is the most promising for exploring the project-to-science-and-practice-at-large gap. It is notable for widely capturing current conceptualizations of knowledge co-production in the field of transdisciplinary research. Such conceptualizations emphasize integration of locally adapted and theoretically generalized knowledge (Krohn, 2008), as well as academic transgression of disciplinary boundaries (Polk and Knutsson, 2008), constructive combination of different types and sources of knowledge (O'Rourke et al., 2016), and informal and formal interactions among different actors from research, policy and practice in a functional and dynamic way (Krütli et al., 2010) (see section 5 and 6).

However, it is important to acknowledge the various models of knowledge utilization presented above remain largely unrefined and untested, so their applicability is largely unknown (Heinsch et al., 2016, p. 102). It is also important to underscore they focus mainly on explaining the link between research projects and practice at large, so fall short of conceptualizing the link between research projects and science at large. The main determinants of knowledge utilization outlined above also apply to knowledge utilization in science.

4. Implications for transdisciplinary sustainability research

In her critical exploration of the relationship between transdisciplinary research and societal problem solving, Polk (2014, p. 449) gained some important insights to understanding this relationship. She found that *"successful transdisciplinary approaches must create a space where science and policy can meet and interact on equal terms. To be successful, this hybrid space must exist beside the formal confines of both disciplinary, and administrative and political cultures. It is important to note that these meeting places are not separate from the surrounding societal and scientific practices; they are* *highly embedded in both. Such a space enables individuals to break the boundaries between different types and sources of knowledge and expertise, and creates sites of interaction that are needed for producing the degree of participation and knowledge integration that can more effectively bridge the gaps between science and policy spheres.*" Polk (2014)'s insights support the *interaction model* or its even more progressive variant, the *hybrid model* in which different forms of knowledge from both science and practice combine and relate to one another to produce a 'third' sphere of knowledge. This inherently dynamic, iterative and interactive process takes place in the hybrid space, which Gredig and Sommerfeld (2007) argue tends to blur, or even dissolve, boundaries between realms of science and practice/policy as Polk (2014) recognized.

Polk (2014) also found that 'socially robust' knowledge produced in such social spaces needs to be in a form that is substantively and temporally compatible with formal and informal decision making as well as planning processes, in addition to identifying relevant target groups (users/organisations) in order to achieve substantive impact. These findings resonate with major determinants of knowledge utilization outlined above: namely adaptation of research results to needs of particular target groups in terms of content, form, time and mode of diffusion; their subsequent dissemination to such groups; and incorporation of research results into existing organizational structures, rules, norms, procedures and routines that Belkhodja et al. (2007) highlighted to ensure knowledge use in science and practice at large. Polk (2014, p. 450) concluded her critical exploration by stressing that "*transdisciplinary processes need to be sufficiently anchored in formal and informal policy (and science) contexts, and the results packaged and disseminated in both science and policy contexts in ways that address (…) institutional, political and sector-based boundaries.*" Her conclusions mirror important findings from the knowledge utilization field, which emphasize the need to embed research processes in realms of (science and) practice and to invest in formal and informal linkage mechanisms between researchers (or project teams) and intended target groups at different stages of knowledge production, dissemination, and utilization in order to ensure greater use in (science and) practice at large.

5. Linking models of knowledge utilization and transdisciplinary research

Based on a current conceptual model of transdisciplinarity developed by Jahn et al. (2012) we now present a revised conceptual model of an ideal-typical, interactive, and iterative transdisciplinary research process that integrates pertinent insights from emerging models of knowledge utilization and accounts for the social and relational nature of knowledge and its use. As illustrated in Fig. 1, our revised model adds two new phases from the field of knowledge utilization–disseminating new knowledge, and using new knowledge–to the three phases established in Jahn et al (2012)'s original model-forming a common research object, producing new knowledge, and evaluating new knowledge. Our revised model thus includes five main phases: (A) defining sustainability problems,

(B) producing new knowledge, (C) assessing new knowledge, (D) disseminating new knowledge (in the realms of both science and practice), and (E) using new knowledge (here too in both science and practice). Transdisciplinary research projects run disorderly through these five phases and extend progressively their boundaries into the realms of both science and practice when assessing and disseminating new knowledge. As acknowledged in the knowledge utilization literature, the key elements to bridge the 'project-to-science-and-practice-at-large gap' are informal and formal linkage mechanisms between the project team and intended target groups in both science and practice (Gredig, 2011; Landry et al., 2001b). Ideally, these linkage mechanisms transcend all phases of an ideal-typical transdisciplinary research process.

