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A pragmatist approach to transdisciplinarity in sustainability research: From complex systems theory to reflexive science

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ABSTRACT

The importance of questioning the values, background assumptions, and normative orientations shaping sustainability research has been increasingly acknowledged, particularly in the context of transdisciplinary research, which aims to integrate knowledge from various scientific and societal bodies of knowledge. Nonetheless, the concept of reflexivity underlying transdisciplinary research is not sufficiently clarified and, as a result, is hardly able to support the development of social learning and social experimentation processes needed to support sustainability transitions. In particular, the concept of reflexivity is often restricted to building social legitimacy for the results of a new kind of 'complex systems science', with little consideration of the role of non-scientific expertise and social innovators in the design of the research practice itself.

The key hypothesis of the paper is that transdisciplinary research would benefit from adopting a pragmatist approach to reflexivity. Such an approach relates reflexivity to collective processes of problem framing and problem solving through joint experimentation and social learning that directly involve the scientific and extra-scientific expertise. To test this hypothesis, the paper proposes a framework for analysing the different types of reflexive processes that play role in transdisciplinary research. The main conclusion of the analysis is the need to combine conventional consensus-oriented deliberative approaches to reflexivity with more open-ended, action-oriented transformative approaches.

1. Introduction

The last decades have witnessed a growing interest in sustainability research. Global environmental change (including climate change, loss of biodiversity or deforestation), population growth, rising inequalities and the financial crisis are requiring policy action backed up by reliable scientific data. However, the mainstream scientific methodologies are often poorly equipped to deal with complex sustainability problems [1]. In particular, solving sustainability problems involves decisions on values that require civic participation and the building of social legitimacy for proposed transition pathways to sustainable societies. Therefore, both scientists and policy makers have called for re-conceptualizing the role of experts, practitioners and citizens in the production and use of scientific knowledge [2,3].

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In this context, sustainability scientists have increasingly recognized the need to move from interdisciplinary approaches to transdisciplinary collaborations, which bring together scientific and extra-scientific expertise [4,5]. Some approaches within sustainability research, such as ecological economics [6–9] have already built an important body of transdisciplinary scholarship and are increasingly influential in academia and at a policy level. More recent approaches, such as models of transition management [10–14] or resilience thinking [15–17] are developing and gaining more visibility. Building on this research, Jahn et al. have defined transdisciplinarity as a "critical and self-reflexive research approach that relates societal with scientific problems; it produces new knowledge by integrating different scientific and extra-scientific insights; its aim is to contribute to both societal and scientific progress" [18].

However, even though transdisciplinarity has become increasingly visible as a general approach to address the shortcomings of prevalent methodologies and modes of organization of scientific research, the transdisciplinarity discourse has not managed to develop a clear, unambiguous approach [18]. In particular, the importance of a reflexive questioning of values, background assumptions and normative orientations of various approaches to sustainability in transdisciplinary research is not sufficiently acknowledged. Indeed, despite having challenged the influential conception of science as a value-neutral inquiry in the exclusive responsibility of highly trained and specialized experts, the prevalent sustainability discourse continues to construe scientific reliability and social legitimacy as distinct requirements that have to be pursued in parallel and traded off against each other. This is for instance the case in the complex systems approach to sustainability science [19]. As a result, reflexive processes are sometimes used to justify an 'unstructured pluralism' based on ambiguous theoretical and value commitments [20,21].

The goal of this paper is to highlight the problems related with such a restrictive understanding of reflexivity and to build a framework that allows a better analysis of the role of reflexivity in transdisciplinary research. The key hypothesis of the paper is that transdisciplinary processes would benefit from adopting a pragmatist approach to reflexivity, which argues for extending the actors' reflexivity through their participation in concrete problem-solving and social experimentation and learning processes. To test the fruitfulness of this hypothesis, the paper proceeds in three steps. The first step briefly reviews the recent arguments for integrating reflexivity in transdisciplinary research processes (Section 2). The second step develops the pragmatist approach to transdisciplinarity and discusses four aspects of reflexivity that can facilitate the integration of transdisciplinarity into sustainability practice (Section 3). The third step starts from a typology of transdisciplinary approaches based on a double distinction proposed in the literature between descriptive-analytical and transformational approaches, and between epistemic and social levels of analysis, and assesses the basic types of transdisciplinary research according to the degree in which they manifest the four aspects of reflexivity (Section 4). The two final sections discuss these results (Section 5), outline the reasons for proposing reflexivity as a regulative ideal of transdisciplinary research, and draw some methodological and organizational conclusions.

2. The challenge of organizing transdisciplinary research for sustainability

Sustainability problems are usually characterized by a plurality of decision-makers, pervasive uncertainties, spatial and intertemporal externalities, interplay of human and natural components and an evolving understanding of policy objectives [22]. They challenge the assumption of a "stable and infinitely resilient environment where resource flows could be controlled and nature would self-repair into equilibrium when human stressors were removed" [23], moving the focus towards issues of building resilience, and analysing qualitative change and non-linear, far-from-equilibrium dynamics. At the same time, scientists, practitioners, policy makers and citizens often express different (and possibly incommensurable) values and perspectives on how sustainability problems should be framed and addressed. In short, at the core of different sustainability challenges lies the problem of managing complex social–ecological systems under conditions of uncertainty and plurality of values and perspectives.

