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Abstract

Ever closer to the brink of global environmental collapse, it is vital that we work collaboratively and collectively as global, national, and local communities to design multi-scale change. Protecting future generations and reversing (or substantively slowing) the current trends requires rapid sustainable progress at the required scale. It is more urgent than ever we understand and more fully realise the power of transdisciplinary (Td) research to support sustainable practice. A defining factor of Td is the focus on collaboration and co-design and the extent that participation and attention to local context is integral to the knowledge building. Specifically there is greater ability for community knowledge, values and aspirations to influence and shape research inquiries to effect meaningful change in real world decision-making and outcomes. Business as usual (BAU) approaches that perpetuate unequal knowledge sharing and dismiss other forms of knowledge beyond traditional science no longer suffice. Transdisciplinary approaches seek to achieve and support sustainable change, but the extent of transformation required to meet ecological protection and regenerative sustainability needs very different operating models for knowing and doing science than the limited traditions of positivist science. However, these powerful defaults and operating paradigms are more deeply ingrained than we might realise, and hence challenges persist. This paper illustrates how Td science differs from typical research paradigms, particularly in terms of the underlying epistemology, the focus on knowledge/power, attention to boundaries and scope, and the degree to which local knowledge, context and community participation underpin the research process. Active conversations are required to better identify and overcome fundamental challenges for science and Td research approaches to support the necessary transformational change. Importantly, we suggest that Indigenous partnerships, knowledge and values are vital in achieving the potential of transdisciplinary research to provide transformational interventions to address complex social and environmental issues like pollution.

Key Points: The challenges in doing Td research are more deeply engrained than we think Indigenous partnerships and knowledge combined with Td approaches help

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better overcome these challenges Inclusion of different knowledges, values and viewpoints is essential to ensuring that wicked problems like waste and pollution are more fully understood, and therefore more effectively tackled.

Introduction

Transdisciplinary (or Td) approaches to research have considerable promise for providing alternative perspectives on the “wicked problems” that are characteristic of ongoing environmental destruction and climate change (Brandt et al., 2013; Lönngren & Van Poeck, 2021). Yet, while Td and related participatory approaches are gaining increasing currency in the environmental and public health sciences (Cornell et al., 2013; Hoffmann, Thompson Klein, & Pohl, 2019; Jahn, Bergmann, & Keil, 2012; Jahn & Keil, 2015; Lang et al., 2012; Lang, Wiek, & von Wehrden, 2017; Maasen & Lieven, 2006; Pohl, 2008; Polk, 2015), the attributes and qualities of the approach are sometimes poorly understood by those using and applying them in research.

In the absence of a clear consensus and definition, most studies recognise that Td approaches require the decentralisation of power and acknowledgement that community involvement is central to guiding the research approach, as well as framing questions, methods and outputs of the inquiry.

Td is effective because it is grounded in collaborative knowledge-building. Transdisciplinary research offers more effective approaches to issues like chemical pollution, and related complex and seemingly intractable problems driven by current modes of production and societal dependence on environmentally destructive chemicals, plastics and fossil fuels. Specifically, Td approaches offer solutions for achieving meaningful change on critical environmental issues like pollution and climate change where progress to change trajectories of environmental degradation have been limited. Td approaches often are deeply challenging for scientists, especially because they involve consideration of other knowledges not typically included in the standard scientific method and approaches (e.g., Indigenous knowledge, local place-based knowledge and community lived experience).

What is Td?

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The metaphor “standing on the shoulders of giants” has described the progress of science, but as *Nature* noted recently, “the future lies in standing on the shoulders of crowds” (Editorial, *Nature* 594, 2021). Collaboration and working closely with affected communities is essential. This type of approach to knowledge production has a better chance “of genuinely making the world a better place, because what emerges will be more suitable for take-up” (Editorial, *Nature* 562, 2018). Defining characteristics of transdisciplinary research approaches are firstly the extent to which community values and local knowledge anchor the co-production of knowledge, and secondly the extent to which participatory action research (PAR) processes give those involved the opportunity to shape and define the formulation of the research, including defining the research questions and determining modes of inquiry that local actors will endorse as supportive of change and action.

