



## The TD Wheel: A heuristic to shape, support and evaluate transdisciplinary research

Anna L. Carew<sup>a,\*</sup>, Fern Wickson<sup>b,1</sup>

<sup>a</sup> Centre for the Advancement of Learning and Teaching, University of Tasmania, Newnham Campus, Locked Bag 1341, Launceston 7250, Tasmania, Australia

<sup>b</sup> GenØk Centre for Biosafety, Forskningsparken i Breivika, P.O. Box 6418, 9294 Tromsø, Norway

### ARTICLE INFO

Article history:

Available online 2 May 2010

### ABSTRACT

Transdisciplinary approaches to research are increasingly touted for the messy social and environmental problems of our time. Such problems transcend disciplinary boundaries, are intertwined with sociopolitical context, and require participation of stakeholders to generate socially acceptable outcomes. A substantial barrier to transdisciplinary (TD) research is devising and applying evaluative criteria or schemas for an approach that is recognized as necessarily tailored, flexible and evolving. This paper addresses the challenge of shaping, supporting and evaluating transdisciplinary research. Firstly, we synthesise the literature on TD research characteristics, highlighting areas of emerging consensus and some implications of these for research design, execution and quality evaluation. Secondly, we present an adaptable heuristic called the TD Wheel (TDW). The TDW is a synthesis of the disparate insights available within the current literature, and is presented as an organizing graphic for TD research. We explain how the TDW has utility at three stages of the research process: shaping (planning and proposing research); supporting (guiding research in-train); and evaluating (planning for evaluation, periodically documenting/checking progress, and reporting on outcomes). The TDW is a provocative graphic geared to help researchers visualize and discuss the elements and process of TD research.

© 2010 Elsevier Ltd. All rights reserved.

### 1. Introduction

Contemporary societies the world over are calling for assistance in solving a range of complicated and pressing social and environmental problems. Examples include: the need to realize sustainable urban development; equitable management of inland waters and catchments; maintenance of biodiversity; the siting of municipal waste facilities; reducing the incidence of childhood obesity; and comprehending and preparing for the challenges of global climate change. In research terms, these types of problems offer a profound challenge because they transcend the traditional disciplinary boundaries that underpin the structure and functioning of many research enterprises. Such problems require researchers to work in ways that breach disciplinary and academic boundaries, and to engage with problems as they manifest in their messy, social and physical contexts [1–6]. Transdisciplinary (TD) research is an emergent approach that is increasingly recommended for those researchers seeking to investigate and resolve such messy problems [7–10].

As impetus builds for more TD approaches to research, a complimentary body of literature is emerging that describes and theorises what transdisciplinarity does or should entail. Until recently, the majority of this fledgling literature on

\* Corresponding author. Tel.: +61 3 6324 3740, fax: +61 3 6324 3301.

E-mail addresses: [anna.carew@utas.edu.au](mailto:anna.carew@utas.edu.au) (A.L. Carew), [fern.wickson@uit.no](mailto:fern.wickson@uit.no) (F. Wickson).

<sup>1</sup> Tel.: +47 77 62 31 37; fax: +47 77 64 61 00.

transdisciplinarity sought to define the approach to research and create consensus on what distinguished it from more established approaches (e.g. disciplinary, applied, multidisciplinary, systems research, participatory action research). As the emerging community of TD scholars appears to have reached broad consensus on the characteristics of TD research [11], the community is now facing the difficult prospect of imagining and enacting schemas to shape, support and evaluate this dynamic approach to research [12].

In this paper, we contribute to moving the conversation on TD research beyond defining transdisciplinarity, and into the complex territory of designing and agreeing on mechanisms to shape, support and evaluate TD research. We begin by providing a summary of the consensus position on the main characteristics of TD research,<sup>2</sup> before progressing to our main purpose, which is the provision of a graphic to help visualize, communicate and advance the concept of TD research. In this paper, we present and explain our graphic, referred to as the TD Wheel (TDW), focusing on both describing its theoretical foundations and explaining how it can be used to shape, support and evaluate research that aspires to be transdisciplinary in practice.