The under-consideration of reflexivity on assumptions and values – as well the social norms and practices that sustain them – has been highlighted as a key problem in transdisciplinary sustainability research by an increasing number of scholars [24–26]. Several authors [19,27] have argued that phenomena do not become relevant to the sustainability scientist as value-neutral facts. On the one hand, normative commitments are embedded in the description of facts to the point that "evaluation and description are interwoven and interdependent" [28]. On the other hand, theoretical analysis is guided, explicitly or implicitly, by a normative agenda focused on intervention and change. It is not simply the *object* of inquiry (e.g. a particular ecosystem) that structures the research process around it; rather, it is a particular *problem* (e.g. biodiversity loss in a particular ecosystem) that requires theoretical and practical action (explanation, prediction, and intervention). As a consequence, issues of global climate change or biodiversity loss do not enter the scientific realm as neutral objects of inquiry; they are from the very beginning (that is, from the phase of problem definition) value-laden and guided by a transformational perspective (envisaged progression towards a more desirable state of affairs).

Transdisciplinarity has emerged as an explicit reaction to these challenges, and as an alternative to the dominant model of research organization and knowledge production. It has been proposed as a "reflexive, integrative, method-driven scientific principle aiming at the solution or transition of societal problems, and concurrently of related scientific problems, by differentiating and integrating knowledge from various scientific and societal bodies of knowledge" [18]. However, the reality of scientific practice is lagging behind this broadly-supported objective, and "while there is lip service paid to the need for civic science, the question of how it can be realized is largely unresolved" [2]. This situation can be explained by the lack of a common terminology and a shared research framework [29], diverging understandings of transdisciplinary requirements

[26] and institutional obstacles to transdisciplinary collaboration, such as lack of adequate hiring and promotion incentives [30]. Nonetheless, there is another important factor that has received less attention: the concept of *reflexivity* – at the core of recent approaches to transdisciplinarity – remains insufficiently clarified and risks generating divergent or even incompatible understandings.

Given its focus on values and its transformational agenda, some scholars have qualified transdisciplinary sustainability science as an applied science [31]. However, such a perspective misses the close interrelationships between the value-laden perspective on sustainability, the need for innovative theoretical approaches to coupled social–ecological systems and the transformational agenda, as can be seen in the need to rethink approaches in political sciences, economics and psychology inter alia to address sustainability issues [32,33]. Moreover, as highlighted in the report of the MASIS expert group on "Challenging Futures of Science in Society" [3], a combination of theoretical scientific developments and contextual ethical and stakeholder dimensions is not unusual in scientific research. Indeed, as stated in the report, the contrast between basic and applied formal hypothetic-deductive scientific research on the one hand and relevant research (to specific context and value-laden goals and objectives) on the other hand "is not a contrast of principles" [3]. The contrast has more to do with the institutional division of labour in current scientific practice than with the nature of scientific research. The combination of scientifically grounded and socially relevant research occurs again and again in history and in present-day science [34,35]. This combination is not present in all disciplines and scientific fields in the same way but, as can be seen from the current debate on sustainability, it is clearly a defining feature of sustainability science [25,26,36].

As this short review of current research on transdisciplinarity shows, reflexivity on the background values and assumptions is a key feature of the analysis of sustainability problems. Such problems – characterized by uncertainty, instability, uniqueness, and value-conflict – do not fit the prevalent model of technical-instrumental rationality. If the dominant discourse on interdisciplinarity in the 1980s and 1990s has mainly focused on articulating the contributions of different disciplines into a coherent framework [36], the more recent analyses of transdisciplinarity have shifted the focus towards the extended co-production of knowledge (by scientific and extra-scientific actors) and the importance of 'unsettling' established assumptions [37]. In this perspective, transdisciplinarity does not aim at establishing a common theoretical framework, but rather at fostering self-reflection; it "calls for humility, openness to others, a contextualization of our own knowledge, and a willingness to engage with and be moved by others." [37]. Without an explicit reflexive dimension, transdisciplinarity is confronted with the risk of either being reduced to formal social consultation, with no real impact in how knowledge is generated or integrated into policy-making, or evolving towards a politicized form of 'democratic science' in which epistemic aspects are subordinated to procedures of social legitimation. In such a situation, the explanatory shortcomings, lack of clear normative orientation and perceived "hidden agendas" of research can severely undermine public trust and the legitimacy of scientific knowledge, weakening its capacity to inform and guide policy-making.

3. Developing a pragmatist perspective on reflexivity

To clarify the role of reflexivity in transdisciplinary science, this section builds a framework for analysing reflexive processes based on contemporary insights in post-positivist philosophy of science. First, as a cross-cutting concept, reflexivity in social processes has been defined in a broad sense as a collaborative process of acknowledgement, critical deliberation and mutual learning on values, assumptions and understandings that enables the generation of "new meanings, new heuristics, and new stakeholder identities" [38]. In the case of scientific research, the role of such reflexive processes is to encourage processes of critical assessment and social learning on the background values and assumptions guiding research, and on the socio-institutional structures supporting particular norms and practices.

The problem of clarifying the role of background values and assumptions in science is at the core of much recent research in contemporary philosophy of science. The clear-cut distinction between facts and values, coupled with the belief that science can approximate objectivity by gradually uncovering an independent, observer-neutral reality have been influential assumptions in the early days of modern science [28,39]. These assumptions – often associated with logical empiricism – have been questioned by various post-positivist approaches. While Thomas Kuhn emphasized the incommensurability of conceptual frameworks and traditions of scientific practice [40], post-structuralists and social constructivists focused on the way knowledge is shaped by social dynamics, discourse and power relations [41–43]. In reaction to the perceived anarchism and anti-realism of some post-positivist approaches, more recent developments, such as Bhaskar's *critical realism* [44,45] and Putnam's *pragmatic realism* [46,47] have attempted to redefine realism, objectivity and truth in a way that avoids the positivistic postulate of a value-neutral and theory-neutral access to reality, but also the relativist scepticism about the possibility of discriminating between competing knowledge claims. In particular, pragmatism distances itself from both value neutrality and value relativism by conceiving knowledge production as a social and reflexive process whereby criteria of scientific credibility and legitimacy are jointly defined within a community of inquiry [28,48,49].