Extending the work of Bergmann et al. (2005), Jahn et al. (2012), and Lang et al. (2012), we conceptualize transdisciplinary research processes as an effort to combine two processes of knowledge production: a societal process, in which users/organisations address a particular sustainability problem, and a scientific process, in which researchers carry out research on that particular problem. We reframe the societal process as the realm of practice to emphasize the standard it seeks to satisfy: appropriateness or adequacy (as compared to the scientific process that seeks to satisfy the standard of validity and truth (Pohl et al., 2017, p. 44)). In the following we briefly describe the five phases of our revised model of an ideal-typical, interactive and iterative transdisciplinary research process.

5.1. Defining sustainability problems

Drawing on Lang et al. (2012) this phase involves formation of a collaborative project team involving actors from the realms of both science and practice and definition of a particular sustainability problem that triggers scientific research questions to be addressed by the team. This phase includes: (i) anchoring research process widely in both realms; (ii) determining the right level of informal and formal interactions between actors from both realms throughout the entire process of knowledge production, dissemination, and utilization; (iii) developing a joint vision for integrating different types and sources of scientific and practical knowledge (Hoffmann et al., 2017b); and (iv) developing an outcome/impact model that specifies scientific and societal outcomes/impacts and defines indicators to assess whether outcomes/impacts are achieved or not (Pohl and Hirsch Hadorn, 2007).

