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Transdisciplinary learning as a key leverage for sustainability transformations

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Learning and transdisciplinary research are widely acknowledged as key components for achieving sustainability; however, the links between these concepts remain vague in the sustainability literature. Recently, emphasis has been given to transdisciplinary learning, highlighting its potential as an approach that contributes to solving real-world problems. To better understand and foster transdisciplinary learning for sustainability transformations, it is relevant to pay attention to two dimensions that define transdisciplinary learning: *social interaction* (individual learning in a social setting, as a group, or beyond the group), and *learning forms* (single-, double-, or triple-loop learning). This article introduces a conceptual framework built upon these two dimensions to understand three specific forms of transdisciplinary learning as a) individual competence development, b) experience-based collaboration, and c) societal interaction. This framework helps to clarify the design of learning processes as well as their interactions in transdisciplinary processes to support transformative change.

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Unlearning unsustainability

The sixth assessment report of the Intergovernmental Panel on Climate Change in 2021, clearly pointed out that the scale of recent changes across the climate system is unprecedented in human history, with human-induced climate change affecting weather and climate extremes in every global region [1]. These developments threaten the very idea of the concept of sustainable development as a way to navigate pathways into a safe and just space for humanity, in which planetary boundaries are respected and social boundaries constituting basic human rights are taken care of [2]. Sustainable development has gradually found its way into academic discourse and has led to the emergence of sustainability science as a field of its own [3]. From the beginning, conceptions of sustainable development were predominantly grounded in an understanding of what is *unsustainable*, and defined less as a specific goal to be achieved, but rather as an ongoing process of change — that is, as a moving target that necessitates communication and deliberation [4].

Not surprisingly, learning and education are considered essential means for achieving sustainability goals, such as the UN Sustainable Development Goals, besides ‘hard’ instruments such as regulations and economic measures [5]. Consequently, the notion of learning for sustainability figures prominently in both academia and policy and has been used in a broad sense to capture the whole spectrum of informal, nonformal, and formal learning. Mutual societal learning processes with an emphasis on the transdisciplinary nature of such learning have been increasingly mentioned as a central concept to foster sustainability transformations [6,7]. Arjen Wals [8] aptly pointed out that ‘learning our way out of unsustainability’ might play a crucial role for such transformations.

While the importance of learning and education has been repeatedly emphasized [9], the increasing use of the concept in a wide range of different contexts and fields is not without its problems, as the concept of learning has remained rather vague [10,11]. For example, Reed et al. [12] highlighted the lack of clarity in the use

of social learning as a concept in natural resource management, Jiménez et al. [13,14] pointed to the confusion between different educational strategies implemented in biodiversity conservation initiatives, and the literature on sustainable transformations refers to shifts in mindsets or paradigms without explicitly connecting this to educational and learning processes [15]. With this article, we want to contribute to clarifying the role, forms, and contributions of learning for sustainability by introducing a conceptual framework of transdisciplinary learning, and elaborating on how an informed understanding of learning processes for sustainability can guide action and further research.

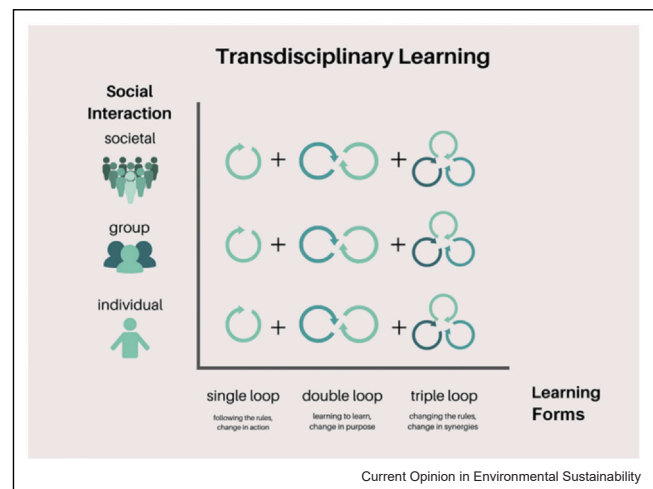
Transdisciplinary learning – a conceptual framework

To be able to utilize the concept of transdisciplinary learning to inform activities in both practice and research, clarity is needed on the two building blocks of learning and transdisciplinarity, respectively, and on specific forms of such learning, and their differences and characteristics.