In the post-positivist literature, a first approach to the role of reflexivity in scientific processes is based on joint deliberation geared towards identifying the scientists' background values and assumptions. In this perspective, critical deliberation and mutual learning appear as key conditions for building an 'epistemology of practice' [50]. In a deliberative community of practice, knowledge is validated not by reference to predefined criteria, but through an iterative and adaptive process in which theoretical refinement and practical experimentation are connected [51] through social learning and the confrontation of different *reasoned* perspectives. Therefore criticism of background values and assumptions is a built-in

feature of deliberation, as the demand to strive towards a common ground is balanced by the equally important demand to question others' – as well as one's own – assumptions, values, ideological commitments and the power structures supporting them. Given its emphasis on argument, mutual criticism and fair participation, such an approach echoes Habermas' ideal of discursive democracy, "where citizens discuss, argue and deliberate publically" and communication is "free from domination allowing a rational and cooperative search for truth" [52].

In recent transdisciplinary research, the deliberative approach has often been connected to the idea of better integrating considerations of social relevance and legitimacy in the scientific discourse, by extending the peer community and reforming the current socio-institutional organization of science. Jahn et al. [18] have argued that "bringing reflexivity into processes of knowledge production is both the claim and main purpose of the transdisciplinary research practice" (pp. 2–3) and that reflexivity is a prerequisite for social accountability. Nonetheless, the emphasis on questions of social relevance, legitimacy and accountability does not clarify by itself the way a more democratic science could lead to better knowledge in sustainability research. By disconnecting the socio-normative aspects from the epistemic aspects, the distinction between 'legitimate' and 'illegitimate' participants in the processes of knowledge production and knowledge use remains ambiguous. Without a clarification of the role of reflexivity, the concept risks becoming a rhetorical device to legitimate the status quo rather than an incentive for real change: "insofar as the precise nature of the public needs being served by this new social contract is often unspecified or left so vague as to be unimpeachable /.../ the campaign to make academic research more socially relevant and more publicly accountable risks becoming something of a Trojan Horse for a set of unexamined political and economic commitments." [53]. In addition, many well-intentioned participants may consider that, despite its limits, their theory or methodological approach has been, by and large, proven to work and therefore excessive self-criticism would be counter-productive. They may feel that it is not worth prioritizing critical introspection over addressing pressing scientific and societal issues. Deliberative approaches may also result in lack of representativeness and may "have unintended, unforeseen, and undesirable consequences from a fairness and/or efficiency perspective" [54]. Furthermore, deliberative consensus is often unattainable and sometimes rejected as an unwarranted attempt at reducing the irreducible pluralism of perspectives and values [55]. It comes as no surprise that the integration of deliberative processes into research practice is fraught with difficulties, even if its importance is recognized in principle. Arguing for reflexivity exclusively in terms of social legitimacy and relevance, while overlooking its broader epistemic and socio-institutional implications, is unlikely to offer a powerful enough reason for social change.

The second key approach to the role of reflexivity in scientific processes developed in the post-positivist literature is based on philosophical pragmatism [28,48]. In contrast with the deliberative approach, pragmatism envisions reflexivity as open-ended processes of inquiry geared towards a broadening of the community of practice through social innovation and experimentation [56,57]. In a pragmatist perspective, scientific development is not based on predefined, context-independent criteria of rational acceptability of scientific processes or deliberative procedures. Rather, it is rooted in a collaborative process of concrete problem-solving in which participants are led to question and jointly reframe their values and understandings. Pragmatism challenges the reductionist model of positivism and the presumed dichotomies between *understanding* and *practice* and between *production* and *use* of knowledge. It questions the 'spectator theory of knowledge' underlying these dichotomies, according to which epistemic activity is a passive contemplation of the 'world out there', and theoretical knowledge is separated from – and a necessary prerequisite of – practical action. Instead, pragmatists insist on the active, experimental and social character of knowledge-building [58]. Research is understood as a socially-mediated process of problem-solving based on experimentation, learning and context specificity. In this perspective, reflexivity does not denote a passive reflection on the assumptions and values implicit in one's own understanding, but rather a creative process whereby participants co-generate new meanings. Starting from a pragmatist approach, it is possible to reconsider the meaning of transdisciplinarity and its epistemic and social role. Rather than searching for trade-offs between criteria of reliability and considerations of legitimacy, pragmatism investigates the way in which epistemic communities confront particular contexts of social experimentation and innovation through mutual learning and co-production of knowledge. In particular, as noted above, reflexivity implies a critical stance towards the understandings, values and assumptions of various members of the epistemic community. However, the simple acknowledgement of assumptions, ideologies and power structures does not offer by itself an orientation for change. To realize the full potential of criticism, it also needs a transformational dimension based on a reasoned, jointly-agreed normative orientation. Thus critical awareness needs to combine with critical action in order to turn science into a vector of social change and emancipation [52].