Transdisciplinary (Td) research does not have a single origin but has developed in parallel across a number of disciplines and contexts, and there is no universally employed definition. Td is commonly understood to focus on knowledge synthesis; a useful review (Jahn et al., 2012) notes the following essential elements:

1. it addresses complex problems with a social dimension;
2. it involves a high degree of collaboration across research disciplines; and
3. it involves a high degree of collaboration between academics and non-academics, and between academic and other types of knowledge systems (e.g., Indigenous).

Non-academics (or non-scientists) who are collaborators are usually members of the communities that are impacted by and/or contributors to the problem being studied, and/or may be impacted by the research and/or its potential solutions.

Td is different to interdisciplinary or multi-disciplinary approaches in the search for knowledge synthesis and holism. Integration has been core to the evolving Td, multi and interdisciplinary literatures (Hoffmann, Pohl, & Hering, 2017; Hoffmann, Weber, & Mitchell, 2022; Klenk & Meehan, 2015; Kliskey et al., 2017; Pohl, Klein, Hoffmann, Mitchell, & Fam, 2021), however we depart from this specific term in recognition of its cultural historical use and colonial connotations. For example, for Māori the Indigenous people of Aotearoa, N.Z.

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and other Indigenous peoples the term integration can be associated with historic trauma and state practices for the assimilation and oppression of language and culture. Integration can also convey intent to subsume or appropriate language and culture, and therefore terms describing synthesis, co-production and the 'interface' of western and Indigenous knowledges are preferred, and we emphasise instead a central axiom of Td as co-production and an 'interface' of relational knowledge building (Norström et al., 2020).

Whilst scientists and researchers increasingly look to Td as a framework for better research, as yet we tend not to progress easily beyond the multi-, and interdisciplinary approaches. The spaces for building transformational change based on more holistic and relational understandings are lagging.

Participatory and emancipatory methods from systems thinking and participatory action research (PAR) to involve and empower stakeholders and communities are similar to those underpinning Td research (Fals Borda, 2001; Flood & Romm, 1996; Midgley, 2000). For example, public participation logics and the IAP2 participation spectrum - inform, consult, involve, collaborate, empower - are related approaches (Bobbio, 2019) that align with Td collaboration and empowerment.

Importantly, Td research requires a deep commitment to knowledge equity and for social and cultural dimensions. The potential of Td research is in the processes of engagement where the outputs are generated by co-design with participant communities. The value and power of Td research is to produce emergent knowledge for attaining fuller, broader and deeper understandings of topics where worldviews, boundary judgements and taken for granted assumptions must be questioned and challenged for transformative change to occur (Djenontin & Meadow, 2018). The intent and focus of the knowledge building in Td is collaborative, dialogical, deliberative and evolving. Td requires long-term partnerships and relationships that sometimes stretch beyond the more narrowly defined boundaries of typical science projects. The outputs generated are not easy to calculate at the beginning of the project, and they endure beyond the conclusion of it (Brown, Harris, & Russell, 2010;

Duncan, Robson-Williams, & Fam, 2020; Duncan et al., 2018; Fam, Palmer, Riedy, & Mitchell, 2017).

The collaborative aspect is what makes Td particularly suitable for researching “wicked problems,” complex intersecting issues where there is no easy solution, where viewpoints and values are in conflict, and where those attempting to solve various problems are also those causing them (Head, 2008; Lönngren & Van Poeck, 2021). The major environmental problems that we face—for example climate change, waste, plastics and chemical pollution, water quality degradation, species extinction—are all examples of “wicked problems” that are symptomatic of socio-political factors including unsustainable agri-industrial mono-systems (Liboiron, 2021). These types of complex interlocking issues sit beyond typical science research design, and are not amenable to being adequately understood or resolved by traditional science (Bunders, Bunders, & Zweekhorst, 2015; Latour & Woolgar, 2013; Wynne, 2011).

Transformational change

Td’s effectiveness in helping resolve complex environmental problems lies in the way it directly considers and supports power sharing and ethics of inclusion for the perspectives of communities to shape and influence the problem definition and enquiry. To be transformative, and therefore effective in generating insights and potential solutions, research must be better attuned to human and social factors including issues of equity; the distribution of risks, costs and benefits within a given context and topic (Apitz, 2018, 2021; Royer, 2022). The transformational agenda espoused in Td approaches is different to other models of science and research engagement such as linear extension approaches that seek to market and facilitate uptake by non-experts of specific technological solutions developed by experts. Td promotes far stronger “two way” mutual learning relationships than do earlier forms of public participation that aimed, at best, to capture viewpoints from “informed” publics on new technologies (Delgado, Lein Kjølberg, & Wickson, 2011; McNeil, 2013; Wynne, 2003), and at worst, simply to foster acceptance of particular scientific and technological trajectories (Raman & Mohr, 2014). In either case the typical settings for science research offer scant

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opportunities for participants to have meaningful influence on research design and decision-making, let alone produce knowledge that can more adequately address wicked problems and the seemingly intractable, legacy, cumulative and emerging risks and effects being observed in ecotoxicological studies of environmental pollution.

