



Conceptualising transdisciplinary integration as a multidimensional interactive process

Christian Pohl^{a,*}, Julie Thompson Klein^{a,b}, Sabine Hoffmann^c, Cynthia Mitchell^d, Dena Fam^d

^a TdLab, Department of Environmental Systems Science, ETH Zurich, Universitätstrasse 16, CH-8006 Zürich, Switzerland

^b Department of English, Wayne State University, 5057 Woodward, Detroit, MI 48202, USA

^c Eawag, Swiss Federal Institute of Aquatic Science and Technology, Überlandstrasse 133, CH-8600 Dübendorf, Switzerland

^d Institute for Sustainable Futures, University of Technology Sydney, 15 Broadway, Ultimo NSW 2007, Australia

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ABSTRACT

Integration is a key process in transdisciplinary research and knowledge co-production. Nonetheless, it is often used as a buzzword without specifying what exactly it means or what actually happens during integration. We propose conceptualizing integration as a multidimensional interactive process. We characterize it as an open-ended learning process without pre-determined outcomes. Integration designates relations established throughout a transdisciplinary research process between elements that were not previously related. Those elements are participants in the process and their thought-styles and thought-collectives and more specifically pieces of knowledge, ideas, or practices from different thought-collectives as well as views of individual researchers and practitioners. Integration can happen at manifold instances of a transdisciplinary research process. It can take place among two, several, or all participants and can be one-sided or mutual. It might include insights, practices, frameworks, or concepts shared by two, several, or all participants. Consensus is only one along with other ways of retaining plurality of thought-styles and seeing integration as a balance between them that remains subject to continuous revision. To analyse or achieve effective integration, further dimensions beyond the cognitive have to be taken into account including at least an emotional and a social-interactive dimension.

1. Introduction

Scholars consider co-production of knowledge and transdisciplinary research (TDR) as promising ways of how science can engage in societal problem solving (Lemos et al., 2018; Mauser et al., 2013). Transdisciplinarity is an old idea (Jantsch, 1970; Mittelstraß, 1992; Winch, 1947) that counters the claim knowledge is produced and stored according to disciplinary structures. It must be reorganised and connected to be relevant for solving societal problems (Berger and Duguet, 1982). Understanding of transdisciplinarity as a process of knowledge production that involves practitioners—referring here to representatives of sectors of society beyond the academy—emerged later, triggered by discussion of Mode 1 and Mode 2 knowledge production (Gibbons et al., 1994; Klein et al., 2001). In comparison, co-production of knowledge is a newer idea with two different understandings of “co”. The first “co” stands for concurrent production of knowledge and social order (Jasanoff, 2004). In the second it refers to collaboration of researchers and practitioners in knowledge production (Lemos and Morehouse,

2005).

Referring to the latter understanding, we consider co-production of knowledge and transdisciplinary research equivalent terms for purpose-driven collaborative processes of knowledge production among researchers of different disciplines, inter- and trans-disciplinary fields, and representatives of private and public sectors including civil society (Hirsch Hadorn et al., 2008; Lemos and Morehouse, 2005; Norstrom et al., 2020; Polk, 2015). The purpose that drives both is solving societal problems: including challenges of public health, education, peace, gender equality, and sustainable development. We use the term “transdisciplinary research” to stress diverse disciplinary perspectives that have to be reorganised for societal problem solving because they are not always a prominent focus in discourse on co-production. Furthermore we focus on the purpose of sustainable development because four of the five authors work in this area.

Transdisciplinary research is crucial for sustainable development because it brings together diverse societal actors and their perspectives, knowledge, and forms of expertise. “Integration” is a widely used term to

* Corresponding author.

E-mail address: christian.pohl@usys.ethz.ch (C. Pohl).

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describe the act of bringing together or bridging perspectives (Bammer et al., 2020; Hoffmann, 2016; Jahn et al., 2006; McDonald et al., 2009). Integration, however, is often a buzzword to name a key event in the complex and multidimensional process of collective knowledge production without specifying what exactly it means or what actually happens during the process. A number of questions may arise. For instance, does integration mean coming to a consensus on a contested issue? Or, does it mean individual researchers and practitioners questioning their own epistemologies and making room for other epistemological positions and truth claims? Or, does integration occur if a policy maker incorporates knowledge of climate researchers into decision making even if the researchers don't assimilate any of the policy maker's knowledge or work in collaborative fashion? Furthermore, are there situations where integration is not appropriate? This article presents a concept of integration that provides answers to these and related questions. It encompasses a more elaborated concept of integration that will contribute to improving bridging and integrating perspectives of (and within) different sectors of society, thereby strengthening contributions of transdisciplinary research and co-production of knowledge to sustainable development.

We develop the concept of integration in five steps. First we position transdisciplinary research as problem solving within a broader discourse of inter- and trans-disciplinarity. Second, we outline transdisciplinary research processes and its participants. Third, we conceptualise integration as a process unfolding in diverse forms at manifold instances during transdisciplinary research. Fourth, we discuss dimensions beyond cognitive factors that might hinder or help such instances of integration. Then fifth, in moving to a conclusion, we use our concept of integration to discuss the four framing questions above.