To address the risks and failures of non-reflexive research practice discussed in the previous section, it is useful to summarize the above discussion of deliberative and pragmatist approaches to reflexivity by distinguishing the four main aspects of reflexivity highlighted by these two main post-positivist approaches. The first aspect emphasizes the importance of *collaborative deliberation* in building a shared understanding of the overall epistemic and normative orientation of research. The second, also related to the deliberative approach, underlines the importance of reflexive processes in the *socially relevant framing of research problems*. The next two aspects are more explicitly influenced by the pragmatist perspective and go beyond a consensus-based deliberative understanding of reflexivity. The third aspect emphasizes the role of *social experimentation and social learning processes* in generating reflexivity on values and understandings in concrete problem-solving contexts. Finally, the fourth aspect deepens this pragmatist perspective by emphasizing the *critical and transformational aspects* of research. This includes not only an acknowledgement of the values, ideologies and power structures that shape the organization of the research process, but also an attempt to clarify and build agreement on an explicit agenda of social change and sustainability transitions. Table 1 illustrates these four aspects of reflexivity with recent

Table 1
Recent approaches that support or build on the four aspects of reflexivity.

Deliberation on the overall normative and epistemic orientation the research	Deliberation in participatory approaches to environmental policy [61] Joint deliberative processes in participatory action research [62] Extended peer review and knowledge validation [4,64] Evaluation criteria of public participation methods [65]
Deliberation on the socially relevant framing of research problems	Process of reconciling/combining various values and perspectives on problem-framing; collaborative definition of problem in the extended peer community [61,64,66,67] Conceptual models of science-policy interface in addressing environmental issues [68] Generation of common epistemic objects as basis for joint research questions ('problem transformation'); joint definition of 'boundary objects' [18,69] Taking into account existing socio-political context in problem-framing [67]
Generation of reflexivity on values and understandings in concrete problem-solving and social experimentation processes	Reflexive governance as collaborative 'problem handling' [10] Relevance of the pragmatist approach for doing 'mixed methods research' [70] Sustainability science as a solution-oriented transdisciplinary endeavour [19] Transition management as iterative methodological fine-tuning of large-scale transition processes [10,11,13,14]
Generation of reflexivity on normative commitments and ideological orientations in social transformation processes	'Structured pluralism' based on an explicit ontological, epistemological and ideological agenda for ecological economics [21] 'Science of sustainability' as a critical theory [71] Focus on human values and social transformation through awareness of power structures and ideological agendas [52] Emancipatory action research: research engaged in the emancipation of underprivileged groups by reflection on – and unveiling of – dominant ideologies and coercive structures [72,73]

sustainability research that addresses or explicitly builds upon them. The distinction between *deliberative* approaches underlying the first two aspects and *pragmatist* approaches underlying the last two aspects of reflexivity is not meant to suggest a polar differentiation or dichotomy. Over the past three decades, the two approaches have influenced each other and created an overlapping area of research interests [57,59,60]. Rather, the distinction is meant to emphasize their complementarity in offering a comprehensive account of reflexivity.

4. Implications of the pragmatist framework: from complex systems theory to reflexive sustainability research

Scholars have addressed the challenges of lack of reflexivity in research at least since the 1980s, with significant pragmatist import [57], particularly in relation to transdisciplinarity and qualitative research [18,51,74]. There is a growing scholarship on reflexive processes in transdisciplinary settings (cf. also Table 1), notably in sustainability research and ecological economics [27,67,75]. However, the research landscape is still marked by terminological differences and insufficient attention to the concrete conditions which are likely to facilitate reflexivity, rather than just reinforce a rhetoric of participation disconnected from research practice. As a result, reflexivity has gained little visibility and has been unable to emerge as a key requirement of transdisciplinary collaboration.

This section presents a typology of transdisciplinary approaches, with the view to explicitly assess the role of reflexivity in transdisciplinary research. The typology is based on two distinctions proposed in the current literature. The first distinction refers to two possible orientations of transdisciplinary research, which are often combined in practice: a descriptive-analytical orientation, for example based on a complex systems approach based on advanced modelling tools, and a transformational approach, based on a collaborative problem-solving process with the view to directly contributing to the transition process towards more sustainable societies [19]. Both the descriptive-analytical and the transformative orientation rely on the involvement of extra-scientific stakeholders, which can however have different functions in the overall research process. Along with Forrester et al. [76], a second distinction can be made between a social and an epistemic role of stakeholder involvement in transdisciplinary research. The social role emphasizes the dimensions of democratic participation, social relevance and legitimacy-building. It calls for a rethinking of the values, norms and responsibilities guiding scientific research which would establish a 'new social contract for science' [77–79]. Such a contract would ensure that scientific knowledge is 'socially robust' and perceived by society to be both transparent and participative [77]. The epistemic role focuses on extending the peer community in order to better address complexity, uncertainty and value commitments. It therefore emphasizes the epistemic potential of participation and co-production of knowledge [80], such as in the 'post-normal science' approach to transdisciplinary research [4,81].

On the basis of this double distinction between epistemic vs. social roles and descriptive-analytical vs. transformative orientations, four ideal types of transdisciplinarity can be distinguished. This typology helps in mapping the conceptual space of transdisciplinarity and in assessing the role of the various aspects of reflexivity in sustainability research (Table 2).

The first type, labelled the "complex systems approach" focuses on descriptive-analytical modelling of complex sustainability problems, with the view to build a more appropriate knowledge base. From the analytical modelling perspective of sustainability, theoretical attempts to describe social–ecological systems have evolved from fairly simple models focused on human–ecological interactions towards dynamic complex systems [82]. Such social–ecological systems have been studied from a resilience thinking perspective [17], being represented in terms of stability landscapes and basins

Table 2
Typology of transdisciplinary approaches in sustainability research.