Co-production of knowledge

Polk notes, the “closeness to practice-based and situated experience and real-life problem contexts” (2015, 110) are essential to “the ability of the research to create socially relevant and scientifically reliable knowledge” (Polk, 2015, 111). Co-production of knowledge is essential to better understanding and reworking wicked problems (Bojovic et al., 2021; Gerlak et al., 2023; Klenk, Fiume, Meehan, & Gibbes, 2017; Moser, 2016; Norström et al., 2020; Turnhout, Metze, Wyborn, Klenk, & Louder, 2020), and Td research highlights good approaches including methods for co-production. The span and stretch of knowledge required for solving wicked problems can only be developed collectively and in relation to the many other actors and multiple viewpoints involved (Nature 2021). Yet numerous commentators (Bojovic et al., 2021; Harris & Lyon, 2013; Kliskey et al., 2017; Muller, Tjallingii, & Canters, 2005) recognise that considerable research is needed to better understand the design of institutional arrangements and sets of conditions necessary to support and strengthen the practice of authentic Td approaches in research to orient “real world” change (Brown et al., 2010; Fam et al., 2017; Raman & Mohr, 2014; Rinaldi, 2023).

Challenges in practice

Across the Td approaches and related commentaries and literature (Jahn et al., 2012; Polk, 2015) there is agreement that significant challenges remain for promises of Td research to be fully realised. Many challenges noted (Aslin & Blackstock, 2010; Brandt et al., 2013; MacMynowski, 2007; Pearce, 2010; Russell, Wickson, & Carew, 2008; Scholz & Steiner, 2015) continue to be ingrained and overlooked in the philosophical and institutional arrangements that underlie traditional approaches to science. Toomey observes that “selective uptake can reproduce disciplinary hierarchies” whereby the social science “approaches emphasising human diversity and social inequality are given little room amidst the more

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dominant perspectives from the physical sciences and mainstream economics” (Toomey, Markusson, Adams, & Brockett, 2015). These factors underpin concerns from the social sciences that whilst Td approaches to research are gaining popularity, there is danger of these being misrepresented or not implemented in an effective manner to achieve the outcomes sought and claimed.

Epistemological challenges

Of the numerous challenges identified in the application of Td approaches, the most significant are the ontological (involving what we know or what is agreed to exist) and epistemological (involving how we know or prove this). Underlying worldviews and knowledge power dynamics (Djenontin & Meadow, 2018; Meadows, 2008; Norström et al., 2020; Serrao-Neumann et al., 2021; Turnhout et al., 2020) present barriers to openness and acceptance of other forms of knowing beyond the traditional methods associated with science. Researchers must acknowledge and value perspectives and understandings that exist outside and independent of the traditional knowledge-validation practices of positivist science. Yet the commitment to the primacy of science-derived knowledge is strong, not only within the practice of scientific research, but also in the mental models utilised by individuals, teams and institutions that produce and use science, and the ways science is taught in schools and universities.

Roux et al. (2017) identify “three wicked pitfalls” that hinder Td’s orientation to “mutual learning” for wicked problems. These are 1) the assumed superiority of science; 2) a preoccupation with empirical and ‘hard’ data; and 3) the “fatal attraction” of simple solutions to wicked problems (Roux, Nel, Cundill, O’Farrell, & Fabricius 2017; 723). A misguided belief in the power of science to effect the necessary changes and overreliance on hard data frequently lead to over-simplification of problems, ignorance about the inherent complexity of social and environmental connections, and therefore under-whelming and ineffectual science-based solutions.