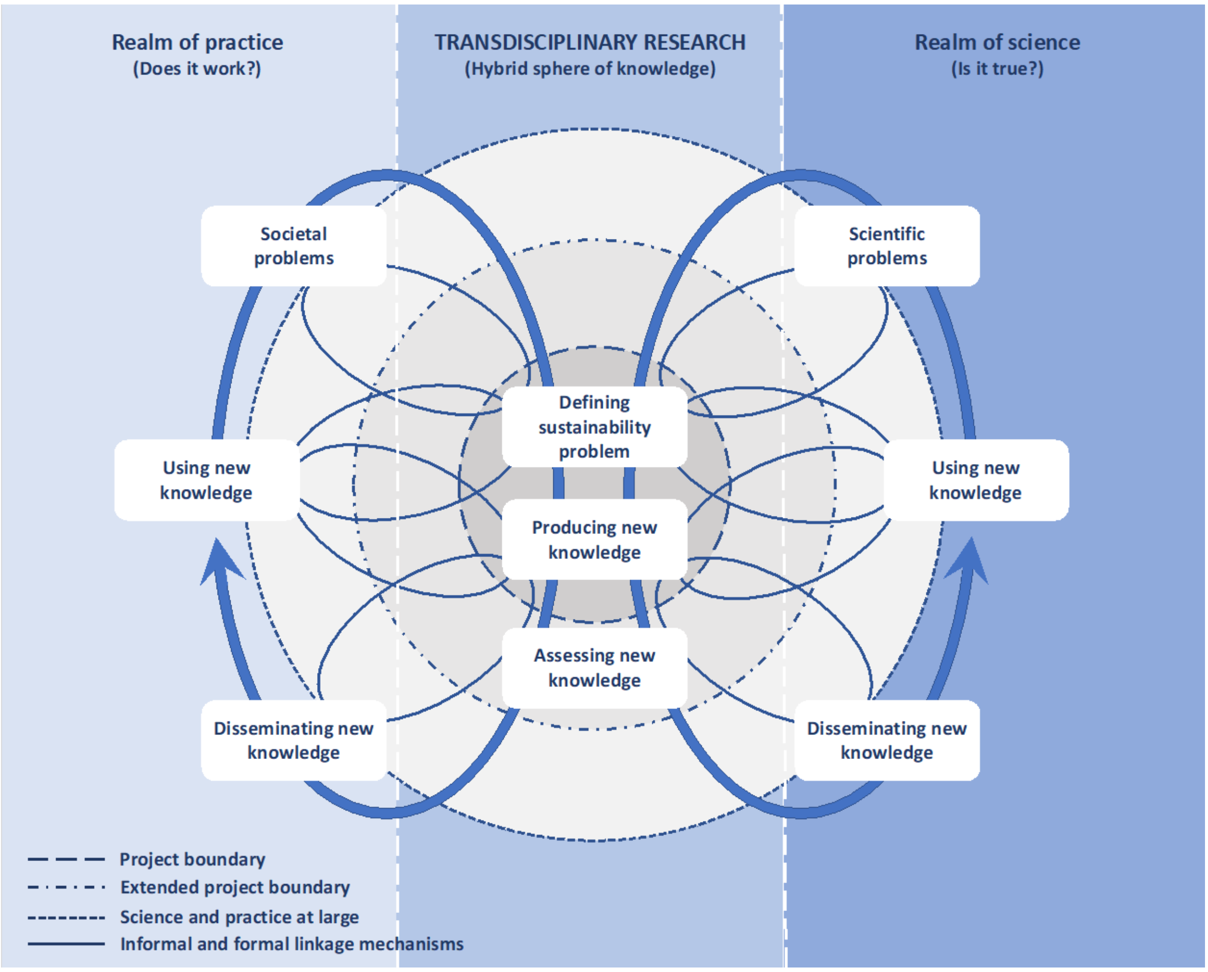

Figure 1: Revised conceptual model of an ideal-typical, interactive and iterative transdisciplinary research process to bridge the ‘project-to-science-and-practice-at-large-gap’, connecting processes of knowledge production, dissemination and utilization (larger round arrows) and establishing informal and formal linkage mechanisms between the project team and intended target groups in the realms of both science and practice (thin spirals). The transdisciplinary research process consists of five phases: (i) defining sustainability problems, (ii) producing new knowledge, (iii) assessing new knowledge, (iv) disseminating new knowledge (in the realms of both science and practice), and (v) using knowledge also in both realms. Transdisciplinary research projects run through these phases in different order (thin spirals) and progressively extend their boundaries into the realms of both science and practice, when assessing new knowledge (dashed-pointed line) and disseminating new knowledge (dashed line). Two rationalites (or goals) need to be balanced in the process: the goal in science of satisfying standards of validity and truth as well as the goal in practice of satisfying standards of appropriateness and adequacy. Different types and sources of scientific and practical knowledge need to be combined and related to one another to produce a ‘hybrid sphere of knowledge’ in which boundaries between science and practice are blurred or even dissolved. The figure is adapted from Jahn et al. (2012), Lang et al. (2012), Pohl et al. (2017), and Gredig (2011).

5.2. Producing new knowledge

This phase involves generation of new knowledge and/or integration of existing knowledge from science and practice with a view to establishing novel and previously unrecognized connections between them (Jahn et al., 2012; Specht et al., 2015). It implies differentiation and subsequent integration of different types and sources of scientific and practical knowledge, recognized by Lang et al. (2012), and Pohl and Hirsch Hadorn (2007). This phase presupposes informal and formal interactions between actors from science and practice in a functional and dynamic way (Krütli et al., 2010). It also presumes collaborative leadership involving cognitive, structural, and procedural tasks (Gray, 2008).

5.3. Assessing new knowledge

Drawing on Jahn et al. (2012) this phase involves assessing new knowledge with regard to its contribution to both societal and scientific problem solving. i.e. its relevance and usefulness for tackling the sustainability problem at hand and for advancing science in the field of sustainability. Building on Landry et al. (2001b), it also implies extending the boundaries of transdisciplinary research projects into the realms of both science and practice and integrating intended target groups (users/organizations) not involved in phases A and B in (i) identifying and selecting knowledge deemed to be relevant and useful from their respective perspective, and (ii) scrutinizing the potentials and limits of that knowledge for both science and practice at large.