## 2. Transdisciplinary research—characteristics

### 2.1. *Transcending and integrating*

The term ‘transdisciplinary’ has evolved from its more literal meaning of transcending the traditional boundaries of university-based research to include the participation of extra-academic stakeholders. While transcending discipline boundaries certainly remains an important activity for TD researchers, Sholtz and Marks [13] make reference to a range of related boundaries beyond discipline-based knowledge divides that TD researchers transcend. These include: affect/effect or fact/value; epistemological divides; and various system conceptualization and boundary judgments. Importantly, Scholtz and Marks [13] and others (reviewed in Ref. [11]) have argued that the crossing of these boundaries alone is not sufficient, but that the TD researcher needs to put effort into integrating these potentially disparate knowledges with a view to creating useable knowledge. That is, knowledge that can be applied in a given problem context [14] and has some prospect of producing desired change in that context.

### 2.2. *Evolving methodology*

A particular element of integration that TD research theorists highlight as uniquely challenging for TD research is the development of research methods and methodologies through the interpenetration of epistemologies [11]. This phrase refers to the evolution of research methods and methodologies via a process of researchers using multiple research approaches to critique and deconstruct the various approaches under consideration. This “collaborative deconstruction” [15] sponsors the development of methods specifically tailored to the selected problem and its unique context. An active argument in the TD literature centres on whether it is always (or ever) possible to reconcile and integrate approaches to research (e.g. methods and methodologies) and research outcomes (e.g. knowledge) that sit on fundamentally different epistemological bases. This dilemma is discussed in Wickson et al. [11] who conclude “in trying to integrate different knowledges and epistemologies, the transdisciplinary researcher does not need to aim towards the development of a single unified ‘truth’ but rather, ...[looks] for coherence, correspondences and ‘ridges’ across the differences; generating knowledge by finding, identifying and communicating patterns across diverse disciplines and discourses”. The implication of these ideas for research practice is that TD researchers need to go beyond the linear application of relatively static methods, and aim for evolving, dynamic and responsive method and methodology. Further, the intentional iteration of the research approach is viewed as an essential and ongoing part of the TD research process.

### 2.3. *Practical problems, problem orientation*

Moving beyond boundary crossing, integration and the evolution of methodology, TD research is intended to make practical, manifest contributions to the resolution of pressing, messy problems [16]. The problems in question are not theoretical and abstracted, but exist within rich, contested real-world contexts. They tend to be those that are perceived or nominated by society as pressing and urgently in need of resolution.

Given that TD research is intended to investigate and resolve practical problems, TD researchers have a need to engage deeply with the problem context. Notably, this requires a commitment to engage with stakeholders who ‘own’ the problem and its context [14,16]. Lawrence and Despres (pg 399) [8] highlighted the engagement aspect of TD research by describing it as problem solving through “the context specific negotiation of knowledge”. The negotiation of knowledge means that a diverse range of knowledge sources and traditions is involved in the research process. In part, this means that TD researchers are expected to actively seek and use knowledge from the community that has a stake in the problem. It is suggested that negotiation between academic and lay forms of knowledge, in the framing of the research problem and its methods and intended products, results in the synthesis and emergence of more valid problem perspectives and new forms of robust,

<sup>2</sup> For readers interested in more extensive treatment of the existence of TD as a distinct approach, we recommend [8,11,13,18].

context-relevant knowledge. Extending from the need for engagement of stakeholders is the notion of “mutual learning” as a desired outcome of TD research [13,17–19]. Mutual learning is the idea that all collaborators in the research project experience some transformation in their knowledge or perspective. In some respects, the engagement aspect of TD research appears to be an effort at democratizing research by affording equal weight to various knowledges and prompting academic researchers, policy makers and laypersons to share decision-making power throughout the research process [20–22]. In this way, TD research could be seen to connect with ideas from Critical Systems Theory as described by Flood [23].

Taken together, these inter-related characteristics of disciplinary transcendence and integration; responsive, evolving methodology; and practical problem focus suggest that transdisciplinarity represents a shift from more accustomed approaches to research. The complexity of each of these characteristics and the challenge of building research which adheres with them all, however, suggests that a broad scale shift to implementing this vision of TD research will need substantial support and commitment.

