



Transdisciplinary environmental research: a review of approaches to knowledge co-production

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About the Nexus Network think piece series

Funded by the ESRC, the Nexus Network is a collaboration between the University of Sussex, the STEPs Centre, the University of East Anglia, and the Cambridge Institute for Sustainability Leadership. The Nexus Network brings together researchers, policy makers, business leaders and civil society to develop collaborative projects and improve decision making on food, energy, water and the environment. In July 2014, the Nexus Network commissioned 13 think pieces with the remit of scoping and defining nexus approaches, and stimulating debate across the linked domains of food, energy, water and the environment.

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Introduction

Transdisciplinary environmental research: a review of approaches to knowledge co-production

Summary

Transdisciplinary research bridges the traditional boundaries between disciplines and between academia and practice. It is increasingly common, motivated by the intellectual demands of dealing with complex interrelated issues at the food, water, energy, and environment nexus. There are also demands from funders and society at large for relevant research which will have an impact on society. Transdisciplinary teams can generate new knowledge to address complex problems while integrating multiple disciplines and stakeholders. This paper reviews 76 publications on trans-disciplinary research and identifies common approaches and challenges. Transdisciplinary research challenges conventional approaches within academia which organise knowledge within disciplines. Working with practitioners, lay voices, and the public also challenges fundamental principles of scientific investigation.

Managing transdisciplinary research

The paper sets out three challenges facing those involved in these forms of generation of knowledge:

Theoretical challenges: Framing problems, balancing reductionism and holism, managing theoretical pluralism.

Methodological challenges: Different conceptions of ‘proof’. Experiential vs. Experimental data, synthesising results from multiple scales, data types and sources.

Practical challenges: Different actors desire different outputs, communication across boundaries, building trust and collaboration

The challenge for those involved in research is to find ways of managing tensions arising within the transdisciplinary process. Firstly, there is a need to recognise diversity of values, methods and reward systems among participants. Secondly, the selection of research teams has to balance optimising team size and diversity to encourage knowledge creation

without overwhelming cognitive distance. This can lead to an inherent paradox in which transdisciplinary research seeks diversity of participants and perspectives, but requires their alignment towards common goals and research outcomes. Thirdly, attention has to be given building trust in collaboration while also being sensitive to how unequal power relations can shape this process (e.g. control of funding, control of outputs).

Developing transdisciplinary researchers: Challenges for academia

The future of transdisciplinary research is dependent on the supply of researchers willing to explore these approaches. There can be tensions between specialisation in mono-disciplinary research vs embracing a transdisciplinary approach that engages with a range of stakeholders and disciplines. Academic progression and promotion favours a mono-disciplinary approach, whereas career pathways for transdisciplinary researchers are less straightforward. This requires further training and mentoring for early career researchers and others involved. This can cover the approaches to transdisciplinary research, the ways of sharing knowledge beyond the academy, alternatives to mono-disciplinary journals, and navigating the balance between conventional criteria of academic quality based on peer review papers, and the demands of the transdisciplinary audience. While a transdisciplinary researcher may be an alternative form of researcher, they need not be excluded from the systems and structure of academia

Evaluation of transdisciplinary proposals and outcomes

This raises questions for funders of research too. Research policy is increasingly sensitive to the demands for transdisciplinary approaches, those managing such funds need to build their capacity. Such changes also require the development of a cadre of transdisciplinary reviewers with appropriate expertise to review proposals, project reports and academic papers. Defining quality and success is contingent on values, expectations, culture, language and reward structures of all participants, funders and end users. Balancing the views of different stakeholders is a particular challenge.

Towards a transdisciplinary approach

Living with tensions: Transdisciplinary research requires the management of diversity and “tangled agendas”. There is no right methodology, except being aware of tensions.

Formation of team: Teams need to be big enough to be diverse but small enough to build relationships.

Negotiation of the research approach: Develop methods of engaging all partners. Facilitators and stakeholder workshops can be key to ensuring good communication, managing expectations and ensuring equality among all participants.

Knowledge creation: To avoid the pitfalls of a multidisciplinary or multi-stranded approach, transdisciplinary projects ensure integration of all aspects of the research. Allow time and space so that there is room to fail and the opportunity to learn from mistakes. Time for co-reflection and learning should be written into the project.