2. Positioning understanding of transdisciplinary research

Transdisciplinary research is part of a broader discourse of boundary crossing that includes interdisciplinarity (ID). According to an authoritative state-of-the-art report, ID is a mode of research, education, and problem solving that integrates information, methods, tools, concepts, and theories from two or more disciplines (National Academy of Sciences et al., 2005, 2). The concept arose in the early 20th century in response to two needs: to address complex problems requiring expertise of more than one discipline and to foster holistic approaches in research and education. Subsequently new fields arose to address unmet interests and needs, including molecular biology, environmental studies, and cultural studies (Klein, 1990).

ID typically focuses on a complex problem, question, or topic in activities ranging from individual borrowing across disciplines to large-scale team-based initiatives. The scope varies though, from Narrow ID involving disciplines with compatible methods and epistemologies—e.g., mathematics and physics—to Broad ID bridging disparate approaches—e.g., chemistry and history. Methodological and theoretical forms also differ. Methodological ID typically improves the quality of results by using a method, concept, or tool from another discipline to test a hypothesis, answer a research question, or advance knowledge in an emerging area. In contrast, theoretical ID develops a comprehensive general view or new synthetic framework (Klein et al., 2010).

The term transdisciplinarity (TD) is typically used to describe approaches that go beyond ID (Pohl and Hirsch Hadorn, 2007, 70–86), though language about key actions in both ID and TD reflects the goal of 'going beyond'. Whereas in ID such actions are linking, blending, fusing, and synthesizing, in TD they are transcending, transgressing and transforming (Klein et al., 2010, 16). The term TD is dated conventionally to the first international seminar on interdisciplinarity in 1970, defined at the time as a common system of axioms transcending the narrow scope of disciplinary worldviews through an overarching synthesis (Apostel et al., 1972; Jantsch, 1972; Piaget, 1972). The first exemplar was anthropology as a general science of humans. At present three discourses stand out (Klein, 2014):

- The first—*transcendence*—is associated historically with the quest for unity of knowledge (e.g., Kockelmans, 1979; Nicolescu, 2010). Subsequently, new overarching syntheses arose with the aim of reorganizing the structure of knowledge, including general systems theory, post/structuralism, feminist theory, cultural critique, and sustainability.
- The second—*problem solving*—dates to the early 20th century, in social-science and defence-related research but escalated in the late 1980s and early 1990s in environmental research (e.g., Jaeger and Scherlinger, 1998; Mittelstraß, 1992, 1998). By 2000 case studies were reported in all fields of human interaction with natural systems and technical innovations (Klein et al., 2001). The focus is “real-world” problems, co-production of knowledge with stakeholders, “socially robust knowledge,” and new protocols and innovations for practice and policies (e.g., Gibbons et al., 1994; Hirsch Hadorn et al., 2008; Nowotny et al., 2001; Pohl and Hirsch Hadorn, 2007).
- The third—*transgression*—critiques limits of disciplinary boundaries, linear and hierarchical models of research process, and the logic of instrumental goals. In contrast to pragmatic forms typically aimed at creating a product or meeting other needs in the marketplace and national defence, this form of critical TD interrogates dominant structures of knowledge and education with the aim of transforming them (Klein et al., 2010; Klein, 2017).

Proponents of TD differ on whether the weight should fall on philosophical reflection, critique, or social relevance. Yet, the cumulative effect of all three discourses highlights heterogeneity and relationality of knowledge today. We are mindful of all three, with the aim of transcending conventional approaches rather than simply integrating them without questioning their epistemological origins, logic, and relevance to addressing complex problems. To conceptualise integration in the field of sustainable development, we take transdisciplinary research as a form of problem solving as starting point. We define TDR through outcomes and design principles of the research process. By asking for outcomes we take up the discourse of transgression and transformation because some changes will challenge dominant structures of knowledge. By factoring in design principles we take up ideas of comprehensiveness of transcendence discourse, although without the quest for a universal unity of knowledge. Accordingly, to be transdisciplinary a research project should first contribute to three outcome spaces (Mitchell et al., 2015):

- Improvement in the *situation* for both researchers and practitioners, e.g., a socio-institutional change in policy or a biophysical change or reduction in resource use;
- Production and dissemination of artefacts that contribute to *stocks and flows of knowledge*: e.g., accessible artefacts for relevant audiences ranging from academic or discussion papers to tweets and social media outputs; and
- Mutual and transformational *learning* for both researchers and practitioners involved in, and impacted by, research.

Second, in order to be transdisciplinary, the process of knowledge production leading to these research outcomes should achieve four specific aims (Pohl and Hirsch Hadorn, 2007; Pohl et al., 2017b):

- Grasp the *complexity* of the issue at stake;
- Take into account practitioners' and researchers' *diverse perceptions*;
- Link *abstract and case specific* knowledge; and
- Develop descriptive, normative and transformative *knowledge for sustainable development*.

Thus, we define TDR by aims of the research process and its outcomes regardless of the number of researchers, disciplines, fields, and practitioners involved. Rather, the key question would be “Who has to be involved at what stage of the TDR process to make sure the process

will achieve all four aims and the project will contribute to all three outcomes spaces?”

3. Transdisciplinary research process and its participants

In the context of sustainable development, a TDR project links two processes of knowledge production and problem handling (Fig. 1): a scientific process to produce knowledge about a particular sustainability concern and a societal process to provide knowledge and practices to address it. According to our definition of TDR these linked processes must achieve specific aims and lead to discernible differences in the situation on the ground (realm of practice), in stocks and flows of knowledge (realm of science and of practice), and transformational learning processes about sustainable development (realm of science and of practice).