### 3. Transdisciplinary research—challenges

#### 3.1. Barriers to proliferation

While transdisciplinary research is increasingly nominated as a useful approach for researching complex problems, there are an array of barriers that potentially hinder its proliferation [24,25]. The sheer scope and complexity of attempting research that aspires to an array of goals (e.g. transcending, integrating, evolving, negotiating, problem solving) represents an early barrier [18]. Maasen and Lieven (pg 401) [26] have said “*negotiating, coordinating and integrating* heterogeneous types of knowledge, values and interests are bound to cause complexities that border on the irresolvable task of rendering incommensurabilities commensurate”. For researchers who choose to proceed beyond this first hurdle, there is a raft of additional problems associated with, for example:

- conceiving and designing the initial research approach;
- advocating for the research to attract funding and institutional support;
- imagining and planning for the management and running of such projects;
- making clear statements about what such research might produce; and
- explaining how the products of such a project might be documented and evaluated.

All of these barriers link to and have implications for one central, fundamental problem: a lack of clarity on the hallmarks of *good quality* TD research [13,17,27,28,29,30].

#### 3.2. The problem of quality evaluation

The lack of clarity about what good quality TD looks like could be attributable to the relative newness of TD as a research approach. A useful analogy on the confusion typical of a new academic endeavor comes from Becher and Trowler [31] who describe stages in the emergence of a new discipline. These researchers chart the process of disciplinary emergence as a progression through recognizable phases. The first phase is characterized by confusion and diversity, next comes paradigmatic agreement where adherents to the field discuss shared foci, problems and practices to negotiate a loose but recognizable Community of Practice [32]. Given that TD research is relatively new, this description by Becher and Trowler [31] and recent analyses of the TD literature [33,34] suggest that the TD research community may have reached the second phase. That is, establishing means and forums to share foci, problems and practices. The final phase in Becher and Trowler's [31] progression coincides with clarity of intention, terminology, goals and practices. For TD research, this phase would see the development of and general agreement on criteria by which the quality of TD research might be judged. Given that TD is an innately tailored and necessarily responsive approach to research, such criteria would need to be uniquely flexible to provide valid, reliable means to evaluate and compare projects, while not stifling the evolution and responsiveness of the approach [7,28,34]. As Spaapen et al. [7] have suggested, a uniform yardstick for evaluation does not do justice to the specific nature of TD research strategies and the dynamic nature of its relation to the research context.

### 4. Transdisciplinary research—evaluative frameworks

Greater clarity on what constitutes good TD research is needed to support the further development and proliferation of the approach. Specifically, the development of good evaluation frameworks or criteria would assist:

- *professional development* to guide researchers attempting to adopt, or improve on their application of the approach [14,21,22,35];
- *institutional support* for institutions and policy makers wanting to foster and propagate cross-disciplinary endeavors [5,36];
- *planning and shaping* of TD research, particularly at the outset of a given piece of research;
- *prospective evaluation* for funding bodies trying to discriminate between various projects [22,37];

- *formative evaluation* to provide guidance or tools for in-train review and reflection to support TD researchers in troubleshooting and reorienting research projects;
- *summative evaluation* for funding bodies and TD researchers seeking to claim or prove outcomes from research projects [16].

#### 4.1. Prospects for evaluating TD

Several promising frameworks and sets of evaluation criteria have been proposed for TD research [7,14,28,38–40]. Each proposed framework has strengths and weaknesses. For example, sets of criteria vary in terms of the authors' apparent assumptions about the main intent or purpose of TD research, and what it is possible to consistently measure. It is possible to distinguish proposed evaluation criteria for TD research between authors who advocate close attention to the supposed institutional and interpersonal pre-conditions for successful TD research [20,37], those who focus more on the importance of good process [7,19,22], and authors who encourage close attention to indicators of the success of final results or outcomes of TD research [14,16].

Amongst proposed evaluation criteria, there is substantial variation in the balance different authors achieve between comprehensiveness and over-prescription. For example Bergmann [39] and Defila and DeGiulio [14] offer complex and time intensive evaluative schemas. In comparison, the prompts suggested by Boix Mansilla and Gardener [28] are provocative and offer general guidance but are not rich enough to support the full-scale design and execution of integrative research. Given the difficulty of designing evaluation processes for research that seeks to meet a range of potentially disparate targets and is intended to be intimately tailored to specific problems-in-context, authors of evaluation frameworks tend to proffer the position that the negotiation or design of evaluation criteria is an integral part of the research process [16] and offer their schemas as 'pick and mix' lists. One of the challenges that then faces TD researchers is in choosing between proposed criteria (with their various implicit assumptions) to select (pick and mix) or design workable evaluation schema.