Outputs: Negotiation is required at an early stage to ensure outputs satisfy all team members, as well as funders.

Transdisciplinary environmental research: a review of approaches to knowledge co-production

Introduction

The challenges of ensuring food, water and energy security while mitigating environmental change require the involvement of a range of stakeholders. Issues such as climate change, land use, agri-environmental management, renewable energy and water use are complex, and addressing biophysical challenges is compounded by the need for economically and socially viable solutions. These challenges require research that cuts across traditional boundaries. Not only is there a desire to cut across academic boundaries (what can be termed interdisciplinary research); there is a need to cut across the boundaries between academia and professional practice. This paper therefore sets out to review the motivations for undertaking transdisciplinary research, and the theoretical, methodological and practical challenges inherent in such an approach. This leads to a discussion of the tensions evident in transdisciplinary collaborative activities and the challenges for participants.

Transdisciplinary research is defined as research which promotes collaboration between academic research and practice, between different disciplines, and between different types of organisations. This is achieved by crossing the boundaries between different disciplines, and through engagement with different types of knowledge: scientific knowledge, lay knowledge and practitioners' experience. Transdisciplinarity engages with a wide group of stakeholders; listening to the public voice as well as engaging with policy makers. Participants become co-creators of knowledge.

Applying science to solve environmental problems in ways acceptable to society requires negotiation of the goals of research, of policy options and of public acceptability. A growing body of research seeks to investigate complex environmental challenges from a transdisciplinary perspective. This is a more deliberative form of science that requires multiple disciplinary knowledges. Embedded within transdisciplinary research is the attention to the complexity of working across multiple disciplinary perspectives and scales, as well as moving across the divides between academic science and professional knowledge.

Transdisciplinary research processes are therefore more complex in themselves, as research team members negotiate goals, priorities, problem framing, research approaches and methods prior to collecting data. Furthermore, teams debate the analysis and the implications of results and the implementation of findings. While transdisciplinary approaches are sometimes seen as the best way to tackle interconnected issues in the food/energy/water/environment nexus,

embedded in this transdisciplinary research process are a series of tensions which this paper seeks to explore.

This “think piece” is based on a review of literature concerning the process of collaboration in transdisciplinary research projects. The review draws on literature identified through journal searches focussing on document titles including the term “transdisciplin”, aimed at capturing those discussing transdisciplinary or transdisciplinarity, published since 1979. The resulting list was screened to select papers that had undergone a process of peer review, were published in scholarly journals, were written in English, and were related to the themes of food, water, energy, and the environment. This search was done manually, assessing the topics of each paper. This identified 67 papers which focused on transdisciplinary practice while conducting research related to the food, water, energy, and environment Nexus theme. Of particular interest were papers which reviewed transdisciplinary programmes or analysed the process of transdisciplinary collaboration across multiple studies. The literature base was extended through following up key references cited in the initial list of journal papers.

This paper explores the emerging literature on transdisciplinarity as well as the theoretical, methodological and practical challenges. This is followed by a discussion of the tensions experienced in such research, the challenges for academia, the challenges in evaluating transdisciplinary research and the development of transdisciplinary expertise. The paper concludes by identifying the future challenges for transdisciplinary research, the ways it can be supported and sets out a research agenda to gain a greater understanding of this form of knowledge generation.

The transdisciplinary turn?

Transdisciplinary approaches draw on a range of paradigms and emerging processes shaping the generation of knowledge and the concern with sustainability¹. Transdisciplinarity draws on ideas of co-production^{2,3} and the generation of knowledge from a range of stakeholders. Such approaches do not prioritise the role of academia in this knowledge production process, but rather see a range of actors collaborating. In this way it draws on debates about the nature of science and the need to have alternative perspectives beyond traditional disciplinary specialist perspectives, building on the seminal differentiating between Mode 1 and Mode 2 science⁴. In Mode 2 science knowledge production occurs through collaboration beyond academia, and is more socially accountable.