In an ideal-typical characterization (Weber, 1962) of a research process we join other scholars rooted in the problem-solving discourse by distinguishing three stages of TDR: problem framing, problem analysis, and exploration of impact (Bergmann et al., 2005; Jahn et al., 2012; Lang et al., 2012; Pohl and Hirsch Hadorn, 2007). While the reality of a transdisciplinary research process is messy and complex, this simplification helps to distinguish different stages and within them identify specific challenges and intermediate steps. Knowledge about and practices to promote sustainable development may be co-produced by researchers and practitioners during all three stages. To conceptualise TDR processes, we further focus on the participants—composed of diverse groups of researchers and practitioners—and how they collaborate and interact (Barreteau et al., 2010; Engel et al., 2012; Hoffmann et al., 2017; Schmidt et al., 2018). However, intensity of collaboration, learning processes, and outcomes among researchers and practitioners, as well as composition of participants is not uniform. It varies across and within stages (Krutli et al., 2010; Stauffacher et al., 2008).

When we look mainly at cognitive dimensions, researchers and practitioners enter a TDR process with particular perspectives and epistemologies, i.e. particular ways of structuring the world and making sense of what they see. Building on Ludwig Fleck (Cohen and Schnelle, 1986; Fleck, 1986a; Fleck and Werner, 2011), we treat these perspectives as thought-styles. Thought-styles are developed and maintained by a collective of persons, who constitute a thought-collective. People become members of particular thought-collectives by learning to see through its eyes, e.g. by training in school or on the job.

Thought-collectives cover disciplines or interdisciplinary fields, but also societal groups in, for example, a religion, a craft, or “the practical thought of everyday-life” (Fleck, 1986b, 102–103). Furthermore, individuals are typically members of several thought-collectives simultaneously. A participant in a particular transdisciplinary project, for example, might be a trained chemist, an experienced official of the federal office of environment, and a feminist. Thought-styles are not stable, either. They change over time, e.g., through exchange among members of different thought-collectives (Fleck, 1986b, 103)

In Fig. 2 each coloured box represents such a thought-collective and its attendant style. The thought-collective “Transdisciplinary research” represents scholars specialised and experienced in designing, leading, analysing or evaluating TDR processes.

In the first stage of *problem framing* participants enter a TD project as implicit representatives of a particular thought-collective. There are many and varied reasons why project initiators may invite individuals to a TD project, such as an individual’s status, power, gender, or political position. In terms of thought-styles they are invited because project initiators are looking for a particular expertise or perspective: for instance, a biologist, a linguist, a feminist, a governmental official, a farmer, a member of an Indigenous community, an NGO or a private company. Participants may have been invited without mentioning which thought-collectives they represent. Furthermore, participants may not even realize they represent a particular thought-collective or thought-style. Hence, making different collectives and styles explicit is an important precondition for collaboration (Giri, 2002). Furthermore, project leaders need to be able to identify, to create room for expression of, and to speak to many different collectives and styles in which problems and potential responses are formulated, especially during problem framing (Mitchell and Ross, 2017). The actual problem framing requires participants to collectively identify within a broader topic (Fig. 2, large circle) specific questions to work on in sub-projects and sub-groups (smaller circles). During problem framing, participants may also realize they are no longer interested or cannot contribute to current formulation of sub-problems, for instance because they miss required expertise or backing of their superiors or peers (figures outside smaller circles).

In the second stage of *problem analysis*, sub-projects conduct research into different sub-problems. Each brings together researchers and practitioners who have expertise or stakes in the sub-problem. However, problem analysis does not always end in improved understanding of

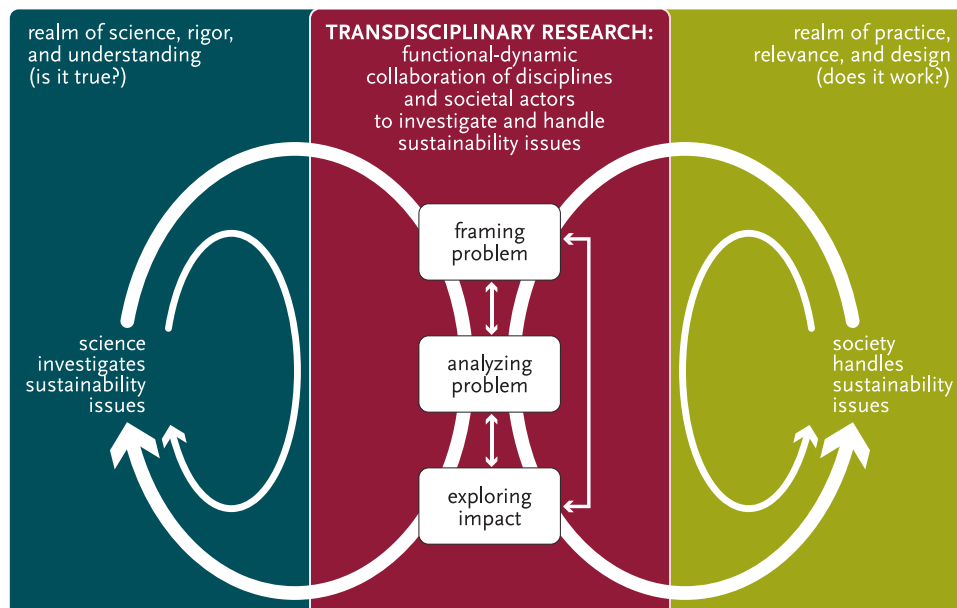


Fig. 1. A transdisciplinary project connects scientific knowledge production and societal problem handling (Pohl et al., 2017a, 44).