At present, there are limited understandings or guidance from biophysical science funders, managers and leaders about what a Td approach entails, what needs to be in place to make it

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rigorous, and how it is distinct from previous forms of community engagement in science. Furthermore, the use of Td approaches is also hindered by both the social and biophysical science-oriented literatures on Td research continuing to be disconnected complex, esoteric and difficult to comprehend. The social and biophysical science literatures that could inform practice continue to exist largely “at the brink” of each other and “running in parallel with stunningly little crossover” (MacMynowski, 2007). More recent Td reviews (Bernstein, 2015; Brandt et al., 2013; Hadorn et al., 2008; Hoffmann et al., 2019; Knapp, Reid, Fernández-Giménez, Klein, & Galvin, 2019; Lawrence, Williams, Nanz, & Renn, 2022; Lorenz, 2022; Pohl et al., 2021; Pohl, 2005; Polk, 2015; Scholz & Steiner, 2015; Steger et al., 2021; Strand et al., 2022; Wuelser et al., 2021) shows continued separate developments and a plethora of descriptions and orientations to knowledge synthesis within the various Td related approaches. This can be overwhelming for academic readers as well as policy and community researchers who might wish to explore the literature to utilise Td approaches more fully in local sustainability projects.

Institutional challenges

There is poor institutional understanding and support for research that externalises control beyond the scientists funded and therefore few Td research agendas that can genuinely span disciplinary and organisational boundaries and be adaptive and responsive to community concerns. For example, research questions generated by community partners often seek solutions across research domains and across research organisations that are not easy to address when such inquiries; a) require a stretch beyond the specific skill sets of the scientific research team and the core research organisation being funded in the project; or b) a political willingness to cooperate between organisations existing in a competitive contested funding environment. This environment drives research organisations to strive to maximise their share of the funding pie and can obstruct organisations shifting resources toward areas now designated as more relevant by community collaborators. Researchers working within such organisations are not incentivised to commit to projects that could result in such a resource shift away from their own disciplines, a pattern that gets in the way of Td approaches.

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Funding mechanisms and research organisations are not generally keen to direct resources to community participants. Yet Td approaches require a significant investment of time as well as sharing of knowledge by community participants, which is enabled by compensating participants for their time and expertise. Additionally, those - typically social scientists - with knowledge of how Td processes might be organised and how to avoid common pitfalls must be well-integrated into the project and sufficiently resourced. Scientists need to be comfortable with the idea that a significant portion of the overall funding may be needed for these aspects of the research which might be viewed by some as ‘non-scientific’ and fundamentally, not necessarily research *per se*. It is good that biophysical science increasingly recognises the importance of social science, people and popular culture in mobilising change, but actually achieving the extent of transformational change promised in Td research approaches requires far more comprehensive and meaningful models of engagement and knowledge building than the spaces allocated for social science currently support. Thus system-wide institutional change is required.

Priorities associated with Td approaches may not align with typical criteria for advancement in science. Td processes are not efficient in terms of generating maximum publishable results in the shortest possible time. There is a trade-off between the genuine effectiveness of the process—its ability to have real-world impacts—and this kind of traditional efficiency as measured in academic metrics. Scientific institutions need to incorporate an appreciation of such trade-offs and distinctions in their evaluative processes. Yet currently in most of our research and funding institutions, patterns persist where the outputs, impact and benefits resulting from the co-production of knowledge (Djenontin & Meadow, 2018) are often viewed as intangible, marginal or secondary to the core science, rather than as central achievements and orientations, and in some instances, a critical enabler to the science research being conducted in the first instance.

The potential of Td approaches to foster transformation is dependent upon individual goodwill, skill and leadership. The potential is hindered by institutional structures and processes designed for business-as-usual science in which transformative change continues to

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be viewed as peripheral to the core fieldwork, laboratory science and journal paper outputs. Thus success is patchy and in pockets where individual champions, long-standing relationships, partnerships and team collaborations are able to navigate the conventions of the science funding and reporting mechanisms that otherwise hinder the relational and transformative potential offered in Td research.