Looking at the literature on learning for sustainable development, one central challenge is a problematic confusion between learning as a process and as an outcome of that process. From a learning science perspective, it is emphasized that learning is first and foremost a lifelong and constant process for one or more individuals, as it is impossible for us not to learn [16]. In a pragmatic approach, this has been taken in the literature to define learning as a process that leads to cognitive change and manifests as behavioral change [12]. However, this view has been contested through research on the development of mental models, which argues that learning happens when cognitive changes occur, for instance, when new knowledge has been acquired, or a shift in an individual's perception has taken place, neither of which necessarily leads to changes in behavior [17]. Learning then can be understood as a process of cognitive changes that leads to new knowledge, perceptions, or competencies, which in turn may be translated to changes in action and behavior. Such learning is apparent in individuals as well as among learners in groups, can happen in formal, informal, and nonformal settings, and especially in transdisciplinary processes, the question who is learning in the process needs to be defined for each specific context.

Particularly in the sustainability science discourse, 'transdisciplinarity' has been defined as a research practice or principle that (i) takes real-world problems as a starting point, (ii) acknowledges context-dependencies related to these problems, (iii) differentiates and integrates knowledge from different domains, inside and outside academia, which are relevant for addressing the

Figure 1



Two dimensions to understand transdisciplinary learning: social interaction (individual, group, and societal), and learning forms (single-, double-, and triple-loop). Based on Figure 12.1 in Barth 2015 [4].

problems, and (iv) aims to contribute to solving concrete real-world problems as well as generating scientific insights beyond these problems (see [18,19]). For the purpose of this paper, we use a broad notion of 'research practice', as an evidence-based learning process that integrates different forms of knowledge. Accordingly, mutual-learning processes have often been declared as essential characteristics of transdisciplinary processes [20]. Westberg and Polk [21] introduce the theory of situated learning to the discourse on transdisciplinarity and add a more nuanced perspective on learning in transdisciplinary processes. Furthermore, in their literature review on knowledge-related concepts in sustainability science, Apetrei et al. [11] derived knowledge for and through learning as one entry point to how knowledge is conceptualized in the literature. This further differentiates social learning and sustainability learning as concepts, and in so doing provides more structure in the learning discourse closely related to transdisciplinarity.

To further conceptualize transdisciplinary learning and to better position and distinguish different forms of how such learning occurs, we draw on a framework based on a distinction between two main dimensions of learning [4]: a) the social interaction, and b) the learning forms regarding the level of reflection about the learning process (Figure 1).

Turning toward the social dimension of learning, we can distinguish three distinctive forms, ranging from individual learning in a social setting, to learning as a group, and to settings that transcend group boundaries.

The first and probably most traditional understanding of *individual learning* refers to learning that happens individually but in a social setting. Here, learning happens by processing information, reflecting on how one's own interests are related to those of others, and building relationships, while being involved in collaborative processes in transdisciplinary settings. Such learning is influenced by the cultural context and the formal or informal social settings in which learning takes place [22,23]. *Learning as a group* goes beyond the learning process of individuals, emphasizing that not only individuals but also social units (such as organizations) are able to achieve a learning outcome that is more than the sum of individual learning [24]. Such group learning is captured most often as organizational learning for sustainability [25], but is also reflected in learning in communities of practice [26,27] or loosely coupled networks [28]. Finally, learning might also *transcend group boundaries* and diffuse to wider social units, triggering system-wide change processes. Such societal learning, that is, learning *as a society* rather than just learning *in society* ('social learning'), is seen as a driver for change that can move the social-ecological system toward more sustainable trajectories [29].