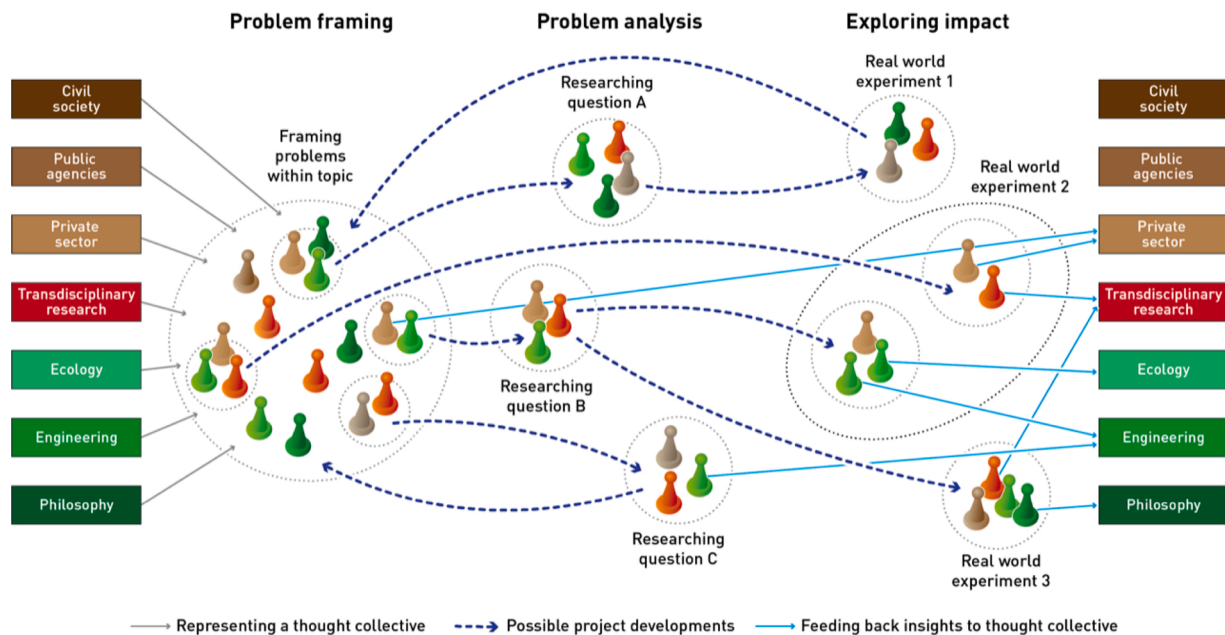


Fig. 2. In a transdisciplinary project, researchers of different disciplines or interdisciplinary fields and practitioners of different sectors of society jointly frame a problem, analyse it, and explore to have impact. Researchers and practitioners may gain insights in all three stages. A project may not go through all three stages and not in a sequential order. A project (larger circle) may also split into sub-projects (smaller circles).

problems and ways to address them. Other outcomes may be inadequacy of the problem framing of stage 1, incommensurability of thought-collectives, fragmentation of the sub-problem as a subordinate part of another problem, or inclusion of several further sub-problems (Fig. 2, broken blue arrows). Also, the stage of problem analysis may not be required in all instances. Participants might agree they know enough to advance to the third stage.

The goal of the third stage is to *explore having impact*. In principle, TD projects can have impact during all stages of the TDR process (Fig. 2, light blue arrows) and through multiple planned and unplanned pathways (Belcher et al., 2019). In Fig. 2, the third stage of TDR process only entails the planned experimental implementations of solutions developed during stages 1 or 2. Implementations of solutions need to be explored because they are interventions in complex socio-ecological systems that might have surprising outcomes (Groß and Hoffmann-Riem, 2005). Moreover, impact may take longer than the limited timeline or lifespan of a particular project. In the case of surprise, two possibilities may emerge. The first is whether a solution to a sustainability issue is working as planned or experiences unintended side effects. Real-world laboratories are a space for such experiments (Fam et al., 2020a; Renn, 2018; Schöpke et al., 2018). For instance, in Germany the *Karlsruhe Transformation Center* (www.quartierzukunft.de) explores measures to adapt green spaces to rising global temperatures in a city district of Karlsruhe jointly with residents (Parodi et al., 2019). The second surprise is whether and how participants feed insights gained in a TD project back to the thought-collectives and thought-styles they represent (Fig. 2, light blue arrows). Neither is clear, however: whether insights and ideas are welcomed and taken up by thought-collectives, and if taken up, how other members of the collective use or adapt them.

More recently Hoffmann et al. (2019) added two further stages to the TDR process referring to the field of knowledge utilization: (1) disseminating new knowledge and (2) using new knowledge in science and practice at large. However, they cautioned TDR may run through all five stages in a disorderly manner and extend their boundaries progressively into realms of both science and practice when exploring impact, disseminating and using new knowledge. Also this realization requires closer attention to the nature and process of integration; we focus here,

however, on the three stages and the diverse collectives of researchers and practitioners directly involved in a TDR process.