#### 4.2. TD Wheel heuristic to shape, support and evaluate TD research

In the second half of this paper, we offer a heuristic or thinking tool to assist researchers in overcoming some of the problems associated with current or proposed evaluative frameworks for TD research. We draw on elements of the various existing frameworks and criteria for shaping and evaluating TD research, and on ideas from the emerging TD literature (discussed above). We use this supporting literature to structure a simple graphic representation of TD research, which we suggest through its generality and adaptability has a range of potential applications in the shaping, support and planning for the evaluation of TD research. The depiction we offer in this paper is called the TD Wheel (TDW) and has the specific aim of providing flexible support for the development of conceptualizations of TD research. This graphic and supporting text are therefore a work of theoretical synthesis, which expresses and integrates the work of others. The graphic we propose is both a visual representation and a heuristic (following the definition of Klamor and Leonard [41]). The TDW heuristic is intended as a thinking tool to be non-prescriptive and provocative; allowing the viewer to understand in ways that a literal rendering cannot [41]. The TD Wheel as a heuristic has the purpose of provoking the viewer to react, reflect and think in new directions. As a normative argument, we do not seek to justify the TDW empirically. The value of the heuristic we have built and present is its generation through synthesis, its simplicity, its adaptability and its capacity to provoke reflection. As we will explain, the TDW is graphic and rich in meaning, and has a range of potential applications in envisioning, supporting and evaluating TD research. We propose the image and its elements as aids to the consideration of what constitutes good quality TD research. We also explain its potential use in generating a 'trace' which is a specific tool for quality evaluation in TD research.

In summary, the TDW offers an alternative way of thinking about, discussing and negotiating TD practice. It is intended to compliment and simplify more accustomed approaches to research design and evaluation generally, and the current emerging literature on TD quality evaluation, specifically.

The TDW is presented in four stages:

- Initially, we present and describe the three elements of TD research—context, process and product—and specifically explore the dimensions and complexities of context for TD research (Table 1).
- Second, a static outline of our heuristic is presented that portrays TD research as a function of its three key elements (context, research processes and research products) (Fig. 1).
- Third, the TDW is set in motion to express the dynamic, non-linear and iterative role of the researcher/s actively engaged in this approach to research (Fig. 2).
- Fourth, we show how TDW might be applied throughout the life of a research project to prompt reflection on the actions and outcomes of the project and project team (Fig. 3).

### 5. The Transdisciplinary Wheel (TDW)

The Transdisciplinary Wheel (TDW) offers a visual representation of the relationship between the three key elements of a TD approach to research: context, process and product. The TDW builds on the idea that context is a formative and

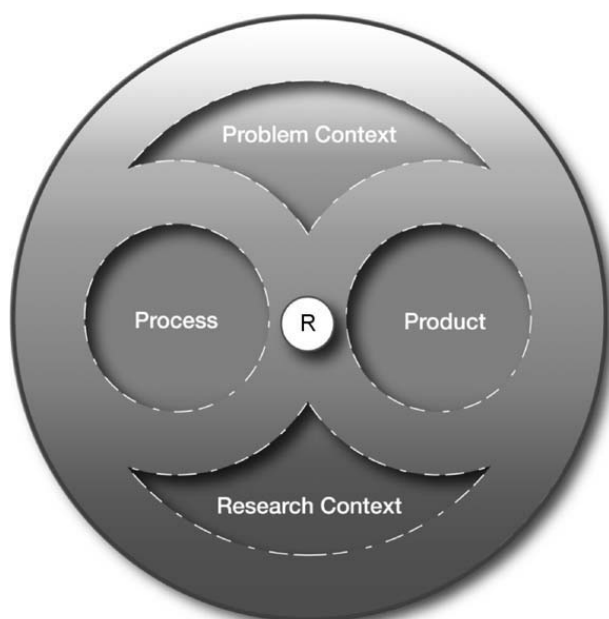


Fig. 1. The Transdisciplinary Wheel (TDW) (R = researcher/s context).

encompassing condition for TD research. In the static version of the TDW presented in Fig. 1, process and product are presented as connected loops that are open to each other, and articulated within a wheel of context. In the TDW, the researcher/s (R) are represented as a motile circle set to travel through the three elements of the diagram. The following three sections explore the elements of process, product and context as depicted in the TDW, and ruminate on the implications of the depiction for TD research design, execution and evaluation.