Different forms of learning can also be distinguished within all three forms of social interaction. Here, we refer to single-, double-, and triple-loop learning — terms that refer to the level of reflection that informs the learning process, as popularized in management science by Argyris and Schön [30]. *Single-loop learning* may be understood as learning by reconsidering decisions made in light of new information ('doing things differently'). Its aim is to bring about more effective or efficient action, while relying on an unchanged set of values and beliefs. *Double-loop learning* in contrast involves the re-evaluation of the underlying assumptions and beliefs that informed a given decision ('doing different things'); it is about changing the rules rather than changing one's responses within a given set of rules. *Triple-loop learning* represents the third and most far-reaching approach. It refers to the recursive practice of learning about the process of learning itself, and involves developing new ways of thinking, and methodologies to support the reframing and transformation that takes place in double-loop learning.

If we analyze transdisciplinary learning against these two axes of social interaction and specific learning forms, we can distinguish between conceptions of transdisciplinary learning in a systematic way. Such a classification clearly involves some simplification, and it is a matter for debate where the boundaries for the respective approaches should be drawn. Nevertheless, it helps to depict specific forms of transdisciplinary learning and to elaborate on characteristics of the learning process, as well as differences and similarities of the learning outcomes. In

what follows, we want to introduce and discuss three specific conceptions.

Transdisciplinary learning as individual competence development

Individual learning is commonly understood as a process involving a change in an individual's behavior or knowledge [31] that can occur on different levels of societal interaction in formal, informal, and nonformal settings. Particularly when it comes to learning processes in relation to sustainability transformations, these settings are often interlinked and all play a crucial role. In the context of transdisciplinary learning, we especially aim to develop a specific individual skill set to actively shape sustainable development.

This means that we generally aim to build knowledge about (un)sustainable development as well as its causes, effects, and interrelations, and, as a further step beyond mere knowledge acquisition, to achieve a certain level of (self-)reflection, leading to a change of behavior toward active participation in shaping sustainable development. Transdisciplinary learning adds another layer by integrating a broad range of expertise drawn from various actors in science and society, and is therefore highly context-dependent and emergent. It allows for co-design processes and hence offers different levels of reflection that may lead to single-, double-, as well as triple-loop learning.

When it comes to formal learning settings, competency-based approaches play a central role [32], targeting specific learning outcomes that are supported by learning processes in particular learning settings. Competencies in this sense are widely understood as the interaction among knowledge, skills, and attitudes (or willingness) that enable learners to cope successfully and responsibly with changing situations in a certain domain, by also reflecting on the experience gained [33]. In an exploratory literature review, van Poeck et al. [34] distinguish between three different learning outcomes in current research on sustainability transitions: *Conceptual learning outcomes* are the most frequently identified and mainly focus on knowledge, but also include values and norms or visions and commitment. *Practical learning outcomes* lay emphasis on a contribution to "some form of sustainability change agency, as well as to more sustainable habits, behavior, technologies, practices or even regimes". *Relational learning outcomes* consider, for example, the development of networks, but is an outcome category that is rarely used. Learning outcomes on an individual level can be assessed, for example, using a context-specific mixed-methods competence assessment, measuring the development of not just knowledge, but also aspects such as volition and attitudes [35]. According to Scherak & Rieckmann [36], assessment methods need to be "constructively aligned with the

intended learning outcomes and the relevant teaching and learning practices” (p. 124). Redman et al.’s [37] typology of eight assessment tools can help to make informed decisions about how to assess individual competence development (e.g. reflective writing, performance observation, and scenario/case test).

Transdisciplinary learning as experience-based collaboration

Transdisciplinary learning also occurs as part of group learning and organizational processes in experience-based collaborations or a Community of Practice (CoP). These learning processes can happen in formal learning settings but more often occur in informal or nonformal settings. A CoP requires a group of people interacting regularly through informal learning activities (e.g. conversations, workshops, and learning by doing) to foster knowledge creation and sharing in a specific domain of interest [38]. Importantly, these communities are based on shared practice, which involves actively testing ideas to address specific problems and learn how to do things better [39], and require the establishment of collegial or personal relations based on trust [40].