	Descriptive-analytical	Transformational
Epistemic	Complex systems approach	Technocratic transition management
Social	Extended peer community	Critical-transformational

of attraction [16], with phenomena cycling within the same basin – following an 'adaptive cycle' of exploitation – conservation – creative destruction and reorganization [82]. They have also been described in terms of interactions between resource systems, resource units, users and governance systems, acting at multiple levels within the same system [83]. These models offer a conceptual framework that is both general enough to accommodate a diversity of types of social–ecological systems and specific enough to provide relevant, applicable knowledge for various sustainability stakeholders. They aim to diagnose and address system vulnerabilities in collaboration with stakeholders [84], based on the assumption that "a better understanding of the problem offers the solution to the problem" [19].

The second type, labelled "technocratic transition management" of transdisciplinarity adds a transformative dimension to the complex systems approach. It recognizes the interconnection of *understanding* and *use of knowledge* and therefore it emphasizes the need to combine theoretical construction with a solution-oriented approach for implementing various transition pathways. Given its reliance on scientific knowledge – understood as offering the best approximation of user-relevant knowledge through an extended complex systems approach [85] – to solve practical problems, it could be properly characterized as *technocratic*. Consequently, even though it is based on collaborative problem solving, scientific and technical knowledge are seen as the core element in informing and guiding policy making and social action.

The third type, labelled "extended peer community", combines the analytical-descriptive and social aspects. It offers a widely-shared characterization of transdisciplinarity, understood as integrating scientific and extra-scientific expertise from the relevant stakeholder communities and linking scientific problems with societal problems [18]. This type is well illustrated by 'post-normal science' approach developed at the beginning of the 1990s by Funtowicz and Ravetz, who argue for extending the scientific peer community and for integrating multiple legitimate perspectives into the scientific analysis [4].

Finally, the fourth type, critical-transformational transdisciplinarity, grounds the transformational dimension of research in the deliberative and learning practices of people engaged in a joint epistemic process. In common with transition management, it focuses on the practical conditions for improving the quality of knowledge, not merely the transparency and legitimacy of the epistemic process. However, it distances itself from what it regards as a narrow understanding of the normative and transformational role of research. Transition management focuses on technical options for social and technological change in which extended participation is taking place within a pre-defined political agenda. In contrast, this last type emphasizes the need to couple the public debate on values and objectives with a critical inquiry into the intellectual and value commitments of the dominant scientific discourse, and on the institutional and power structures supporting it [52].

This typology of transdisciplinarity focuses on the basic orientations of the research process and the social/epistemic role of the involvement of extra-scientific stakeholder expertise. Although all four types mobilize, to a certain extent, reflexive processes in structuring collaborative knowledge building, each of them focuses on some – not all – aspects of reflexivity. To gain an overall perspective on the acknowledgement and integration of reflexivity in recent sustainability research, the remainder of this section assesses these types using the different aspects of reflexive science processes discussed in the previous section:

(1) deliberation on the overall normative and epistemic orientation of the research;
(2) deliberation on the socially relevant framing of research problems;
(3) generation of reflexivity on values and understandings in concrete problem-solving and social experimentation processes;
(4) generation of reflexivity on normative commitments and ideological orientations in social transformation processes.

The complex systems approach scores low on the first, third and fourth aspects, the only exception being its interest in moving from an analysis of value-neutral objects to a more comprehensive explanation of complex interrelated social–ecological research problems involving complex research framing issues (the second aspect of reflexive science). Explanatory models based on the complex systems approach (for instance Redman et al. [86]) integrate normative aspects as *features of the investigated phenomena* (values of social actors under study, institutions and social norms, political and economic influences). However, they do not match this interest in the problem under consideration by a comparable interest in the way the research process is itself shaped by researchers' own values and beliefs, as well as institutional arrangements and power structures. Therefore the *implicit values underlying researchers' own understanding of sustainability* often remain unacknowledged. Yet, without a prior clarification of these values (e.g. social justice, intergenerational equity, intrinsic value of nature, etc.), sustainability research risks confusion or ambiguity in its choice of methods, criteria of performance and normative orientation [21]. The complex systems approach understands transdisciplinarity as an attempt to go beyond the

limitations of disciplinary approaches by encouraging epistemological and methodological pluralism. Still, it does not offer a clear criterion of selection for combining multiple models of research and thus remains at the level of 'unstructured pluralism' [21]. As it does not fully integrate the socio-normative dimension of research (third and fourth aspect of reflexive science) and remains ambiguous about its own normative orientation (first aspect of reflexive science), 'unstructured pluralism' is unable to develop a truly reflexive approach to knowledge production.