4. Integration as manifold interactions during TDR process

Integration is widely regarded as the crux of both ID and TD. Klein and Newell (1997) call it the “acid test”, Pohl et al. (2008, 421) consider it “the core methodology underpinning the transdisciplinary research process”, and Jahn et al. (2012, 3) name it “the major cognitive challenge of transdisciplinarity”. There is no one-size-fits-all approach or methodology for integration because both ID and TD vary in purpose, scale, and scope as well as the problems and questions at hand, mix of expertise, degree of coordination and communication, and timing and responsibility for integration (Klein, 2008). In a literature review, O’Rourke et al. (2016) also cited different approaches: including unification by reduction, a global theory or an overarching abstract model, theories in particular contexts, interconnections between fields, local theories, and micro-level integrations. Variances occur as well in scale (global or local), commensurability (integrable inputs or conflicts requiring reduction before combining), and comprehensiveness (broad compass or focused outputs).

In addition, O’Rourke et al. (2016) identified two major patterns: (1) top-down versus bottom-up approaches and (2) blueprints that organize methods versus repositories that collect resources. They identified “faultlines” of definition across them. The first is linear, exposing differences in algorithmic step models versus heuristic and constructivist frameworks. The second is between integration as an individual phenomenon versus a collaborative one, and the third is emphasis on disciplines versus inclusion of societal perspectives. Those who favour a heuristic approach, Laursen and O’Rourke (2019) explained, content integration is a creative process that lacks generalizable steps due to contingencies and complexities of interdisciplinary contexts. O’Rourke (2017) further distinguished theoretical integration, focused on ontological and epistemological relations, from methodological integration, focused on practical interconnections in local contexts. The primacy of integration is also being questioned and even problematised as the “integration imperative” (Klenk and Meehan, 2015).

A historical shift in definition also challenges the older connotation

of integration as a synthesis of accepted postulates and content, emphasizing instead an integrative process of constructing new conceptual modes (Repko, 2008). Fam and Sofoulis (2017) further warn the older connotation of integration may potentially compound rather than ease problems of collaboration. The goal may be to bring different knowledges and expertise to bear on a problem in order to find a more multi-faceted, complete and integrated solution. Alternatively, when such integration is pursued from a positivist point of view, different kinds of knowledge are likely to be generalised: for example, processing social data and feeding it into a predictive model along with technical, environmental and economic data. In contrast Fam and Sofoulis (2017) argue for an interpretive point of view (cf. Schwandt, 2000) that yields insight into interactions between knowledge communities and contexts in which they operate from an actor's point of view.

We concur in treating integration as an interactive process of co-constructing knowledge that might happen during all stages of a TDR process. Being mindful of the transgressive discourse of TD, stage models of integrative process risk imposing a top-down, lean, and universal algorithmic set of procedures. To counter this concern we conceive of integration as an open-ended learning process without pre-determined outcomes. Furthermore we agree with the definition of integration as relations established throughout a TDR process between elements that were not previously related (Bechtel, 1986, 32–33; Jahn et al., 2006, 302; O'Rourke et al., 2016, 67). More specifically, these elements include pieces of knowledge, ideas, or practices from different thought-collectives, as well as views of individual researchers and practitioners. Integration, then, does not mean pieces of knowledge add up to a simple sum of the parts or a coherent and comprehensive whole. Rather it is a metacognitive process by which participants may reshape their mental representations of a concept or domain when brought into close contact with different views (Keestra, 2017). Similarly, integration does not mean that participants of a TD project comprise one specific thought-collective or thought-style of their own. Integration also does not necessarily include all participants. Sometimes many individuals will become related through a shared belief or theory. At other times integration will occur among particular individuals shaped by their specific experiences and expertise.

Fig. 3 depicts our understanding of integration. Here again, variance

stands out. Arrows and exclamation marks symbolize diverse instances of integration. It can take place between two, several, or all participants. It can be one-sided (individuals integrating an insight from another participant into their thought-styles) or mutual (a collaborative effort of multiple team members). It can also happen during problem framing, problem analysis, or during exploration of impact. And, it might include insights, practices, frameworks, or concepts shared by two, several, or all participants.

Even so, the question of what integration exactly is still remains (arrows and exclamation marks in Fig. 3). We emphasize “consensus” is only one specific kind of integration, building on Star and Griesmer's insight that “[c]onsensus is not necessary for cooperation nor for the successful conduct of work” (Star and Griesmer, 1989, 388). By consensus we mean, for instance, the idea that “the project team reach [es] a common understanding of the sustainability problem to be addressed and does [...] accept a joint definition of the problem” (Lang et al., 2012, 30). Such consensus seeks agreement among participants about how to perceive and understand an issue, while other kinds of integration do not. Thus, integration can be thought of alternatively while acknowledging different levels of integration akin to levels of learning and transformation:

- “Weaving” different knowledge systems (Tengo et al., 2014): This metaphor explains how to achieve the goal of “a broadly accepted common knowledge that maintains the integrity of each knowledge system” (Tengo et al., 2017, 18). Each system is symbolised by a thread and the integrated knowledge by the woven material. Tengo et al. (2014, 581) developed the concept of weaving to combine Indigenous and scientific knowledge: e.g. to study arctic sea level rise and climate change, or free-ranging domestic reindeer grazing and biodiversity. A topic is studied from the different knowledge systems in parallel and a “synthesis may include and illuminate areas of high convergence between knowledge systems as well as contradictory evidence” (Tengo et al., 2017, 23).
- “A system of thought in reflective equilibrium”: Following Boix Mansilla's (2010, 298), use of the concept for explaining interdisciplinary learning, it occurs when separate components are weighed in light of each another and prior assumptions. This process scaffolds

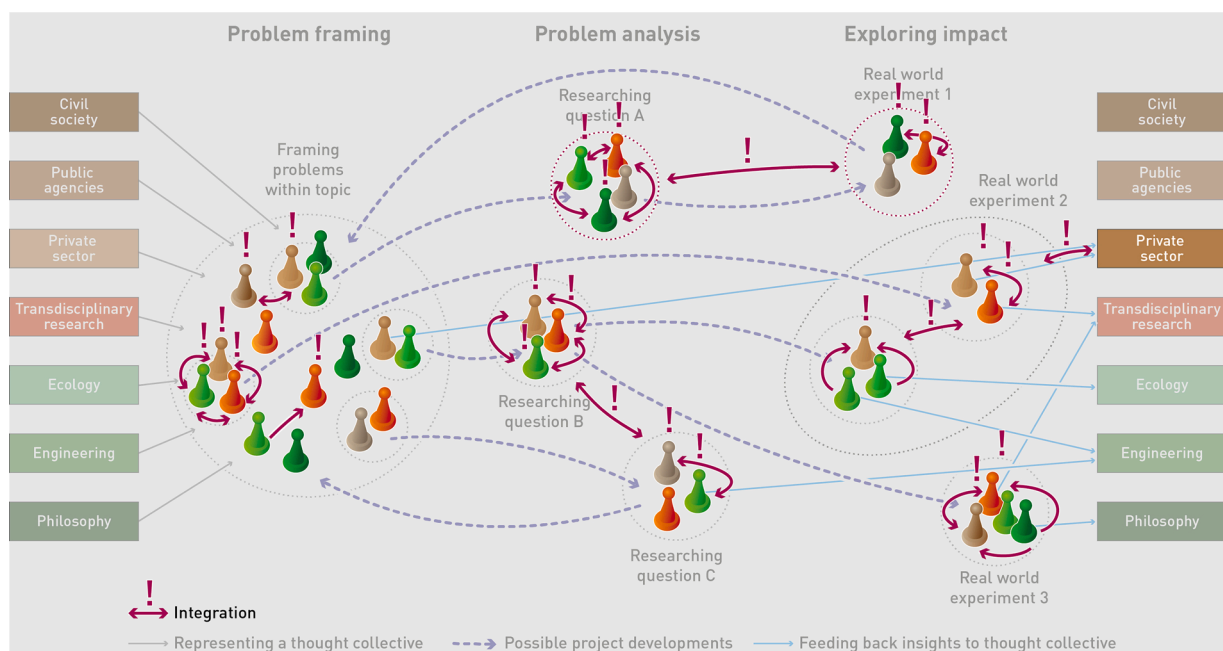


Fig. 3. Integration (symbolized by arrows and exclamation marks) can happen at manifold instances of a transdisciplinary research process. It can take place between two, several, or all participants and can be one-sided or mutual. It might include insights, practices, frameworks, or concepts shared by two, several, or all participants.

understanding for a richer and crossdisciplinary outcome, with “crossdisciplinary” a composite term for both inter- and trans-disciplinary approaches. Pragmatic constructivism is thus the heart of crossdisciplinary learning, built by different participants with their respective thought-styles working together with the aim of making sense for all of them.

- “Accommodations” (Checkland and Poulter, 2006): Integration as accommodation combines desirability and feasibility from diverse perspectives of those experiencing a problem. It occurs when they see “a certain course of action was both desirable in terms of this analysis and feasible for these people with their particular history, relationships, culture and aspirations” (Checkland, 2000, 15). “Accommodations” are part of Checkland’s soft systems methodology, an approach to structure and transform real-world issues jointly with those concerned.

In all three alternatives to consensus, thought-collectives and their thought-styles in the form of knowledge systems, beliefs, and people are not fused into a new consensus. They co-exist and are connected through a continuous process of exchange and learning on a shared topic. Hence, the answer to the question of what integration actually is follows. It can be conceptualised in different ways. Consensus is only one along with other ways of retaining plurality of thought-styles and seeing integration as a balance between them that remains subject to continuous revision. Mitchell and Ross (2017) emphasize, though, the need for deft management of disjunctions between diverse epistemologies, navigating across different forms of knowledge, knowing, and truth. Fam et al. (2020) suggest balancing requires expertise in comparative epistemology, appreciating different thought-styles and recognising interactions, synergies, and potential for unbridgeable differences such as incommensurability of certain knowledges or knowledge communities where integration by consensus is not a viable or preferred option. In Indigenous communities, for example, this option may be considered akin to assimilation with negative historical connotations (Chilisa, 2017). Fam et al. (2020) identified cooperation, domination, predation, symbiosis, as further alternatives to consensus, all with both positive and negative implications.