The growing impact of science on society has also encouraged society to have an increasing role in science. The voice of the public in debates about science and the way it impacts on citizens is growing⁵. The deliberative turn in science has resulted in publics being engaged in debates about science priorities and setting agendas⁶. Participation in problem identification, framing, research and analysis to shape science to fit society's needs has been termed a democratization of science⁷. Fundamental to this is the recognition of lay and experiential knowledge, coming from commercial, practice-based, or personal experience. Participative approaches can vary in their level of engagement, interaction and power sharing between researchers and the participants⁸. Research reviewing sustainability science has identified a sequence of engagement from informing (one-way exchange of information) through consulting (2-way exchange of information) and collaborating (influencing the outcome) to empowerment, where practitioners are given authority to implement findings⁹.

The pursuit of “sustainability” is widely recognized as requiring an interdisciplinary approach to deal with the complexity of biophysical problems and their interaction with society and the economy. Further, achieving sustainability goals requires engagement with policy and the wider public^{1,10}. This has resulted in the emerging field of sustainability science^{9,11}. The complexity and urgency inherent in some areas of research and policy has resulted in the concept of post-normal science which focuses specifically on issues where ‘facts are uncertain, values in dispute, stakes high and decisions urgent’^{12, p744} and which engages with the extended peer community. However, the drive towards transdisciplinary research also comes from governments and funding agencies. Increasingly there is a drive to ensure that research has impact, i.e. is relevant and salient to real world challenges, and makes a difference to lives, livelihoods and society^{13,14}. This has given rise to an increasing number of transdisciplinary and interdisciplinary research programmes (for example, in the, DEFRA LINK funding, ESRC case awards, and the Rural Economy and Land Use programme, and internationally, EU Framework 7 projects, Australian Research Council's Research networks, US National Science Foundation funded Engineering Research Centres). In a study of ten transdisciplinary agri-environment research projects more than six cited criteria from funders as shaping the move to a transdisciplinary approach¹⁵.

Underlying differences in the concept of knowledge: theoretical challenges.

While there are incentives to pursue transdisciplinarity in terms of complex problems and global challenges related to the food, water, energy, and environment nexus, there still remain a range of challenges, most notably around theoretical considerations of the nature of knowledge, conceptions of robust evidence and the role of academic disciplines. As shown

earlier, transdisciplinary research involves the framing of problems from both a range of disciplines and from academic and practice based perspectives. The concept of academic disciplines is an established way of organising learning and knowledge, but as such are social constructs rather than fixed categories¹⁶. Disciplines are distinguished by areas of interest, assumptions, priorities, vocabularies, methods, research practices and communications media (associations, journals, conferences)¹⁷.

For transdisciplinary research there is much innovation at the boundaries of disciplines and points of intersection with other disciplines^{18,19}. The complex problems related to sustainability and the food, water, energy, and environment nexus lead to research at such boundary spanning spaces. As diverse actors come together to address common issues each actor may have different perceptions of a research problem or ways of framing it which can result in problems with managing research projects and the expectations of all participants⁶. Transdisciplinary research can allow interpretive flexibility and negotiation which enables communication between different communities with different sources and types of knowledge. While transdisciplinary research can be threatening to some, it also allows researchers to transcend boundaries and avoid the “institutional and conceptual straight-jacket of the disciplines”^{20,p453} giving some a sense of freedom as they abandon constraints and move to new disciplines²¹.

A further theoretical challenge comes from the call for non-reductionist and holistic approaches that include multiple theoretical approaches and attention to the dynamics of whole systems^{16,22}. It is this holistic approach that is found in examples of research where the boundaries are blurred such as in sustainability science, community conservation and sustainable livelihoods²³. This can lead to conflictual relationships between different disciplines or different professions as transdisciplinary research challenges academic protectionism²⁴. These approaches recognise many forms of knowledge that include experiential and practice based alongside academic/scientific knowledge^{25,26}. The theoretical pluralism required challenges the concept of quality as defined against disciplinary standards²⁷. A review of sustainability science research identifies the needs for transdisciplinary research to address quality in three areas: credibility of research amongst scientific communities; salience of research to practitioners; and legitimacy of results for the wider society⁹.

Overcoming contrasting views on how to generate knowledge: methodological challenges

As transdisciplinary teams bring together people with widely differing viewpoints and approaches to the concept of knowledge, challenges arise concerning the selection of methods for investigating problems. These challenges relate to both the nature of knowledge (what can be termed epistemology) as well as the approaches to collecting evidence. For example, there can be differences between academia and practitioners in terms of the rigor required behind particular evidence¹⁵. A business or civil society organisation may want to know what works in a particular location, while academic research may be looking for evidence that would satisfy a peer review process. This raises particular challenges with regard to the nature of ‘proof’ that affects how a transdisciplinary project designs data collection and how it shares any results.

