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

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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)'s 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.

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, which is one of the most cited ones, 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

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helpful in advancing our theoretical understanding of 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 utilization 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 and, finally, (v) 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 on 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). She condensed the 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, which 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 into 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 as 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 science and 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 that 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 and influence to application (Landry et al., 2001a, 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 utilization 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)'s 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 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. (2016)'s 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, the authors 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 the 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 the 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 the public understanding of science. Lewenstein (2002) introduced the term 'deficit model' to express an 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 collaboration 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 the 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, as well as 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 out in Landry et al. (2001b, p. 334), "*some 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 the demand for research results as the major determinant of knowledge utilization. In this model, Landry et al. (2001b) explained that 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 the identification of a research problem by potential users. This model explains knowledge utilization in terms of 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 that 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 the 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 the 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 the 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 the 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 that research results are more likely to be used in practice when researchers identify and select useful results, when they adapt results (and products) to particular user needs in terms of content, calendar, form and mode of diffusion and when they disseminate adapted results to potential users. However, as Landry et al. (2001b) highlighted, the 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 the 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 the needs of researchers or the 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 as well as 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 and workshops as well as the active transmission and discussion of results. Thus, this model draws a stronger connection between processes of knowledge production, dissemination and utilization. It presumes that the more sustained and intense interactions between researchers and potential users are, 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 such 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 the 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 that 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 that 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. To our understanding, 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 into 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, 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 the major determinants of knowledge utilization outlined above: namely, the adaptation of research results to the needs of particular target groups in terms of content, form, time and mode of diffusion, their subsequent dissemination to such groups, and the 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 that 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, namely, forming a common research object, B and C, 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 through these five phases in a disorderly manner and progressively extend 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

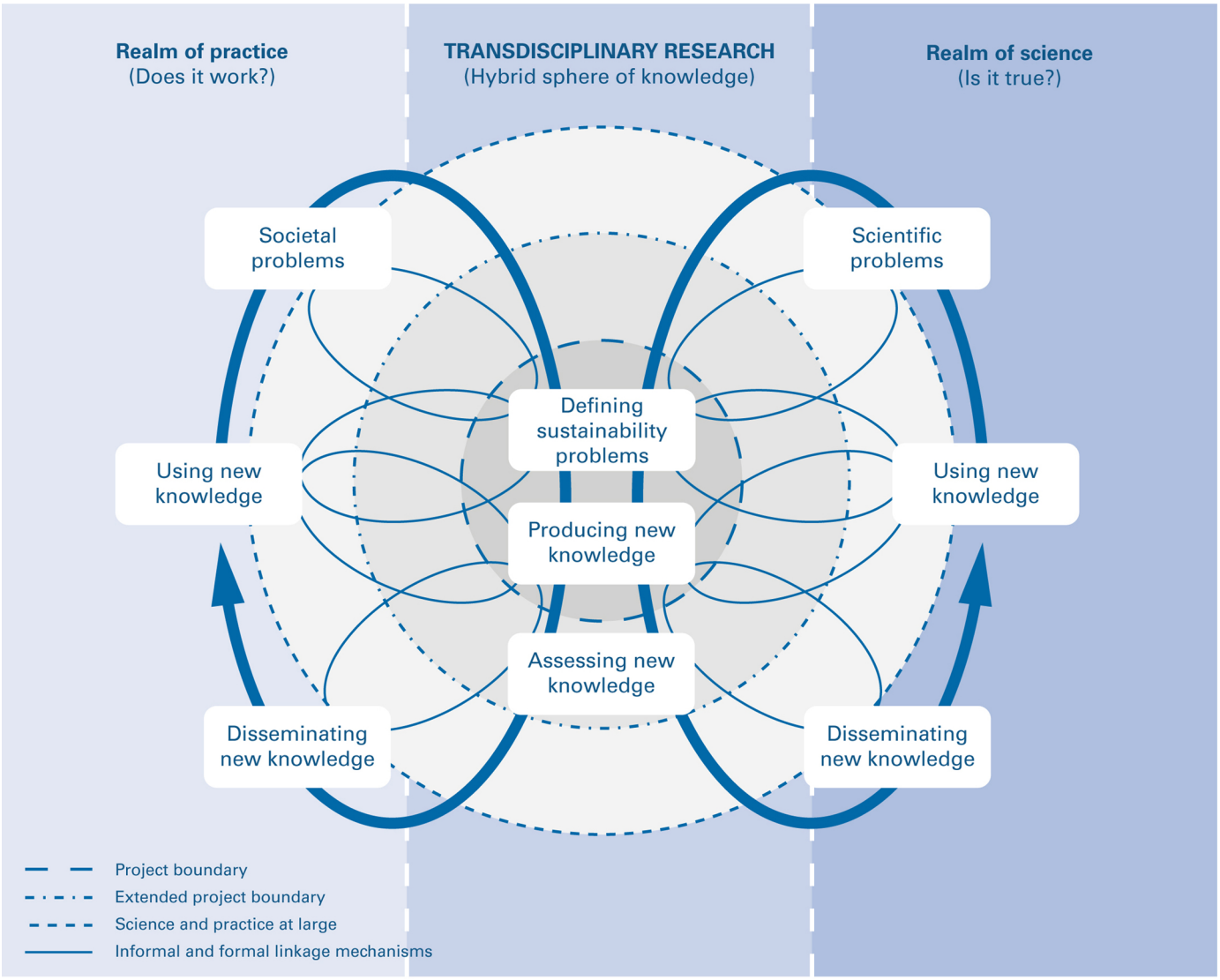

Fig. 1. Revised conceptual model of an ideal-typical, interactive and iterative transdisciplinary research process to bridge the 'project-to-science-and-practice-at-large-gap', connecting processes of knowledge production, dissemination and utilization (larger round arrows) and establishing informal 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).

collaborative project team involving actors from the realms of both science and practice as well as the definition of a particular sustainability problem that triggers scientific research questions to be addressed by the team. This phase includes: (i) anchoring the 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).

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 for the purpose of (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, 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, initiating new research projects or programs and insuring 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 the complexity of the problem by involving a variety of scientific and societal actors while accounting for a 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 disseminate 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 on a 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 as well as including as many (members of) the target groups as possible.

This combination of insights from the fields of transdisciplinary research and knowledge utilization is clear and straightforward 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 mean exactly 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 so, 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 an encompassing process, meaning that there will always be a boundary between science and practice at large. And what expectations are realistic concerning the extent to which transdisciplinary research projects will contribute to changes in science and practice at large? Furthermore, where does the responsibility for 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 that future empirical research 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: (A) defining

sustainability problems, (B) producing new knowledge, (C) assessing it, (D) disseminating it in the realms of both science and practice and (E) using it in both realms. To this end, our current research employs the revised model as a basis for developing indicators to assess the 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 the theory and practice of transdisciplinary research.

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