Whilst these entwined and deeply engrained epistemological and institutional challenges persist, the default models continue to privilege the primacy of Western science and business as usual settings in which much environmental science is performed. In these settings, environmental science research is emmeshed with, and often in service of, the goals of economic growth (Liboiron, 2016, 2021). Economic rationalism (Liboiron, 2021; Pusey, 2018) shapes much science funding, research and development (Berman, 2011; Owen, Macnaghten, & Stilgoe, 2020). For example, much of the environmental resource management, ecological assessment and monitoring that underpins risk management approaches used internationally have locked in fixed time periods for continued pollutions and permitted discharges. These existing permissions enable industry and economic growth prerogatives for continued environmental resource use, pollution or degradation, but with limited ability to impel reduction or elimination of the activities or pollution. The belief that science can be objective, universal, and value-free continues to be deeply embedded among scientists and the current science policy models as outlined in a recent review of NZ science funding system (Kukutai et al., 2021). Yet philosophy of science (Wynne, 2003) and science policy studies (Gillette, Inkpen, & DesRoches, 2021; Jasanoff & Kim, 2015; Miller & Wyborn, 2020; Pielke Jr, 2007; Wynne, 2003) show that science is by no means free of values or politics, and nor should it be claimed as such. Similarly, (Betini, Avgar, & Fryxell, 2017) argue that the potential of cognitive bias relating to decision-making in science and the lack of widespread adoption of techniques to overcome intellectual and practical barriers continue to hamper improvements to scientific investigations.

The defaults are not historical or dormant and continue to be expressed in recent conflicts over what ought to count as valid knowledge, such as those expressed in a NZ Listener article

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(Corballis, Rata, & Nola, 2020) on mātauranga Māori Indigenous knowledge being a threat to science (Stewart, 2021a, 2021b). These include debates about the degree to which reliability and rigor including objectivity, relevance, and reproducibility should be upheld as universal criteria for validity (Mebane et al., 2019; Parkhurst, 2017). Depending on how these concepts and criteria are interpreted, Td approaches will continue to struggle to gain a good foothold. Knowledge that is generalisable or comparable continues to be more highly valued in science than knowledge that is highly contextual, culturally specific or entangled in the local relationships in which it is produced. This means that, for example, knowledge accumulated over generations of observation in a particular place may not meet all positivist scientific-methodological criteria for valid knowledge production, yet exclusion of such knowledge from collaborations to address wicked environmental problems is short-sighted and serves to alienate relevant communities.

Furthermore, positivist criteria for valid knowledge make it easy to continue overlooking the extent to which numerous taken for granted western assumptions and worldviews reproduce the current limitations of the knowledge-seeking endeavour. Science practiced in a culture or institutional setting that understands the environment to be an economic resource (or an entity that provides “services” that can be quantified in monetary terms) will offer a different focus from knowledge produced through Indigenous cultural worldviews that see the environment as ancestral entities and intrinsic qualities to be protected. For the former, the research question “what is the highest level of contamination by x chemical that does not produce measurable impacts on human health?” makes sense. For the latter, such a worldview where humans assume the right to pollute the environment to a level that does not affect human and ecological health is the antithesis of Indigenous values to protect and not contaminate collectively valued ecological environments (Ataria et al., 2023; Beausoleil, Munkittrick, Dubé, & Wyatt, 2022; Boelens et al., 2023; Borrelle, Provencher, & Ngata, 2021; Fernández-Llamazares et al., 2020; Liboiron, 2021). Concepts of pollution as permitted discharges and thresholds are not compatible with the fundamental precepts of being a good ancestor, Indigenous descendant and guardianship of the natural environment. Furthermore

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personification of the environment, a common feature of Indigenous knowledge, creates expectations and obligations to the environment that are akin to the expectations and obligations of care and protection for family members (Boelens et al., 2023; Brierley et al., 2019).

Given these deep differences in worldview, the success of Td approaches depend also on an acceptance of pluralism (Lorenz, 2022; Midgley, 2000; Norström et al., 2020) and an emphasises on co-existence and recognition of difference, rather than only striving for harmony, consensus and resolution of conflict and difference (Nicole Klenk, 2018; N. Klenk & Meehan, 2015). Whilst conflict is not new to science—indeed, one could argue that disagreement is essential to scientific progress and is the supposed motor of Kuhnian scientific revolutions (Friedman, 2002)—such conflict is played out against a background of shared assumptions, including assumptions about the value of science vis-à-vis other forms of knowledge. For Td approaches to be successful, more fundamental differences must be respected and not supposedly resolved simply by subsuming or assuming that only scientific methods can produce valid results. More explicit attention is needed to disrupt these deeply held worldviews and assumptions, and to actively address the knowledge/power dynamics and imbalances (Apitz, 2018; Royer, 2022) that can remain unaddressed in typical science research design.