In terms of the design of research, a major difference between actors in a transdisciplinary process is between experiential and experimental data. Power struggles among research teams emerge as members value disciplinary or experimental and practical knowledge differently. Those focused on practice will be collecting experiential data constantly through their own forms of experimentation, but locating this in the complex reality of managing multiple variables without any comparative control²⁸. This holistic approach allows for the exploration of the interaction of variables, but also challenges researchers looking to isolate particular variables and identify causality. These tensions can also be found between methodological traditions within academia, most notably the difference between approaches that are exploratory and those that are testing particular hypotheses.

The transdisciplinary research process also requires negotiation of how data is actually collected and nature of engagement with the research subject. There can be opposing views concerning the type of data (qualitative or quantitative data), sample frames (size and location), and the means of collection (researcher led or practitioner reporting). What distinguishes inter and transdisciplinary studies from multidisciplinary studies is that synthesising and interpreting data from multiple scales and disciplines happens as research is formulated and undertaken, rather than as an afterthought. Taking the example of agricultural research, there can be a focus at the cellular and molecular scale (plant breeding), microbial scale (soil science, plant disease, health), field scale (agronomy, agricultural economics) through to ecosystem (ecology) and global scales (climate science).

Practical and logistical challenges in managing transdisciplinarity

There are logistical challenges inherent in managing such diverse research teams which draw on such a diverse group of actors: academic researchers, contract researchers, NGO's and campaign groups, consultants, professional practice experts, strategic case actors, local case actors^{15,29}. Each type of actor brings specific expertise and also institutional and organisational ways of communicating and working¹⁵ and each type aspires to goals according to their institutional role. Thus academics may see the collaboration as a research project leading to the production of new knowledge, whereas local actors may see the collaboration as a way to harness research towards real world problems and implementation of solutions. Accordingly actors and organisations will desire different outputs³⁰. These outputs may include publications, relevance to public goals, budgetary control, meeting the needs of stakeholders (of NGOs). Thus agreement on the end goal of the project and corresponding outputs can be challenging, with some participants disengaging if they feel further work will not meet their own goals. In a review of 236 sustainability science projects, only 9 engaged in processes through to implementation of findings⁹.

Communication among team members has been shown to be a crucial aspect to facilitate collaboration, avoiding the boundaries created by disciplinary jargon which inhibits mutual understanding^{15,31,32,33,34}. Few concepts are self-evident to all members of the research team, and differing concepts and meanings are not neutral³⁵. Building relationships to encourage deeper connection among participants is important, even though meetings take time and cost money. The context and location of the transdisciplinary research can also vary³⁶. In some cases, universities link with businesses, but in others non-university research organisations link with practitioners and businesses³⁶. As individual participating organisations change and develop, representatives attending meetings may change over the course of the project. Facilitators are important in ensuring that all voices are encouraged to speak out and are heard³⁷. Face to face meetings and communication are better than written reports for exploring differences, and fostering social learning^{35,37}. Long term amicable relations engender openness and trust, allowing research teams to raise questions and challenge ideas in a mutually constructive way. Strong ties between members of research teams result in exchange of more 'fine-grained' information and hence more intensive collaboration^{30,p 54}.

Many project teams reflect on the learning process as they are negotiated and debated during the research project³⁸. Researchers need several years of collaboration to develop respect for other each other's cultures and values, and to enable them to develop new projects³⁹.

Commitment is also important with participants making the effort to understand each other and having, openness to other's values, norms and goals.