The technocratic transition management approach scores moderately on the first three aspects of reflexivity, concerning deliberation and mutual learning in socio-technical transitions, reflexivity on problem-framing, and reflexivity generated through problem-solving in social innovation and experimentation (the first three aspects of reflexive science). A representative example is the transition management approach, a governance model of sustainable development that focuses on reflexive deliberation, co-evolution, learning and adaptation to long-term structural change. This approach is specifically applied to persistent, long-term problems in socio-technical systems, which include not only infrastructures, technologies and policies, but also cultural norms and behavioural patterns [87], for instance in waste management or energy transitions [88]. It considers sustainability problems in their societal, economic and environmental aspects and develops solutions for managing social change through a series of transitions. These processes are considered in a multi-level environment including actor practices (taken as the micro level), product regimes, regulatory regimes, science and research regimes (at meso level) and infrastructures, values and social norms at macro level [12]. The main weakness of the approach lies in its lack of critical reflexivity on normative/ideological orientations guiding social transformation processes (the fourth aspect). Indeed, transition approaches, even if they have mainly been used in a sustainable development context, essentially develop a general theory of socio-technological transitions, and not a theory of strong sustainability or integrated social–ecological relations. As a result, they risk being hijacked by prevailing institutional arrangements and power players, as shown by [87] in the context of Flemish environmental policy. Moreover, even for the first three aspects of reflexive science, the integration of reflexivity in the process can still be strengthened. The practice of transition management shows a relatively low level of flexibility and responsiveness to feedback from practitioners and other social actors (ibid). In current transdisciplinary practice in transition theories, social action is guided by reliable science, while scientific methodology is subjected to feedback from earlier implementations. Therefore, the rift between understanding and use of knowledge is maintained, and the background of assumptions, values and norms shaping the practice of research is not fully explicitly integrated into the transition analysis.

The extended peer community approach, best illustrated by post-normal science, scores high on the first two aspects and moderately on the last two aspects of reflexive science. Indeed, reflexivity is at the very core of the approach. Its basic principle is that the relevant scientific peer community needs to be extended to include extra-scientific stakeholder expertise, in order to deal with radical uncertainty, divergent social values and multiple legitimate perspectives. This approach is based on a differentiation between contexts of normal science, defined as puzzle-solving, paradigm-based research, and contexts of 'post-normal science' [4,80] where standard assumptions and procedures are in need of revision. It addresses *both* the deliberative procedures of knowledge validation (overall orientation and framing) and the organizational aspects of science (critical reflexivity on the technocratic approach guiding many social transformation processes). However, the reflexivity mobilized through extra-scientific stakeholder expertise is supposed to be already given in the social context of the scientific practice. As seen also above, from a pragmatist perspective this is not always the case, as for many complex sustainability problems the value commitments and background assumptions are not predefined but generated jointly with the scientists in the process of inquiry itself. Therefore, the approach scores low on the social innovation and experimentation criteria. Indeed, if one acknowledges the co-generation of meanings, values and preferences, a special reflexive attention will need to be paid to broadening of the initial set of pre-given normative commitments and background assumptions in practices of social innovation. A good example of the latter is the emergence of the theme of "traditional knowledge" in ethno-botanical research in the late 1980s [89]. The innovative partnerships set up by this research community, based on prior informed consent agreements with leaders of indigenous communities, have led to the recognition of different possible epistemologies and a co-generation of the criteria of valid ethno-botanical research. However, this would not have been possible if the involvement of the indigenous actors had remained at the level of consultation on (and validation of) a predefined research agenda, which does not enable collaborative experimentation of new ways of doing science.

Lastly, the *critical-transformational type* scores high on the second and fourth aspects of reflexivity, related to clarifying the shared normative orientation for research, integrating multiple perspectives into problem-framing and clarifying the normative and transformational agenda of research. However, it scores moderately on the first and third aspects, which focus on the processes of deliberation, social experimentation, learning and innovation that contribute to building a shared orientation for transdisciplinary research. In contrast with the complex systems approach, it explicitly construes research as a collaborative process based on mutual adjustment of beliefs and values through deliberation. In contrast with technocratic transition management, it takes more seriously the collaborative and deliberative aspects of research in an extended peer community, as well as the critical and emancipatory potential of participation. And lastly, in contrast with the extended peer community approach, it acknowledges the need to specify the concrete conditions under which extended social participation can add to the quality of interdisciplinary collaboration. These differences are doubled by an emphasis on the potential of critical reflexivity to identify and challenge influential assumptions and values that are usually taken for granted, but also the ideological environment and power structures that support them. Thus the robustness and relevance of deliberative models are reconsidered from the perspective of their capacity to integrate dissent and irreducible plurality, and

Table 3
Summary of the qualitative evaluation of the four types of transdisciplinarity in terms of different aspects of reflexivity. The numbers refer to the numbering used in the text.

	Complex systems approach	Technocratic transition management	Extended peer community	Critical-transformational transdisciplinarity
(1) Deliberation on the overall normative and epistemic orientation the research	Low	Medium	High	Medium
(2) Deliberation on the socially relevant framing of research problems	Medium	Medium	High	High
(3) Generation of reflexivity on values and understandings in concrete problem-solving and social experimentation processes	Low	Medium	Low	Medium
(4) Generation of reflexivity on normative commitments and ideological orientations in social transformation processes	Low	Low	Medium	High

to acknowledge overt or covert forms of dominance shaping public discourse and participation [52]. If the extended peer community approach emphasizes the *enabling* character of collaborative praxis (in terms of ability to address problematic situations), the critical-transformational type is more interested in the *empowering* character of consciousness raising, resistance and liberation from coercive structures ([52], p. 12). Therefore the transdisciplinary involvement of extra-scientific actors goes beyond one-directional information or consultation on a predefined agenda. It aims at establishing a form of collaboration which empowers participants to actually influence the agenda and to question and possibly modify the dominant structures and understandings which guide epistemic processes (Table 3).