### 5.1. TD research context

According to the description we presented in the introduction to this paper, a prime concern for TD research is its intimate and iterative association with context. Recognizing and accounting for context is a necessary precondition for designing and executing quality TD research because of the multiple constraints and opportunities implicit within a rich context. For TD research, the element of context has three inter-related aspects—problem context, research context, and researcher/s context. We use the term *problem context* to refer to the broad social or environmental setting of the research problem. The

**Table 1**

Important Aspects of Context in Transdisciplinary Research (drawn from [18,20,21,25,26,30,36,37,40,42–44]).

| Context                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Problem context</p> <ul style="list-style-type: none"> <li>• The degree of contestation associated with the problem or 'decision stakes'</li> <li>• The level of uncertainty, complexity and novelty associated with the problem</li> <li>• The extent of agency (power to create change) that is held by those with a stake in the problem</li> <li>• The accessibility of the problem context (i.e. capacity for the researcher/s to be embedded in context)</li> </ul>                                                                                                                                                                                                                                                                                                                                                |
| <p>Research context</p> <ul style="list-style-type: none"> <li>• The funding available to research in a non-traditional way</li> <li>• The physical proximity of researchers (e.g. same building vs. different countries)</li> <li>• The opportunity for formal and informal face-to-face discussion between collaborators</li> <li>• The time available to manage collaboration and communication (both within the research group and with multiple 'external' audiences)</li> <li>• The resources available for effective project management</li> <li>• The existing power hierarchies at the research institution</li> </ul>                                                                                                                                                                                             |
| <p>Researcher/s context</p> <ul style="list-style-type: none"> <li>• The past experience researcher/s have of working together, across disciplines and in context</li> <li>• The interpersonal politics and relations between the research collaborators</li> <li>• The skills available to juggle diverse approaches and data types and to integrate/synthesize theory and methods</li> <li>• The inclination to engage with stakeholders and to seek and value diverse knowledge types and sources in an inclusive and democratic research process</li> <li>• The ability to reconcile complex, diverse perceptions and negotiate shared ethics/values</li> <li>• The willingness to recognize and account for one's own values, biases, and beliefs and to acknowledge the limitations of one's own knowledge</li> </ul> |

institutional situation (i.e. research institute/s) with which the research is associated is termed the *research context*, while the *researcher/s context* is a term constituting the skills, experiences and intentions of the researcher/s (R) engaged in the project.<sup>3</sup> We have used this subdivision for the purpose of discussing the intricacies, complexities and challenges that various manifestations of context offer a TD research project.

Some examples of important (and potentially problematic) aspects of problem context, research context and researcher/s context are provided in Table 1. These have been drawn from published accounts of the realities of interdisciplinary and TD practice, however the lists represent only some of the myriad considerations that various authors suggest context embodies. Each of the manifestations listed in Table 1 are likely to feature in different ways in individual TD research projects, and consideration of the manifestations of context has implications for the way that TD research needs to be designed and the chances of successful execution of TD research.

Table 1 lists a range of factors that can influence or impinge on the design and execution of TD research, however, the multiple ideas simplified in this table are sufficiently rich as to deserve more expansive discussion. For example, one of the aspects described within the problem context is “decision stakes” [42]. Decision stakes refer to the degree of contestation or discord associated with a particular problem and the influence of this discord on the way that the problem should be investigated and resolved. Funtowicz and Ravetz [42] suggested that highly contested problems warrant an intensely consultative approach to research that includes iterative review by an extended community of peers (stakeholders, laypersons, policy makers). The implication for TD research is that in highly contested problem contexts, appropriate time and resources may need to be allocated to designing and managing extensive, structured peer or stakeholder review. A second aspect of problem context from Table 1 is “the extent of agency”. This highlights the need for project objectives to take account of the project team’s capacity to influence or direct change. It is suggested that an appraisal of stakeholders’ personal agency to direct and decide change, or their capacity to influence decision-makers would allow establishment of realistic objectives regarding the project’s intent to affect real-world change (problem solving). A third example is the need to consider the accessibility of the problem context. This relates to whether TD researcher/s are likely to be able to gain legitimate and continuing access to a given context. A problem context at great physical distance from the researcher/s home institution or that endangers the safety of the researcher (e.g. war zone, disease outbreak) would limit the researcher/s capacity to access and intimately engage with the problem context. Again, this consideration would influence the objectives a TD project might set out to achieve.