Discussion

Managing tensions arising within the transdisciplinary process

Underpinning this paper is an understanding of the potential tensions between different stakeholders involved in transdisciplinary research. It is therefore necessary to have a clear conceptualisation of these tensions in order to understand how transdisciplinary research manages to overcome them. The different parties involved in collaborative research can come from different professional as well as disciplinary backgrounds⁴⁰. Much research in innovation studies has focused on the business-academia relationships⁴¹ with further research also emphasising the role of other professions such as civil society⁴² and professional practice experts²⁹. Within these professions there are common cultures, values, methods and expectations^{40,43}. These can be described as different logics that shape the reward systems and conceptual approaches. Such cultural difference between players, can lead to disincentives to work across professional boundaries⁴⁴. However, the range of innovative transdisciplinary projects emerging show that there is a need to avoid deterministic approaches that assume that those within a culture will behave in a common way⁴⁵. These examples of transdisciplinary research show that those involved do have a degree of agency that allows them to find ways of overcoming or living with the tensions. This can involve individuals and organisations having the capacity for holding multiple logics at one time⁴⁶ in what has been referred to as ambidexterity and managing paradox⁴⁷. Such multiple logics can be found in inter organisational relationships, within organisations and also within individuals who are confronting tensions simultaneously. This leads to the blurring of professional boundaries⁴⁰. Where the cultural distance between parties is great, there may need to be intermediaries who are able to bridge the boundaries by recognising and working with the competing tensions⁴⁸.

There is a paradox inherent in transdisciplinary research as its strength lies in gathering a diverse group of perspectives and players, but they must then be aligned towards common goals and research outcomes, ultimately resulting in “convergence on univocal statements”^{30, p64}. Greater diversity within teams stimulates creation of new knowledge, however too much diversity challenges mutual understanding and communication within the team³⁰, with transdisciplinary team members being on different wavelengths. Low diversity of cognitive dissonance (i.e. from similar disciplinary backgrounds) generates less new knowledge and

learning among team members, whereas higher cognitive distance gives greater possibilities for transdisciplinary learning and generation of new knowledge^{30,49}. However excessive diversity among the transdisciplinary group challenges mutual understanding and communication within the team and so reduces generation of new knowledge³⁰. Indeed bringing together multiple perspectives and methods can result in some ambiguity between different groups and multiple, simultaneous ways of understanding^{35,50}. It is the reaction of transdisciplinary research to ambiguity that can be critical. Actors may have different perceptions of a research problem or ways of framing it which can result in problems with managing expectations⁶ and result in conflict among team members⁵⁰.

Transdisciplinary collaborative processes are not always harmonious and relationships are shaped by power relations. Power shapes who is involved in research as well as the ways that they are involved. Power is also exerted through the control of funding, the use of contracts to other partners who are subcontractors, or through peer pressure⁴⁰. Participation can be tokenistic if there are considerable imbalances and some stakeholders are not represented³⁷. For example a study of agricultural transdisciplinary projects in New Zealand found that “some participating research organizations, as well as some business stakeholders, find it difficult to relinquish their embedded competitive interests, and this has led to power struggles that inhibit collaboration”^{51,p221}. Power asymmetries are also evident in participatory research projects involving farmers in developing countries^{52,53}. However, even when there are unequal relationships, a weaker party can make an influence through creating some room for manoeuvre or using resistance as a strategy. Managing the sharing of outputs can be a key concern in negotiating power among within transdisciplinary research projects. Desired outputs can vary according to stakeholders, so that publications appeal to some, but others may want outputs more relevant to public goals³⁰, and NGOs and other stakeholders may want outputs relevant to their own organisations⁴⁰. The relative costs of tackling imbalances of power need to be recognised. These include stakeholder workshops, face-to-face team meetings, data collection methods, reporting and knowledge exchange with different audiences (public, industry, practitioners, academic, and media). The holding of research funding is the most explicit form of power. Power is therefore exerted at the initial stage, as funding bids are written and teams convened, and also as the project continues and develops, and final outputs are prepared. The type of funding available will dictate which stakeholders are eligible to apply, with traditional research council money requiring academic institutions to play a leading role, and so become gatekeepers to funding for other partner institutions. As research goals are framed to meet the requirement of the funding programme, priorities and

promised outputs may have to be altered. The language used in project documentation may be more accessible to some than others.

Developing transdisciplinary researchers: Challenges for academia

The move to transdisciplinary research requires a range of researchers and practitioners who have the capacity to work together, and produce valuable knowledge. This therefore raises questions regarding the types of training and education that are required to cope with the challenges and tensions set out in the previous sections. Central to this debate has been the mono-disciplinary focus of academia. Concern about the over-specialisation of science were debated in the 1970's⁵⁴, along with calls for universities to be more engaged with sectors outside of academia to support innovation⁵⁵.