In their role of addressing real-world problems, CoPs need to continuously reflect on whether specific actions and approaches are working or not to guide future actions (single-loop learning), as well as include a variety of participants with different stocks of knowledge [40]. Transdisciplinary CoPs [39] share these characteristics, but are formed by heterogeneous members with a variety of experiences and knowledge, drawn from different disciplines, institutions, and societal domains. This diversity generates more opportunities for reflection upon different theoretical and methodological perspectives, backgrounds, and worldviews guiding the practice of the group (double-loop learning).

There are many types of transdisciplinary CoP regarding, for example, size or scale (local, national, and international), ways of interaction (face-to-face, online, and hybrid), or the domain of interest. Transdisciplinary CoPs that focus on addressing sustainability issues are often designed as science-practice or science-society interfaces where researchers and practitioners learn together to find solutions to sustainability challenges. These solutions are commonly designed at a technical level of action (e.g. to learn about specific tools or frameworks for natural resources management [41,42]); but also at the social level (e.g. developing sustainability-related competencies for current or future educators [43–45]), the cultural level (e.g. management practices in marine-protected areas integrating the culture and traditions of local and indigenous communities [46]), and other levels of action [47].

One of the most influential transdisciplinary CoPs is the Intergovernmental Science-Policy Platform of Biodiversity and Ecosystem Services (IPBES), which constitutes a space for individual and organizational learning [48]. IPBES is an independent intergovernmental community seeking to develop knowledge to inform and foster knowledge-based policies to secure biodiversity and well-being. Knowledge generation in IPBES aspires to be inclusive, meaning to include diverse forms of knowledge from a broad range of actors [49]. However, IPBES faces a range of challenges to implementing this inclusive approach (see, e.g. [49–51]). Similarly, at a lower (national) scale, Dendoncker et al. [52] analyzed the impact of the Belgium Ecosystems Service CoP, and found that although different stakeholders and values were usually accounted for, genuine transdisciplinary studies in which knowledge is coproduced between researchers and practitioners were still to be undertaken.

Transdisciplinary learning as societal interaction

Transdisciplinary learning beyond individuals and group boundaries can enable societal learning, which is utterly important for triggering systemic change toward sustainability. Some authors have improved our understanding of the learning that occurs between researchers and practitioners within transdisciplinary projects (e.g. [20,47,53]). In addition, Adler et al. [54] propose to conceptualize the transfer of knowledge across transdisciplinary projects as ‘arguments by analogy’, and Wuelser et al. [55] differentiate between seven types of transferable knowledge (i.e. transdisciplinary principles, transdisciplinary approaches, systematic procedures, product formats, experiential know-how, framings, as well as insights, data, and information).

However, less literature has focused on how transdisciplinary learning occurs beyond individuals and groups, and thus beyond transdisciplinary projects in the sense of societal learning that triggers systemic change [15,56]. On a societal level, transdisciplinary learning can support collectivizing engagement of diverse actors from different contexts to build momentum for systemic change, through socializing insights from context-specific mutual-learning processes (e.g. within a specific project). Such insights can stem from informal single-, double-, and triple-loop learning processes and foster societal learning beyond transdisciplinary projects in the sense of third-order effects [57]. For example, practitioners engaging and learning in transdisciplinary processes will make decisions that can influence the systems in which they operate (e.g. food companies or farmers influencing the food system).

Transdisciplinary learning on a societal level can also be fostered through amplifying insights from individual education processes and experience-based

collaborations. Amplification is a concept in sustainability transformations literature, which describes processes that can scale insights within, outside, or beyond the process to foster transformative change toward sustainability [58,59]. For example, by disseminating principles and approaches that have worked in a project to other projects in different contexts, or by influencing norms and beliefs in the study region of a transdisciplinary project. Through amplification, insights can become confirmed and consolidated with other people, ultimately becoming institutionalized to facilitate behavior change that supports the realization of sustainability [60]. In addition, despite being context-specific, insights from single-, double-, and triple-loop learning can diffuse translocally and inform shared ideas, activities, and objectives that foster transformative change across and beyond transdisciplinary research projects [61]. Indeed, context-specific insights can inform people beyond local contexts, such as global sustainability initiatives and discourses [62].