In addition to these approaches to conceptualizing integration, further ideas describe the area where participants meet and interact for integration, or the object around it and the process by which it happens. The concept of *Trading Zone*, for instance, designates the space in which integration occurs in social and cognitive terms. It provides a platform for building and sustaining a culture of collaboration, facilitated by exchange of ideas, theories, beliefs, values, and data (Galison, 1997). The concept of *Boundary Objects* in turn highlights means by which integration occurs, mediated by common focal points such as technologies, data, depositories, products, standard forms, concepts, models, and research questions. They are robust enough to foster unity across practices though still plastic enough to adapt to local domains (Star and Griesemer, 1989).

5. Integration beyond the cognitive dimension

So far we have conceptualised integration mainly from a cognitive perspective. Echoing Jahn et al. (2012) it is necessary to also treat integration beyond the cognitive dimension, specifically in regard to understanding, monitoring, or leading integration in practice. Jahn et al. (2012, 7) refer to social-organisational factors (defined as “different interests or activities of participating researchers, subprojects, and larger organizational units”) and communicative factors (defined as “different means of linguistic expression and communicative practice”). Comparably Mitchell and Ross (2017) point out that beyond the cognitive dimension and thought-styles, diverse ways of being and acting will influence how participants engage in the process of integration.

When Boix Mansilla et al. (2016, 602) investigated factors that made

interdisciplinary collaborations in large research programs successful, they further concluded “success of an interdisciplinary collaboration cannot be reduced (as it often is) to intellectual productivity. Building a successful research network hinges on qualities such as the group’s growing capacity for disciplinary exchange, the construction of a cognitive common ground, emerging group identity, and development of trust.” Emotional factors facilitating success include positive feelings about project members and self: including respect, admiration, and recognition. Primarily social-interactional factors include a climate of conviviality, social-interactive qualities of participants, effective leadership, meaningful personal relations, group identity, complementary team roles, socializing outside meetings, and group working styles and routines (Boix Mansilla et al., 2016, 589). In the aggregate, these findings affirm the underlying concept of integration incorporates cognitive, emotional, social-interactional and even other dimensions. Fig. 4 exemplifies such an understanding of integration as a multidimensional interactive process.

Finally, the question remains how cognitive, social-interactional, emotional, and possible further dimensions of integration relate to each other and influence the effectiveness of integration. In our concept of integration these relations depend on how deeply the act of integration challenges thought-styles of respective participants. In one case, an insight might fit readily into the existing knowledge and can be used with no substantive change to existing thought-styles or collectives. In another case, one might be transformed by knowledge co-production with members of other thought-styles and fundamental assumptions of the involved thought-styles and thought-collectives need to be revisited. As soon as fundamental assumptions are challenged by integration, the influence of emotional and social-interactional dimensions of integration becomes important. That is, when the act of integration requires an integrating participant to change fundamental beliefs, it will be important, whether or not (s)he trusts the person providing the insight and whether or not both collaborate in a climate of conviviality.

6. Discussion

Our aim was to develop a concept of integration that goes beyond the buzzword. Based on our findings and analysis we characterize integration as follows: Integration is an open-ended learning process without pre-determined outcomes. It designates relations established throughout a TDR process between elements that were not previously related. Those elements are participants in a TDR process and respective thought-styles and thought-collectives and more specifically pieces of knowledge, ideas, or practices from different thought-collectives as well as views of individual researchers and practitioners. Furthermore, integration can happen at manifold instances of a transdisciplinary research process. It can take place among two, several, or all participants and can be one-sided or mutual. It might include insights, practices, frameworks, or concepts shared by two, several, or all participants. Consensus is only one along with other ways of retaining plurality of thought-styles and seeing integration as a balance between them that remains subject to continuous revision. To analyse or achieve effective integration, further dimensions beyond the cognitive have to be taken into account. Following (Boix Mansilla et al., 2016) we suggest including at least an emotional and a social-interactional dimension for a more comprehensive concept of integration. If integration requires changing basic beliefs then, emotional and social-interactional factors may become more important.

How, then, does this understanding help us to answer the questions we asked in the introduction? First, does integration require coming to consensus on a contested issue? Our findings indicate not necessarily so. Consensus in the sense of a final single view among participants is only one specific kind of integration. Other kinds of integration do not require achieving a shared perspective. Instead, they allow different perspectives shaped by thought-collectives with their respective thought-styles to coexist. Concepts describing this form of integration include weaving