Today, academic progression and promotion is still reliant on publication of research in top ranked journals centrally positioned within each discipline⁵⁶. Reviews of sustainability science⁹ have found that papers were generally published in journals with low impact factors (defined by the average citations per paper). This suggests that transdisciplinary researchers are choosing not to submit work to the higher cited journals or that these journals are rejecting transdisciplinary research. This study also found that there is a large amount of non-peer-reviewed literature in the area of sustainability science which may be more accessible and relevant to non-academic participants and stakeholders in transdisciplinary research.

There are calls for a re-orientation in higher education to enable transdisciplinarity to occur within individual's thinking processes⁵⁷. Increasingly transdisciplinary masters and doctoral programmes are offered that seek to foster an ethos of engagement among disciplines and beyond the academy from the outset of academic careers⁵⁸. These programmes have a role to play in creating alternative academic spaces and a sense of belonging. Transdisciplinarity can create alternative norms, implicit values and institutions. The elements of such an academic orientation include a common repertoire of practices, funding arrangements, publication outlets, a choice of conferences to attend and networks to join⁵⁸. However, such an alternative space can impact on the traditional models of career progression^{15,59}. Reviews of such approaches found that students felt that they lacked a solid disciplinary base⁵⁸ and were concerned about perceptions of what constituted good quality science⁶⁰. There are challenges for transdisciplinary PhD's and postdoctoral researchers seeking a more permanent foothold in traditional academic institutions where appointment of lecturers is based on publications in high impact factor mainstream journals. However, for those seeking to leave academia, the experience of transdisciplinary research and the links to practice supported their transitions into positions outside of academia⁵⁸. This raises the question of whether transdisciplinary training should focus on building the capacity of people to take their place in the academic

world or to encourage people with an understanding of academic research to work in business, civil society or the public sector.

Questions remain concerning the extent to which transdisciplinary research should be a new area for early career researchers, or whether it is better approached by more established academics with a foothold on university career ladders and with existing professional reputations based on embracing publication in mainstream journals. Transdisciplinary research is seen as an academic borderland with academics uncertain whether it is an “in-between space” or a “cross-cutting” space^{58,p518,61}. Those promoting such approaches need to consider whether the transdisciplinary researcher is a new form of researcher, or an excluded non-entity not fitting into the system and structure of academia.

Evaluation of transdisciplinary outcomes and processes

While coordinating and managing transdisciplinary research projects and teams has already been shown to pose particular challenges, the evaluation of transdisciplinary projects has emerged as a further area of complexity. Currently, clear standards are lacking for researchers, funders and programme managers^{62,63}. Here we consider evaluation from the perspective of research funders, who will be concerned with the return on investment of public funds; research team members, who will be concerned with the quality of the research and the impact of the project on their own professional roles; and research users, who will be concerned that the outputs are relevant⁶⁴.

Initial evaluation by funders occurs at the proposal stage, and determines whether funding is granted. Transdisciplinary proposals bring together multiple disciplines, fields and professions, working among different organisational and institutional settings⁶³. Evaluation of such proposals challenges individual reviewers who may hold only one area of expertise pertinent to projects¹⁵. Furthermore, transdisciplinary project proposals incorporate flexibility in terms of goals and participants, and anticipate that methods will emerge through the research process, which makes evaluation all the more challenging⁶⁵. Acknowledgement of the process of building collaboration, and recognition of the existence of functioning research teams is important, and may be a further factor to be acknowledged by those commissioning research and evaluating proposals, although this should not be at the expense of encouraging new configurations of perspectives and disciplines⁴⁰. Evaluation of projects either during the process or on completion raises different challenges. Conventional evaluation measures include achievement of outcomes, measures of new knowledge and scientific data (publications) and impact on society (achievement of initial problem-oriented goal). Funders

will also be concerned that projects come to completion, and are on budget. Evaluation of transdisciplinary research needs to reflect the objectives of the different actors involved and therefore aims to produce outputs that are scientifically valid, salient, socially robust and legitimate for all^{36,38,66}.