5. The promise and challenges of reflexive transdisciplinarity in sustainability research

In the two previous sections, the concept of reflexivity was clarified by reviewing research on social–ecological systems, long-term socio-technical transitions and critical knowledge production and knowledge use. The approach in this paper echoes the distinction made between *system knowledge* (theoretical understanding of the system), *orientation knowledge* (of the opportunities and constraints of decision-making) and *transformation knowledge* (of the practical ways of implementing these decisions) [18,90]. Using this typology, the complex systems approach and transition management would score highly on system knowledge, while the extended peer community type would score highly on orientation knowledge and the critical-transformational type on transformation knowledge. However, evaluating the four types according to the degree to which they manifest different aspects of reflexivity offers a more nuanced and comprehensive perspective, as it emphasizes the interconnection of requirements of *reliability*, *relevance* and *legitimacy* in the joint production of knowledge [69]. The point is not to make judgments of the comparative merits of each type of transdisciplinarity or to select an 'optimal' type from the list, but rather to point out the growing acknowledgement of the need for reflexivity and to highlight the shortcomings of non-reflexive science approaches.

Indeed, as shown throughout this paper, the prevalent sustainability discourse has not sufficiently clarified the concept of reflexivity underlying recent transdisciplinary research. In the absence of such a clarification, transdisciplinarity risks becoming overly politicized, at the expense of scientific soundness and reliability [53]. These problems are particularly relevant in the context of transdisciplinary collaborations in complex system theory approaches, as they generate a kind of 'unstructured pluralism' that can undermine the building up of knowledge [20]. As highlighted above, unstructured pluralism fails to integrate the specificity of the normative and social-institutional context of distinct sustainability problems, and rests on ambiguous epistemological and normative grounds. Moreover, this ambiguity can also affect the practical implementation of research results, as stakeholders may have different perceptions on the legitimacy and fairness of the epistemic process.

Therefore the need for a more systematic integration of reflexive processes into transdisciplinary science can be advocated on *epistemological*, *normative* and *pragmatic* grounds.

(1) At epistemological level, a critical consideration of assumptions, values and socio-institutional determinants of research can expose bias and reductionism, as shown for instance by the ongoing debate on environmental valuation methodology [91,92]. Recent empirical research indicates that reflexive processes can improve both problem framing and methodology. A good illustration is provided by projects aiming to facilitate collaborative knowledge-building among different types of stakeholders. For instance, the Integrated Local Environmental Knowledge (ILEK) project, managed by the Research Institute for Humanity and Nature (Japan) focuses on "processes of local knowledge production and circulation that can lead to bottom-up solutions to global environmental problems" [93]. The project attempts to facilitate the dialogue between scientific explanation and everyday ways of understanding, in order to generate a convergent vision that is able to inform policy-making. In order to do that, it supports "local science networks" animated by residential researchers who act as "vertical translators" (between different levels of intervention, from local to global) and "horizontal translators" (between different types of stakeholders) (ibid). Additional evidence is provided by the case

of Barefoot Fisheries Advisors (BFAs) in the Galician co-managed Territorial Users Rights for Fishing [94]. Building explicitly on the concept of *knowledge translators*, this project documents the success of BFAs in aggregating and mediating between distinct types of expertise, as well as in building social capital to sustain future collaboration.

(2) At normative level, reflexive processes facilitate convergence on values and normative commitments, or at least a better management of value differences and conflicts. This is shown for instance by the use of participatory methods to facilitate preference-formation, elicit shared values and thus support collaborative problem-framing [95] or conflict management [96]. In one such case, convergence on values is built through multi-stakeholder ethical assessments involving an 'ethical matrix' to evaluate several scenarios and then further enrich evaluations through stakeholder involvement [97,98]. While the ethical matrix, which "specifies and interprets selected acknowledged ethical principles according to every stakeholder's situation", the participatory process "anchors the values in the real situation and that paves the way to the acceptability of the ethical judgments" [97]. As became apparent during the deliberative exercise, the same stakeholders were able to engage in different valuation types *according to the role they were adopting*: self-regarding economic agents in their professional role, but also other-regarding, ethically-concerned participants in their role as proxies for the biosphere or the future generations. The process thus revealed the importance of methodological and institutional arrangements which do not restrict the plurality of value expressions and the space of social experimentation, as well as the attitude of joint responsibility resulting from direct involvement rather than expert-driven consultation.

(3) Participatory reflexivity also plays a key role in addressing more pragmatic considerations. It can be used to mobilize public support for scientific knowledge production, thus enhancing public trust in scientific expertise and in policy interventions that rely on such expertise. This process can be illustrated by recent attempts to integrate participatory processes in environmental valuation and policy-making in order to address the limits of monetary valuation and cost-benefit analysis (CBA) [61,91,92]. Monetary valuation misrepresents (or ignores) the diversity of types of valuation expressed by stakeholders, while CBA assumes comparability and transferability of values across individuals and across valuation contexts. To tackle these problems, participatory methods such as citizens' juries, consensus development panels, future search conferences, most significant change technique, scenario planning, appreciative inquiry, principled negotiation and ethical matrices [99–102] are used to elicit stakeholder values and facilitate convergence on preferable (rather than optimal) solutions [103]. Participatory valuation – often complemented by multi-criteria analysis (MCA) – strives to elicit *agreeable* solutions which can be endorsed by participants with different value systems and interests, through dialogue and negotiation. In doing so, it "takes the decision on the most desirable solution, respecting the diverging value systems of different stakeholders, out of the domain of the economic calculus: the agreeable solution is not necessarily the economically optimal one" [103]. Bottom-up processes of preference formation and elicitation of values help in extending environmental valuation to include sustainability and fairness goals, along with economic efficiency [104]. Therefore, even if it cannot solve all conflicts, MCA helps in providing "more insight into the nature of conflicts and into ways to arrive at political compromises in case of divergent preferences so increasing the transparency of the choice process".