5.4. Disseminating new knowledge

Building on Landry et al. (2001b) and Pohl and Hirsch Hadorn (2007), this phase involves disseminating useful results to intended target groups (users/organizations) not involved in phases A, B, and C. It includes concerted efforts to adapt and tailor research results/products to particular needs, interests, and objectives as well as to specific structures, rules, norms, procedures and routines of intended target groups, and to develop strategies to communicate research results at a time that suits their agendas (Rich and Oh, 1993). It implies (i) using different social media to reach intended target groups, (ii) meeting and exchanging with specific target groups, and (iii) participating in particular workshops, seminars, forums as well as in advisory boards and expert commissions (Hering et al., 2012). It also involves intervening in relevant disciplinary, inter- or transdisciplinary debates and contributing to journals, networks or conferences (Pohl and Hirsch Hadorn, 2007).

5.5. Using new knowledge

Building on insights from the knowledge utilization field, this phase involves enhancing knowledge utilization in the realms of both science and practice including six stages that occur sequentially and sometimes iteratively (Landry et al., 2001b; Landry et al., 2003): (i) reception: intended target groups such as researchers, practitioners, professionals, and funders receive research results/reports/papers tailored to their particular needs, interests and objectives; (ii) cognition: target groups read and understand research results/reports/papers; (iii) reference: target groups cite research results/reports/papers; (iv) efforts: target groups adopt research results, (v) influence: research results/reports/papers influence decision-making by researchers, practitioners, professionals and funders, with a view to, for instance, initiate new research projects or programs, and ensure academic capacity building and academic career opportunities as pointed out by Pohl and Hirsch Hadorn (2007); and (vi) application/implementation: target groups implement research results.

In light of our revised model of an ideal-typical transdisciplinary research process, we suggest an extended definition for transdisciplinary sustainability projects that aim at larger scale changes in both science and practice (Hoffmann et al., 2017a): Such transdisciplinary projects (i) address societally relevant sustainability problems that trigger scientific research questions; (ii) grasp complexity of the problem by involving a variety of scientific and societal actors while accounting for diversity of perspectives on the problem (Lang et al., 2012; Pohl and Hirsch Hadorn, 2007); (iii) generate new 'social robust' knowledge by integrating various perspectives being brought together in creative and critical ways (Klein, 2012; O'Rourke et al., 2016); (iv) assess new knowledge together with intended target groups (users/organizations) with respect to its relevance and usefulness for both science and practice; (v) adapt and tailor relevant and useful knowledge in terms of content, form, time and mode of diffusion to intended target groups not involved in the research process and disseminates useful knowledge to target groups; and (vi) enhance knowledge utilization from cognition to implementation by establishing informal and formal linkages between the project team and intended target groups throughout the entire process of knowledge production, dissemination, and utilization. In this extended understanding, transdisciplinary research can be regarded as a comprehensive, multi-perspective, problem- and solution-oriented approach that transgresses boundaries between science and practice with the aim of contributing to both societal and scientific problem solving for sustainability at large (cf. Pohl (2011) and Hoffmann et al. (2017a)).

6. Conclusion

Reviewing the literature on knowledge utilization revealed how close the interaction model is to current conceptualizations of knowledge co-production in the literature on transdisciplinary research, an observation also addressed in Pohl et al. (2010), Polk (2015), and Enengel et al. (2012). Scholars of both fields have emphasized the importance of iterative formal and informal interactions with various target groups in the realms of both science and practice over the course of knowledge generation, dissemination, and utilization to induce change in both realms. Concepts of transdisciplinary research processes are, however, diverse and some include testing, evaluating and adjusting new knowledge in experimental areas as the final step (Rogga et al., 2018). Recently this step has been elaborated and explored under the label of real-world laboratories, learning laboratories, or living laboratories (see Rogga et al. (2018), Krütli et al. (2018), Renn (2018), Schäpke et al. (2018)). Experimental implementation of new knowledge in real-world laboratories extends project boundaries to include more societal (and scientific) actors in processes of knowledge generation, dissemination and utilization. However, real-world laboratories explore such processes on a small scale, and do not address the question of how to induce changes in both science and practice at larger scale. For larger scale changes, the interactive model of knowledge utilization suggests adding informal and formal linkage mechanisms between the project team and intended target groups in the realms of both science and practice and including as many (members of) the target groups as possible.