Disrupting the status quo

Research approaches that centre Indigenous values and aspirations help important questions of what assumptions exist in the worldviews and pre-set constrained definitions of the topic being studied. Critical reflection on boundaries, worldviews, pluralism and multiple ways of seeing are features of systems thinking (Foote, Midgley, Ahuriri-Driscoll, Hepi, & Earl-Goulet, 2020; Ison & Straw, 2020; Meadows, 2008; Midgley, 2000). These important epistemological challenges are tackled in contemporary Indigenous knowledge (IK) frameworks that emphasise the importance of ‘two eyed seeing’ (Bartlett, Marshall, & Marshall, 2012) and ‘braided rivers’ (Macfarlane & Macfarlane, 2018). Such approaches help disrupt taken for granted dominant worldviews and alternately highlight pluralism, difference

and multiple ways seeing as central to the research methods and inquiry. The questions raised from IK partnerships help disrupt taken for granted interpretations of facts, including explicit discussion of what makes valid knowledge and what data is counted or discounted in decisions. Importantly the frameworks articulated in the resurgent Indigenous theories of knowledge give valuable pointers for the conversations and functional mechanisms required for establishing respectful and equal partnerships for knowledge sharing (Allen, Ataria, Apgar, Harmsworth, & Tremblay, 2009; Brierley et al., 2019; Broughton et al., 2015; Colbourne, Moroz, Hall, Lendsay, & Anderson, 2020; David-Chavez & Gavin, 2018; Hikuroa, 2017; Moewaka Barnes, Harmsworth, Tipa, Henwood, & McCreanor, 2021; Parsons, Fisher, & Nalau, 2016; Parsons, Nalau, & Fisher, 2017; Smith, 2021).

Respect for diverse viewpoints is not simply a “nice to have” within Td approaches, but combined IK and Td approaches make this essential to the integrity and success of the research. Criteria for good use of science as evidence in policy have been expanded beyond scientific-methodological criteria to include a degree of social robustness: that is, the evidence gathered should be considered appropriate to the context, and there should be feedback and accountability back to citizens, as well as processes for transparency and debate (Apitz, 2018; Backhaus, Brooks, & Kapustka, 2010; Goven, Langer, Baker, Ataria, & Leckie, 2015; Maasen & Lieven, 2006; Nowotny, Scott, & Gibbons, 2003). In contemporary Indigenous Māori scholarship on science (Kukutai et al., 2021), evidence-informed rather than evidence-based approaches to science and policy are demanded for rigor and robustness. In these approaches, research must be ethical, critical, adaptive and culturally informed, and conducted dialogically and transparently so that communities can deliberate and have confidence in the evidence and facts presented.

IK offers critical scholarship in literature that help decolonise (Liboiron, 2021; Smith, 2021) and actively recognise and disrupt the philosophies and risk management practices built on defining the dichotomy of nature and humans. Separations of human technology and nature have been long institutionalised and are at the root of our current waste and environmental pollution problems including fuelling free-market capitalism and impacts of widening social

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inequities. The disconnection of waste in the current modes of consumption and production cannot continue as drivers of practice (Shove, 2003; Shove & Warde, 2002). Global capitalist structures have long driven these perverse activities, and unless these are held to account then any transformative change is likely to be minimal or have local impact.

Combined IK and Td approaches can therefore strengthen the potential of research to be accountable to a broader range of social and environmental criteria and considerations (for example see Text Box). There is growing work evidencing how combining Indigenous knowledge (IK) in Td styled Kaupapa Māori aligned approaches contribute to more effective modelling and deeper understandings of interconnecting social and environmental problems (Allen et al., 2009; Foote et al., 2020; Holker et al., 2010; Lundquist et al., 2016; Moewaka Barnes et al., 2021; Moller, Lyver, et al., 2009). Working in partnership in respectful and equitable ways helps challenge taken for granted assumptions and extractive tendencies in research and wider BAU practices.

Crucially IK helps anchor and strengthen points of connection with, and care of the environment, and each other, as can be seen in recent research to reduce environmental pollution, microplastics and contaminants of emerging concern. Research conducted as part of the Managing the Risk of Organic Contaminants (EOCs) and Aotearoa Impacts and Mitigation of Microplastics (AIM2) projects shows how partnership based IK centred approaches are invaluable in the design and implementation of research to better support pro-environmental action.