The imbalances in power relations found within transdisciplinary collaborations can also be found in the decision making process regarding evaluations. Evaluating impact of projects is contingent on the values, expectations, culture, language and rewards structures of the members of the research team, the funders and the end users^{63,64}. Each actor will therefore be able to have different objectives but there may be different degrees of influence over what is being evaluated. The evaluation process is still a tool to exert power as certain parties can define what is evaluated and what is measured. Some suggest projects should be protected against the conventional accountability mechanisms of evaluation, with calls for evaluation that focusses on a range of indicators decided by participants and the deliberative aspects of the project⁶. This is a challenge when evaluations are commissioned by funders who may have their own objectives. The evaluation process is therefore not without tension as the different logics and values of the participants of transdisciplinary projects will have different interpretations of what is good science, what is salient to practitioners and what is good for society or the wider environment. Funders may have a dominant voice in this process with participants also able to shape some of the evaluation criteria. The voice of citizens and wider environmental goals may only be mediated through NGOs, public sector bodies and individual researchers involved in projects.

Transdisciplinary research projects frequently have wider objectives regarding the building of capacity for future collaboration and learning. Success can be determined based on the process as well as the outcomes⁶ with attention given to softer criteria concerning impacts on the knowledge creation process and the individuals involved^{63,65}. From the perspective of the project team, the project process must be seen to be transparent, equitable, effective, congenial and inclusive. For example, a survey of 188 participants in transdisciplinary research projects included the impacts on the participant defined as network building, trust in others, understanding of others, and community identity⁶⁵. Evaluations of transdisciplinary research in medical fields included the impact on careers (particularly changes in disciplinary focus), the level of integration of different disciplinary knowledge and the social interaction among the team members⁶³. However, these transdisciplinary research processes can prove extremely time consuming and costly, and can even put other project goals at risk.

Teams may engage in reflection as well as being evaluated against set criteria⁶⁴. Many projects reflect on the process after the project is completed^{31,66,67,68,69,70}, and some build in a process of reflection and co-learning during the project^{64,68}. Transdisciplinary collaboration has been called a social practice, in which collaborative skills are acquired, and tolerance for challenges of communication and mutual understanding are developed³². These reflective processes enable researchers to learn about the process of collaborative transdisciplinary research, which takes place alongside the specific research goals of the project. Building a transdisciplinary research team is dependent not only on the skills of the team members, but the trust and mutual respect that is developed among them⁴⁰. It can take time for such relationships to develop, and for the team membership to settle. This highlights the importance of ongoing funding for transdisciplinary research; to reap the benefits of established teams rather than sporadic funding where teams disperse¹⁵.

From the perspective of the individual, satisfaction is achieved through alignment of the objectives of the project with those of the home organisation³⁰. This can include the nature of the project goals, and the type of output produced. If the goals of the transdisciplinary project do not align with those of the institution employing the researcher then the process can be seen as additional to the workload, or even counterproductive. On the other hand, if the objectives are aligned, then the work of the project contributes to achieving evaluation criteria in the organisation, and so also career advancement. Larger projects have a negative impact on satisfaction due to problems with communication across wider cognitive distance³⁰ however this same research also noted that high partner commitment enhances satisfaction. Individual learning through the process is also seen as contributing to satisfaction. Willingness to engage in further transdisciplinary research collaboration is a key indicator of satisfaction; however some participants in transdisciplinary research become wary of transdisciplinary research and retreat from further research projects of this nature³⁶.

Towards a transdisciplinary approach.

The strength of transdisciplinary research is that it brings together research teams specifically formulated to address a particular issue. Transdisciplinarity as a research approach requires practices which use the simplest language possible and produce results which are widely understandable⁹. Transdisciplinary processes require an openness to choice of methods to correspond with the specific research problem being addressed and the skills, backgrounds and competencies of the group of people participating. A transdisciplinary methodology is therefore focused on processes of dialogue, collaboration and negotiation, rather than specific data collecting methods. Thus it is not possible to stipulate a research method, however this

review of transdisciplinary collaboration has identified processes which underpin successful collaboration. These are summarised below.

Living with tensions. Transdisciplinary research requires the management of diversity and “tangled agendas”^{71,p442} to work towards achieving a common goal. There is no right methodology, but each project brings together suitable methodologies arising from the collaborative team. Transdisciplinary research collaborations potentially give rise to challenging situations, and it is good to be aware of tensions at each stage in process.