This combination of insights form the fields of transdisciplinary research and knowledge utilization is clear and straight forward on a conceptual level. However, practical consequences how to actually conduct transdisciplinary research are less clear, raising a number of future research questions. For instance, what does it exactly mean to include informal and formal linkage mechanisms in each phase of a transdisciplinary research project? Are some phases–such as defining a sustainability problem–more open to such mechanisms than others? And, if yes, should this phase then be conceptualized as an encompassing process of joint problem framing with the target groups? However, all target groups in the realms of both science or practice can never be involved or will be interested in such process, meaning that there will always be a boundary between science and practice at large. And what are realistic expectations for the extent to which transdisciplinary research projects will contribute to changes in science and practice at large? Furthermore, where does the responsibility of individual projects start, and where does it end? And, could there be different types of transdisciplinary research projects, some aiming at inducing larger scale changes and some aiming at exploring impact in smaller real-world laboratories? And might both of these types require different strategies for formal and informal linkage mechanisms in different phases?

Finally, for transdisciplinary research projects that aim at inducing changes in science and practice at large, we suggest future empirical research to be carried out to validate and further refine each of the five phases of our revised conceptual model of an ideal-typical, interactive and iterative transdisciplinary research process: (i) defining sustainability problems, (ii) producing new knowledge, (iii) assessing it, (iv) disseminating it in the realms of both science and practice, and (v) using it in both realms. To this end, our current research employs the revised model as a basis for developing indicators to assess processes, results, and effects of transdisciplinary research projects that aim at inducing large scale changes in both science and practice. The indicators will enable us to provide empirical evidence from different case studies with the aim of testing, validating, and refining our model. This article thus summarizes the first phase of our effort to bridge theory and practice of transdisciplinary research.

Acknowledgements

This research was supported by Eawag, the Swiss Federal Institute of Aquatic Science and Technology, and USYS TdLab, ETH Zurich. We thank the editors of this Special Issue and two anonymous reviewers for their thoughtful comments that helped to strengthen our original manuscript.

References

Beal, G.M., Dissanayake, W., Konoshima, S., 1986. Knowledge Generation, Exchange, and Utilization. Westview Press, Boulder.

Belkhodja, O., Amara, N., Landry, R., Ouimet, M., 2007. The extent and organizational determinants of research utilization in Canadian health services organizations. Science Communication 28, 377-417.

Bergmann, M., Brohmann, B., Hoffmann, E., Loibl, C.M., Rehaag, R., Schramm, E., Voß, J.-P., 2005. Quality Criteria of Transdisciplinary Research. A Guide for the Formative Evaluation of Research Projects. Institute for Social-Ecological Research (ISOE), Frankfurt am Main

Cornell, S., Berkhout, F., Tuinstra, W., Tàbara, J.D., Jäger, J., Chabay, I., de Wit, B., Langlais, R., Mills, D., Moll, P., Otto, I.M., Petersen, A., Pohl, C., van Kerkhoff, L., 2013. Opening up knowledge systems for better responses to global environmental change. Environmental Science & Policy 28, 60-70.

Davies, H.T.O., Nutley, S.M., 2008. Learning More about How Research-Based Knowledge Gets Used: Guidance in the Development of New Empirical Research. William T. Grant Foundation, New York.

Dewe, B., 2005. Von der Wissenstransferforschung zur Wissenstransformation: Vermittlungsprozesse—Bedeutungsveränderungen, In: Antos, G., Wichter, S. (Eds.), Wissenstransfer durch Sprache als gesellschaftliches Problem Lang, Bern, Switzerland, pp. 365-379.

Enengel, B., Muhar, A., Penker, M., Freyer, B., Drlik, S., Ritter, F., 2012. Co-production of knowledge in transdisciplinary doctoral theses on landscape development—An analysis of actor roles and knowledge types in different research phases. Landscape and Urban Planning 105, 106-117.

Estabrooks, C.A., Derksen, L., Winther, C., Lavis, J.N., Scott, S.D., Wallin, L., Profetto-McGrath, J., 2008. The intellectual structure and substance of the knowledge utilization field: a longitudinal author co-citation analysis, 1945 to 2004. Implementation science : IS 3, 1-22.