Text box: Case study example of Td and IK combined

Td and IK combined give greater opportunities to locate broader multi-pronged initiatives with Indigenous processes and values emphasising relational capabilities and capacities for transformational change. Indigenous worldviews and knowledge systems are vital to help Td and related participatory methods to surface, question, and more fully consider broader and underlying socioeconomic and social-political and cultural-historical aspects in research (Borrelle et al., 2021; Liboiron, 2021; Liboiron, Tironi, & Calvillo, 2018). Adequate resourcing is crucial. Communities must be engaged in questioning and shaping the direction

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of research, rather than being data points, hypothetical or peripheral end points, or audiences for result dissemination. Thus, Indigenous and community partnerships and participation time and expert knowledge must also be appropriately recognised and resourced. People and processes must be intrinsic to the problem definition and design of potential solutions, particularly for wicked problems. Research projects need ethical commitments as well as resourcing to correct inequity and imbalance resulting from underlying historical knowledge power dynamics. Indigenous partnership based models for Td research help locate community centred ethical commitments early on in the research design.

Td approaches are more effective when power inequalities among participants can be identified and addressed. Implicit assumptions of superiority (or inferiority) can undermine the potential to collectively build useful knowledge. Collective knowledge-building occurs in trusted long-term relationships (Allen et al., 2009; Foote et al., 2020; Goven et al., 2015). Relinquishing a position and attitude of control is necessary for such relationships to develop.

Reflexivity and mutual learning

Two way mutual learning is a key goal of Td approaches. Individual and team reflexivity promotes genuine inclusivity that can effectively address power differentials and knowledge/power dynamics. A stance of humbleness and mutual learning is essential to address these kinds of problems and ensure co-learning by all involved. Co-production of knowledge requires a departure from what social scientists would call a “shield of value neutrality” (Lahsen & Turnhout, 2021) where the authority of science as being somehow value free remains unquestioned.

The degree to which all parties, including researchers and policy makers, are part of the problem being studied is a defining attribute of ‘wicked problems’. This compels that the transformations sought be tested and developed in Td orientations for open, inclusive and reflexive research (Brown et al., 2010).

Successful collaboration across markedly different individual “values, priorities, worldviews, expertise, and knowledge” requires the practice of reflexivity (Polk, 2015, 114). Reflexivity is important for co-production of knowledge (Tress, Tress, & Fry, 2005). Reflexivity is a

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process of self-scrutiny: identifying and examining one's own values, priorities, worldviews, expertise, and knowledge, the assumptions which one has about their status in relation to others, and how that might affect the collaboration. Individual and team processes for fostering greater reflexivity are necessary for mutual learning to occur. In the social disciplines, some describe Td approaches as needing different 'ways of being' (Nicolescu, 1999; Rigolot, 2020). This parallels calls for greater attention to context, location, positionality and different ways of knowing from IK (Christie, 2006; Ngata & Liboiron, 2021; Roué, Nakashima, & Krupnik, 2022; Smith, 2021) and traditional ecological knowledge (TEK) (Berkes, 2009; Moller, Kitson, & Downs, 2009). Being able to locate oneself inside or in relation to a given topic or issue, and not view research problems as outside oneself are important steps that tend not to fit comfortably in traditional positivist science approaches.

NZ research shows that techniques developed in Indigenous partnerships and co-design that include locating research planning in local places and spaces of Indigenous control (Goven et al., 2015; Smith, 2021), can prompt scientists to appreciate and defer to different forms of expertise as they experience unfamiliar protocols, and physical and relational settings that they do not understand or control. These techniques support subtle changes resulting in scientists being outside of their own comfort zones and therefore are likely to make them more open to and willing to be reliant upon others' expertise.

Supporting transformative change

Substantive and transformational shifts are urgently required in order to halt and reverse the advancing destruction of our fragile and interlinked global ecological environments (Apitz, 2008, 2021; Backhaus et al., 2010; Claudet et al., 2020; Hajer et al., 2015; Oen, 2019; Rockström et al., 2009). Entwined epistemological and institutional challenges make it especially difficult for Td research to meaningfully shift our continued trajectories of cumulative pollution, climate change and habitat destruction. As shown in the case study example, Td and IK partnership approaches offer greater possibilities for environmental and social connections to better locate complex and wicked problems and navigate transformational change beyond the BAU defaults of research.