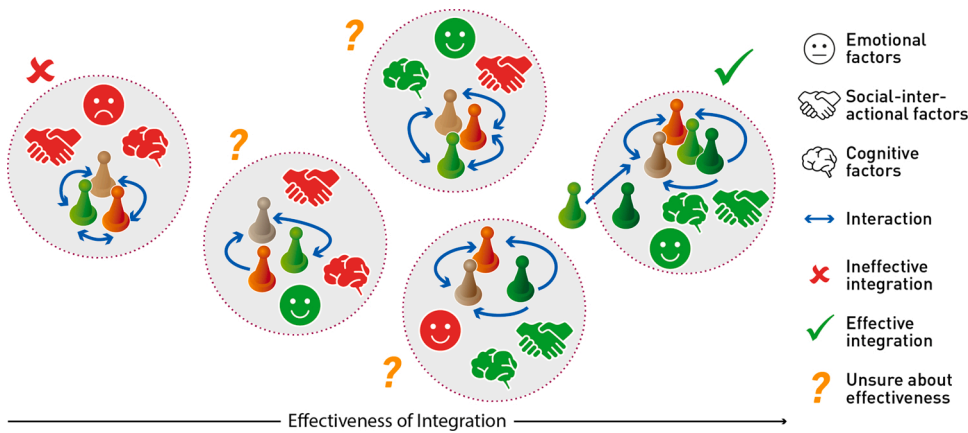


Fig. 4. To analyse or achieve effective integration, further dimensions beyond the cognitive have to be taken into account. Following Boix Mansilla et al. (2016) we suggest to include at least an emotional and a social-interactional dimension in a more comprehensive concept of integration. Effective integration does not require all factors to be fulfilled. It is, however, unclear how the factors relate to each other and to effective integration. We assume if integration requires changing basic beliefs then emotional and social-interactional factors become more important.

of knowledge systems, a system of thought in reflective equilibrium, and accommodation of what is desirable and feasible for participants in a project's context. As a result, different kinds of integration are options. The question is what kind of integration is needed in which stages of a TDR process or whether specific kinds match with particular types of societal problems.

A second question follows. Does integration mean individual researchers and practitioners question their own epistemologies, and make room for other positions and truth claims? Understanding epistemologies as thought-styles, our findings align with the second part of the question. Before starting collaboration and integration, project initiators should make participants aware of the different thought-styles in a project. This step may or may not lead participants to accept and make room for other epistemologies. Our findings do, however, not affirm the first part of the question. It is possible that integration and exchange with members of other thought-collectives challenge fundamental assumptions of participants' thought-styles. However, in other instances of integration, participants pick up an insight that fits readily into their existing knowledge and underlying thought-styles. Or, alternatively, only some participants question their epistemologies. So, only if members of distinct thought-styles co-produce knowledge and if integration requires challenging fundamental assumptions in all of these thought-styles, then integration necessarily requires all participants to question their own epistemologies.

The third question follows in turn. Does integration occur if a policy maker incorporates knowledge of climate researchers into decision making, even if the researchers don't assimilate any of the policy maker's knowledge or work in collaborative fashion? Our findings indicate integration does not necessarily require mutuality. Rather, it is an umbrella term for all manifold instances and possible combinations of participants. However, given that integration can be one-sided or mutual, clarity about what kind of integration is meant is needed in each case.

Fourth, are there situations where integration is not appropriate? We see a danger that a particular kind of integration fails to meet needs of a specific situation or goals of a specific TD project. For instance, looking for a consensus among diverse thought-styles is the wrong approach if the problem at hand can be addressed by weaving together participants' thought-styles or by accommodating respective thought-collectives. In some contexts, it might be sufficient for one thought-collective to integrate insights from another, whereas other situations require mutuality. So, the challenge is rather to find the adequate form of integration for the specific goal and situation of the TD project.

7. Conclusion

The concept of integration developed in this article underscores the crucial, though under-examined nature, the central claim of TDR and

knowledge co-production posits. It also indicates how much still needs to be learned about integration in order to improve TDR and knowledge co-production for sustainable development. Thus, rather than arriving falsely at final answers, we offer recommendations for future research based on our findings and overall argument:

- What contextual factors influencing the process of integration, such as the availability of resources for different participants, including structural or systemic incentives, barriers, and disparities in access to resources (Sofoulis, 2015; Fam and Sofoulis, 2017). Or, more explicitly referencing the power dynamics involved and multiple contexts (Fam et al., 2020a) in which the variety of thought-collectives and thought-styles exist, as well as kinds of thought-collectives and thought-styles favoured in the current research policy environment. National research priorities are further contextual factors as well as general policy climates and prevailing local microclimates (Duncan et al., 2020).
- What methods, tools and processes help participants in TD projects recognise their own knowledge, expertise and disciplinary contributions in relation to others and contextual factors that influence integration in practice, both positively and negatively (cf. Bergmann et al., 2012; Eigenbrode et al., 2007; McDonald et al., 2009; O'Rourke and Crowley, 2013; Pohl and Wuelser, 2019; Vogel et al., 2013)? Relatedly, what methods, tools and processes exist to analyse, monitor, and lead such complex multidimensional integration processes? And, following suit, are current approaches adequate or do they prioritize specific aspects of integration such as cognitive dimensions?
- What is the role of learning with respect to integration, as Boix Mansilla (2017) asks? Learning is evidently integral to integration. However, what forms of learning accompany different forms of integration (Ross and Mitchell, 2018)? Furthermore, how might TD projects be designed and lead to enhance learning by all participants (Mitchell et al., 2015)?
- How do we further investigate integration as a balance of thought-collectives and their thought-styles, in addition to understanding, achieving, and evaluating balance and reflective equilibrium? What about the power dynamics at play when researchers try to weave scientific knowledge with Indigenous knowledge (Matuk et al., 2020).

To conclude, the crucial role of integration in inter- and trans-disciplinary research highlights the need for further exploring how to effectively lead, monitor, and assess integration while strengthening related expertise among researchers and practitioners. In our view, it even calls for developing and promoting a new profession of "integration experts" (Bammer, 2013; Bammer et al., 2020) specializing in leading inter- and trans-disciplinary integration and for advancing related

career paths to unfold the full potential of inter- and transdisciplinary research.

Declaration of Competing Interest

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