Outlook and future research

Transdisciplinary research in sustainability science has been characterized as a knowledge coproduction process, in which a variety of actors from science and other areas of society (e.g. government or practitioners) interact in mutual-learning processes to develop, test, and implement solutions to real-world problems that foster transformative change. Despite emphasizing the relevance of learning in transdisciplinary settings, much of the literature has neglected to include insights from learning theories (see e.g. [10]), especially concerning the mutual-learning processes that are fundamental for transdisciplinary research. Some authors have made progress in understanding how learning occurs in transdisciplinary projects (e.g. [21,47]) as well as how to learn about transdisciplinary practices in general [63,64]. By discussing how including a learning perspective can enrich research that seeks to understand and foster *transdisciplinary learning* happening at different levels of social interaction (individual, group, and societal) and learning forms (single-, double-, and triple-loop), we want to both make a contribution to and further develop existing approaches.

Strengthening transdisciplinary processes by more deeply considering learning perspectives

Learning is a key element in transdisciplinary research, particularly regarding mutual-learning and integration processes [20,65]. As outlined above, transdisciplinary learning processes can happen and stimulate learning on all three levels (individual, group, and societal), and have the potential to enable people, both individually and as collectives, to change their behavior and act, by gaining the necessary sustainability competencies [66,67]. Including insights from learning theories, such as individual sustainability competence development

(building knowledge, skills, and attitudes), and learning in CoPs can enrich transdisciplinary research in its endeavor to foster transformative change. This would mean addressing the design of transdisciplinary projects (e.g. adaptation of formats and methods, or planning of societal and scientific effects) to more deeply consider learning processes on these levels. For example, when planning workshops in which researchers and practitioners participate, the workshop processes should not only focus on generating general outcomes (e.g. artifacts), but also on ‘effective’ learning processes, leading to certain learning outcomes at different societal levels [58]. This can be done by offering time and space for reflection on the process, and not only the outcomes [4,68], and accepting failures as part of the (learning) process [69]. Such formats can also play an important role for competence development in more formal educational settings to prepare future change agents to engage in and lead transdisciplinary processes [70].

Transdisciplinary learning for transformative change

Learning has been mentioned in several transformation frameworks (e.g. transition management [71], social–ecological transformations [72]), but often without a thorough inclusion of learning theories or an emphasis on transdisciplinary aspects of learning. Including a learning paradigm in the discussion of transformations bears new potential for research and action. It puts emphasis on learning processes that enable actors to be prepared to adapt to new (sustainability) challenges, even in times of crises (e.g. Covid-19, climate change). Despite more reflexive and evolutionary approaches in recent transformations and transition literature (e.g. [73]), much of the literature is dominated by a seeming ‘planning paradigm’ that emphasizes that we can plan urgently needed transformations. However, this is only possible to a certain extent, as fundamental system change is also about *learning how to learn* (triple-loop learning), which generates the resilience needed to face increasingly uncertain futures. In this context, the generation of strong networks of actors with different expertise (e.g. knowledge systems including indigenous and local knowledge), worldviews (e.g. cosmovisions), and influence in the systems, can be strengthened by establishing transdisciplinary learning processes.

To enable *deliberate* transformative change that is not only planned, but also reflexive, resilient, and learning-oriented, we need to create spaces in which transdisciplinary learning (individual, group, and societal; single-, double-, and triple-loop) can take place. A promising example in this regard are real-world laboratories, or similar research and learning settings [74,75]. Thus, as learning happens along transformations, more research is needed to improve the design of transdisciplinary learning spaces for science and society.

Concluding remarks

Fostering sustainability transformations requires learning from, for, and with diverse societal actors, both formally and informally as well as individually and collectively. The proposed framework provides a structure to better understand and enable such learning processes, through considering both the different levels of interaction and specific learning forms. While it is conceptually helpful to distinguish the levels and forms of learning, it is evident that they are highly interconnected. A deliberate and iterative process of distinguishing the levels and forms of learning seems to be a promising way to use their full potential. Taking learning seriously, the proposed framework can contribute to continuously developing our understanding and practice of transdisciplinary learning for sustainability.

Data Availability

No data were used for the research described in the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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