Based on these three arguments, reflexivity can be proposed as a *regulative ideal* to guide transdisciplinary research on sustainability. Such an ideal is not meant as a rigid methodological and normative standard of research design. Rather, it offers a framework that integrates broad epistemological and normative orientations, on the basis of which different methodological options can be envisaged. Being the result of collaborative inquiry and practice, these broad orientations can be adjusted or revised on the basis of further debate, experimentation and evidence. However, the endorsement of this ideal should not overlook the associated practical difficulties and risks. One key difficulty is to 'translate' the reflexive processes into concrete social and institutional changes. The significant psychological and reputational costs of cognitive and attitudinal change have been richly documented by social psychologists [105–107]. While participants may be sympathetic to the idea of self-questioning and 'displacing' well-entrenched assumptions, they may not be equally willing to see their own cherished beliefs and values being criticized. They may also be reluctant about undermining un-reflexive social norms and institutional structures when considering the way this will affect them, considering the potential of reflexivity to subvert established institutional norms and practices, thus threatening the power relations supported by them [52]. Moreover, social experimentation and learning in deliberative groups may, under certain conditions, amplify cognitive errors, group polarization and inefficient aggregation of privately-held information [108]. These factors – along with vested interests in maintaining the status quo or reinforcing existing power structures – can 'hijack' the participatory process and undermine its representativeness and legitimacy [53], as illustrated by a Flemish policy initiative to reform the housing and building sector [87].

Such risks may be mitigated by a better integration of social learning and experimentation processes into institutional structures and social practices. At the level of education system such initiatives are on the rise. An example is provided by a collaborative project managed by the local authorities in the district of Kashiwa city and the University of Tokyo (Japan), which aims to develop a model of "social experimentation for sustainability". The project involves students from different graduate programmes and other stakeholders who "learn transdisciplinary approaches to addressing interwoven problems requiring both technical solutions and policy innovations" [109. In another case from the United States, researchers focus on developing a graduate curriculum aimed at fostering transdisciplinary competencies such as critical thinking and critical use of learning resources and technologies, self-directed learning and the ability to create and participate in reflective communities [110]. However, the effectiveness of such initiatives depends on possibilities for wider social transformation,

anchored in practices of mutual monitoring, criticism and intervention. By instituting loops of self-reflection [111], contentious issues can be addressed iteratively and gradually adjusted, rather than being protected through institutionalization, ad-hoc assumptions and discouragement of public inquiry into the issue. The agenda of reflexive research is intimately linked with an agenda of democratic social change.

6. Conclusion

The key argument of this paper is that a clarification of the role of reflexivity in transdisciplinary sustainability science would benefit from adopting a pragmatist perspective on the different aspects of reflexivity identifiable in recent sustainability research. By emphasizing the role of collaborative deliberation and practical knowledge generated through processes of social innovation and experimentation, pragmatism challenges the tendency to frame scientific *reliability*, social *relevance* and social *legitimacy* as distinct requirements on knowledge, to be traded off against one another. The substance of the four aspects of reflexive science resulting from this discussion is not new: each of these aspects has been addressed by recent research (particularly in the context of sustainability – see Table 1). However, the attempt to bring together these different strands of literature in order to clarify the key requirements of reflexivity is, to our knowledge, a novel development. Moreover, our approach emphasizes the interconnection of epistemic, normative and organizational aspects of science in addressing current social and ecological challenges. In a reflexive transdisciplinary approach, the descriptive-analytical and transformational dimensions of research [19] are understood as entangled and mutually reinforcing aspects. In its descriptive-analytical mode, reflexivity calls for a critical acknowledgement of the values, assumptions, as well as institutional and power structures that shape the current epistemological model and the organization of science. In its transformative mode, reflexivity calls for building a shared normative vision which can challenge dominant assumptions and power structures, and guide social change.

The adoption of a conception of reflexive science informed by pragmatism has consequences at the level of both the methodology and the socio-institutional organization of science. At the methodological level, the pragmatist conception of reflexivity requires a nuanced and non-reductionist understanding of sustainability problems which acknowledges the fact that, "as structural variables change, participants need to have ways of learning and adapting to these changes" [112]. Indeed, in the pragmatist conception reflexivity on background assumptions and values is generated in collaborative problem-solving process shaped by experimentation, social innovation and mutual learning. Therefore methodological choices are not made in a hypothetical value-neutral and theory-neutral environment, but are informed by a critical deliberative process based on evolving values and understandings.

At the organizational level, a pragmatist approach to reflexivity calls for developing more appropriate evaluation procedures for transdisciplinary projects, which take into account their open-ended and adaptive character [66]. It also emphasizes the need to design mechanisms of stakeholder participation which manage to actually transform values, practices and institutions, rather than just guiding participants through a consultative mechanism in order to legitimize a predefined agenda. Such mechanisms of collaboration between experts, practitioners and policy-makers should be structured enough to generate and sustain collective action, yet flexible and inclusive enough to support genuine participation and, where necessary, challenge the status quo. Lastly, reflexivity requires refocusing educational policy on approaches that are centred on problem-solving and experimentation, and particularly on 'strategic competences' and 'normative competences' that are essential for tackling sustainability problems with various stakeholders involved in concrete transition pathways [113]. As social, economic and ecological interconnections deepen and become more visible, solving sustainability problems requires institutional and governance arrangements that are better equipped to integrate learning and experimentation in order to adjust to a diversity of challenges.

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