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Co-production can be a challenging process, but it leads to better research in two senses: both technically, because it must take account of more contextual factors and dynamics, and because it is more ethical and equitable and more likely to lead to greater and wider impacts. Combined IK and Td approaches are more powerful in disrupting BAU by calling for a thorough reappraisal of the epistemological underpinnings of knowledge. Importantly Indigenous partnership based Td approaches are explicit in the focus on ethics, equity and aspirational goals for transformative change. This brings greater scrutiny of institutional factors where new processes and structures for science leadership, funding and management are required to better support co-production of meaningful knowledge to address continued environmental degradation.

Td approaches call for a direct focus on ethics where attention to social participation, justice and inequality are intrinsic to the research design, organisation and delivery (Apitz, 2021; Bunders et al., 2015; Ludwig & Boogaard, 2021; Manuel-Navarrete, Buzinde, & Swanson, 2021; Pineo et al., 2021; Pohl, Krütli, & Stauffacher, 2017; Reed et al., 2023; West & Schill, 2022; Zonta et al., 2023). The social sciences are not a mere extension or “add on” (Canning, Hird, & Smith, 2010; Fam et al., 2017) to the biophysical work, but rather a commitment at the inception of the project that must be reflected in different organisational structures, processes and the leadership of research. We need deeper and wider reflection of how emmeshed our models, theories and worldviews are to the continued business as usual science practices that implicitly help perpetuate the status quo and legacy of unlimited growth, industrialism and capitalism. We need more rapid shifts to recognise the value of different knowledge and value systems that propel a look beyond BAU and acceptable limits of pollution. IK especially asks that we fundamentally rework our relationships, connections and valuing of our environment and each other. IK implores also that we value our precious and limited planetary resources and shared global environment with respect.

Conclusion

This paper advocates that in many geographic regions, Indigenous partnerships and knowledge are critical and vital for the design of effective transformative change and

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improved environmental and sustainable outcomes being sought through Td research. Crucially, the critical insights and reflections generated in dialogue within Indigenous partnerships can help more effectively overcome the deeply ingrained epistemological challenges that continue to impede the transformative power of Td approaches in environmental science. If we do not strengthen the deeper work and honest reflection on knowledge, power and privilege, the fundamental epistemological challenges will persist and the application of Td research will continue as piecemeal and partial at best.

Globally, we are at a crucial time in our human history that requires us to switch gears very quickly to adapt and change. Collaboration across communities, cultural institutions and different bodies of knowledge has considerable potential to redesign to eliminate significant redundancy and inequitable structures, and accelerate opportunities for transformational change (Apitz, 2018, 2021; Backhaus & Slunge, 2021; Barth, Jiménez-Aceituno, Lam, Bürgener, & Lang, 2023; Kapustka, McCormick, & Stahl, 2013). Td approaches together with IK are needed if science and policies for environmental management are to be effective. Inclusion of different knowledges, values and viewpoints is essential to ensuring that wicked problems like waste and pollution are more fully understood, and therefore more effectively tackled. This paper concludes that IK and Td combined approaches can better create the necessary conditions for reflexivity and mutual learning which in turn lead to the co-production of contextually relevant, useful and sometimes disruptive transformative knowledge that is more appropriate to the complex sociocultural, historical and political dynamics of the cumulative environmental crises we confront.

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Text Box: Case study example of Td and IK combined

Te Hau o Te Whau (the essence of the Whau) ki te rohe o Te Kawerau ā Maki

Recent work in the Whau River catchment, West Auckland, Aotearoa New Zealand, using co-design, community and Indigenous partnership approaches has revealed how the combination of Td and IK invited greater social environmental connection and action. Collaborative processes broadened local awareness of the cultural histories of the area and connections to the waterways, and enhanced community ‘capacity to act’ to care for the water. The science data was actively questioned with the value of the research determined in regular dialogue for the information to enhance local community capacities to improve water quality.

Moving from a BAU focus with science primarily focused on measuring the presence and impacts of contaminants in local aquatic environments, the Td Indigenous knowledge collaborations strengthened the focus on how the contaminants entered the waterways, catalysed attention on the journey from ‘macro to micro’, and emphasised relational connected capacities for urban action. Cultural meaning, connection and restoration of the spirit and essence of the waterways became more centred in the research and wider community collaborations. Actions included more frequent organised streamside litter clean ups (and appreciation of their value), attention to brands and types of litter, engagement with schools and businesses, native plantings, and better connectedness across various forum for the research to inform local planning. Crucially IK partnerships prioritised the criticality of environment and people in the conceptualisation, implementation, and communication of the research.