Gibbons, M., 1994. The new production of knowledge : the dynamics of science and research in contemporary societies. SAGE Publications, London.

Gray, B., 2008. Enhancing transdisciplinary research through collaborative leadership. Am J Prev Med 35, S124-132.

Gredig, D., 2011. From research to practice: Research-based Intervention Development in social work: developing practice through cooperative knowledge production. European Journal of Social Work 14, 53-70.

Gredig, D., Sommerfeld, P., 2007. New Proposals for Generating and Exploiting Solution-Oriented Knowledge. Research on Social Work Practice 18, 292-300.

Greenhalgh, T., Wieringa, S., 2011. Is it time to drop the 'knowledge translation' metaphor? A critical literature review. J R Soc Med 104, 501-509.

Hansson, S., Polk, M., 2018. Assessing the impact of transdisciplinary research: The usefulness of relevance, credibility, and legitimacy for understanding the link between process and impact. Res Evaluat 27, 132-144.

Heinsch, M., Gray, M., Sharland, E., 2016. Re-conceptualising the link between research and practice in social work: A literature review on knowledge utilisation. International Journal of Social Welfare 25, 98-104.

Hering, J.G., 2018. Implementation Science for the Environment. Environmental science & technology 52, 5555-5560.

Hering, J.G., Hoffmann, S., Meierhofer, R., Schmid, M., Peter, A.J., 2012. Assessing the Societal Benefits of Applied Research and Expert Consulting in Water Science and Technology. GAIA - Ecological Perspectives for Science and Society 21, 95-101.

Hessels, L.K., van Lente, H., 2008. Re-thinking new knowledge production: A literature review and a research agenda. Research Policy 37, 740-760.

Hoffmann, S., Pohl, C., Hering, J.G., 2017a. Exploring transdisciplinary integration within a large research program: Empirical lessons from four thematic synthesis processes. Research Policy 46, 678-692.

Hoffmann, S., Pohl, C., Hering, J.G., 2017b. Methods and procedures of transdisciplinary knowledge integration: empirical insights from four thematic synthesis processes. Ecology and Society 22, 27.

Huberman, M., Thurler, G., 1991. De la recherche à la pratique: Éléments de base? . Lang, Bern.

Jahn, T., Bergmann, M., Keil, F., 2012. Transdisciplinarity: Between mainstreaming and marginalization. Ecological Economics 79, 1-10.

Klein, J.T., 1990. Interdisciplinarity: History, theory, and practice. Wayne State University Press, Detroit.

Klein, J.T., 1996. Crossing boundaries: Knowledge, disciplinarities, and interdisciplinarities. University Press of Virginia, Charlottesville.

Klein, J.T., 2012. Research Integration: A Comparative Knowledge Base, In: Repko, A.F., Newell, W.H., Szostak, R. (Eds.), Case studies in interdisciplinary research. Sage, Thousand Oaks, pp. 283-298.

Krohn, W., 2008. Learning from Case studies, In: Hirsch Hadorn, G., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U., Zemp, E. (Ed.), Handbook of Transdisciplinary Research. Springer Dordrecht pp. 369–384.

Krütli, P., Pohl, C., Stauffacher, M., 2018. Sustainability Learning Labs in Small Island Developing States: A Case Study of the Seychelles. GAIA - Ecological Perspectives for Science and Society 27, 46-51.

Krütli, P., Stauffacher, M., Flüeler, T., Scholz, R.W., 2010. Functional-dynamic public participation in technological decision-making: site selection processes of nuclear waste repositories. Journal of Risk Research 13, 861-875.

Landry, R., Amara, N., Lamari, M., 2001a. Climbing the Ladder or Research Utilization. Science Communication 22, 396-422.

Landry, R., Amara, N., Lamari, M., 2001b. Utilization of social science research knowledge in Canada. Research Policy 30, 333-349.

Landry, R., Lamari, M., Amara, N., 2003. The extent and determinants of the utilization of university research in government agencies. Public Administration Review 63, 192-205.

Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., Thomas, C.J., 2012. Transdisciplinary research in sustainability science: practice, principles, and challenges. Sustain Sci 7, 25-43.

Lewenstein, B.V., 2002. Editorial: A decade of public understanding. Public Understanding of Science 11, 1-4.

Nowotny, H., 1999. The Need for Scoially Robust Knowledge. TA-Datenbank Nachrichten 8, 12-16.

Nowotny, H., Scott, P., Gibbons, M., 2001. Re-thinking science knowledge and the public in an age of uncertainty. Polity, Cambridge.

O'Rourke, M., Crowley, S., Gonnerman, C., 2016. On the nature of cross-disciplinary integration: A philosophical framework. Stud Hist Philos Biol Biomed Sci 56, 62-70.

Pohl, C., 2011. What is progress in transdisciplinary research? Futures 43, 618-626.

Pohl, C., Hirsch Hadorn, G., 2007. Principles for designing transdisciplinary research. Oekom Verlag, München.

Pohl, C., Krütli, P., Stauffacher, M., 2017. Ten Reflective Steps for Rendering Research Societally Relevant. GAIA - Ecological Perspectives for Science and Society 26, 43-51.

Pohl, C., Rist, S., Zimmermann, A., Fry, P., Gurung, G.S., Schneider, F., Speranza, C.I., Kiteme, B., Boillat, S., Serrano, E., Hadorn, G.H., Wiesmann, U., 2010. Researchers' roles in knowledge co-production: experience from sustainability research in Kenya, Switzerland, Bolivia and Nepal. Science and Public Policy 37, 267-281.

Polk, M., 2014. Achieving the promise of transdisciplinarity: a critical exploration of the relationship between transdisciplinary research and societal problem solving. Sustain Sci 9, 439-451.

Polk, M., 2015. Transdisciplinary co-production: Designing and testing a transdisciplinary research framework for societal problem solving. Futures 65, 110-122.

Polk, M., Knutsson, P., 2008. Participation, value rationality and mutual learning in transdisciplinary knowledge production for sustainable development. Environmental Education Research 14, 643-653.

Pregernig, M., 2006. Transdisciplinarity viewed from afar. Science and Public Policy 33, 445-455.

Renn, O., 2018. Real-World Laboratories - the Road to Transdisciplinary Research? GAIA - Ecological Perspectives for Science and Society 27, 1-1.

Rich, R.F., Oh, C.H., 1993. The utilization of policy research In: Nagel, S. (Ed.), Encyclopedia of Policy Studies, 2nd ed. Marcel Dekkar, New York.

Rogga, S., Zscheischler, J., Gaasch, N., 2018. How Much of the Real-World Laboratory Is Hidden in Current Transdisciplinary Research? GAIA - Ecological Perspectives for Science and Society 27, 18-22.

Schäpke, N., Bergmann, M., Stelzer, F., Lang, D.J., Guest, E., 2018. Labs in the Real World: Advancing Transdisciplinary Research and Sustainability Transformation: Mapping the Field and Emerging Lines of Inquiry. GAIA - Ecological Perspectives for Science and Society 27, 8-11.

Specht, A., Gordon, I.J., Groves, R.H., Lambers, H., Phinn, S.R., 2015. Catalysing transdisciplinary synthesis in ecosystem science and management. The Science of the total environment 534, 1-3.

Stokes, D.E., 1997. Pasteur's quadrant basic science and technological innovation. The Brookings Institution, Washington.

Suchman, L.A., 1991. Plans and situated actions: The problem of human machine communication. Cambridge University Press, Cambridge.

Technopolis Group, 2018. Impact evaluation of National Research Programmes 59, 60 and 61. Final report. Technopolis Group, Brighton, p. 103.

Van de Ven, A., Johnson, P., 2006. Knowledge for theory and practice. Academy of Management Review 31, 802-821.

Ward, V., House, A., Hamer, S., 2009. Developing a framework for transferring knowledge into action: a thematic analysis of the literature. J Health Serv Res Policy 14, 156-164.

Ward, V., Smith, S., House, A., Hamer, S., 2012. Exploring knowledge exchange: a useful framework for practice and policy. Soc Sci Med 74, 297-304.