Formation of team. Research teams are convened according to the project and to include appropriate stakeholders and skills. The balance between skills needed and the impact of team size on knowledge creation and communication is crucial. Once the project is underway, appropriate language and methods of communication ensure inclusivity and open debate and discussion. The choice of a project leader who is a grounded scholar and reflexive practitioner⁶, with experience in transdisciplinary research can facilitate the process and manage tensions. Boundary spanners⁷² can facilitate the transdisciplinary process by bringing diverse cultures together and supporting communication²⁰.

Negotiation of the research approach. In addition to design and development of scientific methods, the project must also develop methods of engaging all partners. Facilitators and stakeholder workshops can be key to ensuring good communication, managing expectations and ensuring equality among all participants.

Knowledge creation. To avoid the pitfalls of multidisciplinary, multi-stranded approach, transdisciplinary projects ensure integration of all aspects of the research. Managing transdisciplinary projects can be complex and therefore allowing time and space so that there is room to fail and the opportunity to learn from mistakes is helpful. Thus time for co-reflection and social learning should be written into the project⁶. Tangled agendas can result in a range of aspirations from the project, including the implications of the results. Transparent systems of data analysis facilitate clarity and dialogue around the interpretation of results.

Outputs. Final project outputs in transdisciplinary projects aim to have an impact on a wide range of practitioner and academic stakeholders. Negotiation is required at an early stage to ensure outputs satisfy all team members, as well as funders.

Conclusions

Transdisciplinary research is becoming increasingly common, motivated by a range of drivers ranging from the intellectual demands researchers face in dealing with complex interrelated issues at the food, water, energy, and environment nexus, to the demands from funders and society at large for a more relevant research agenda which will have an impact on society. However a transdisciplinary research approach challenges conventional systems of research within academia. The demand to communicate across disciplinary divides, and to synthesise new knowledge from knowledge pools which have previously been enshrined within disciplinary boundaries threatens the fundamental system which organises knowledge within disciplines, and those disciplines themselves. Working with practitioners, lay voices, and the public also challenges fundamental principles of scientific investigation. However bringing transdisciplinary teams together can generate new knowledge, and in particular knowledge relevant to addressing complex problems which integrate multiple disciplines and multiple stakeholders. The balance of team composition and size is seen as crucial, as there appears to be an optimum level of cognitive distance and team size to ensure maximum knowledge generation.

Transdisciplinary research is seen as being harder to achieve than traditional research, both in terms of the breadth of knowledge involved, and the time taken to meet, negotiate, and develop research relationships to engage with transdisciplinary team members. Members of transdisciplinary teams have to learn to accept the different logics and values of other participants and find ways to work together. Power balances among disciplines and among scientists and lay practitioners need to be negotiated. For academic researchers, this is juxtaposed with additional concerns over the quality of the research (once compromises are made) and the rewards arising, in terms of academic publications and promotion along career pathways. While some find it rewarding and stimulating, citing high levels of personal satisfaction others find the challenges off-putting, and return to their disciplinary bases. As governments, and in their turn research funders seek more impact from research, calls for transdisciplinary research will continue. The importance of transdisciplinary research is particularly evident in the challenges of the food, water, energy, and environment nexus where problems have been clearly framed as interlinking and interdependent, impacting on society, technology and the economy⁷³. There are therefore a set of challenges that face the transdisciplinary agenda: Firstly, is there a need for transdisciplinary training programmes at post graduate level support this type of research, although there are also real concerns about how such graduates are placed to access careers in what is still a very discipline-focussed academic career structure. Secondly, there is a need for a cadre of researchers with experience

of transdisciplinary research who are able to commission research programmes, review proposals, and evaluate research. Thirdly, there needs to be further exploration and debate on how best to evaluate transdisciplinary research, and differentiation between the evaluation of the individual's experience, the management of the project process, and the outputs of the project as a whole. Finally, while much research has reflected on the transdisciplinary process from the perspective of academia, there is as yet less research which presents the voice of other participants although there are some emerging examples^{74,75,76} which include a focus on those whose contribution makes interdisciplinary research transdisciplinary, such as business, civil society, policy makers, and the wider public. While these actors make valuable contributions to the transdisciplinary research projects, their views should also be captured so they are able to make valuable contributions to the wider debates about the benefits, pitfalls, and future directions of transdisciplinary research.

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