Similar expansive discussion could be built around factors in Table 1 associated with research context and researcher/s context. For example, several authors writing on research context discuss the adverse impact that a lack of physical proximity and limited opportunities for unstructured interaction between researcher/s can have on TD research. These authors emphasize the importance of frequent informal face-to-face time for: building shared repertoire [45]; negotiating shared values or intent; co-creating and innovating; learning from each other [18,19]; and deciding changes in process, method or planned outcomes. The researcher/s context focuses on the personal and interpersonal skills, experience and attitudes that are important for members of a research group tackling TD research. Implicit within this list are skills that generally influence the capacity of individuals to work effectively as a team (e.g. respectfulness and openness toward others, capacity to listen and explain, leadership skills). Several aspects from the researcher/s context list are, however, more distinctive to TD. These include: a strong inclination to seek, value and integrate a diverse range of perspectives; capacity to account for one’s own values and to negotiate shared values; experience in or openness to working across disciplines, with stakeholders and in context; and the skill to juggle and synthesize diverse knowledges, methods and theories.

As the preceding discussion demonstrates, there is substantial value to those designing and carrying out TD research in considering and planning for the influence of context on the research. Table 1 supports the TD researcher in making some of the implicit aspects of context explicit. Recognizing and accounting for context is necessary for designing and executing quality TD research. This is because understanding context allows the TD researcher to make realistic statements about what the project is likely to achieve (research products), and the resources (time, money, skills) and research and management activities (research processes) that may be needed to meet these desired ends within the given context.

## 5.2. TD research process

While both the terms ‘process’ and ‘product’ might apply to most forms of research, they manifest idiosyncratically in TD practice. The distinguishing features of TD research process emerge from a commitment to respond to context. These features include:

- an intent to engage stakeholders and tailor the research processes;
- a research approach involving integration and collaboration (within, across and beyond disciplines), including the development of novel methods through collaborative deconstruction [15]; and
- an outcome of process that has been reflected upon and is demonstrably distributive.

<sup>3</sup> Subdivision of context into these three aspects is somewhat artificial given that, for example, stakeholders who are nominally described within the problem context aspect would be expected to be or become researcher/s at some point during the research process.

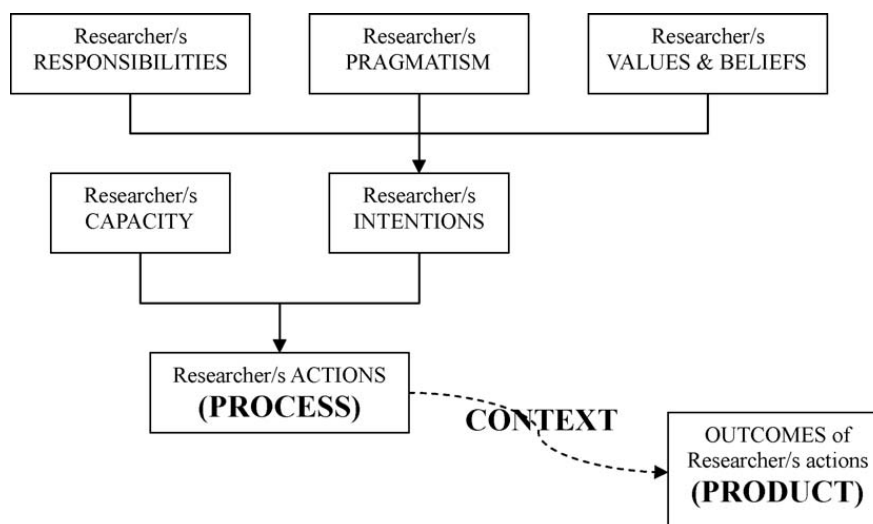


Fig. 2. Distinction between researcher/s actions as process, and the products of TD research.

In making process a focal point for describing TD, it is important to highlight our intention is not to prescribe specific research processes.

Earlier, we discussed the different intent that various TD evaluation criteria assume for TD research. This discussion foreshadowed a distinction between the terms process and product. While process is clearly a precursor to and strong determinant of product, the two are not equivalent. In this paper, we use the term process to mean the actions that TD researcher/s take in managing and conducting their research. Fig. 2 shows the relationship between process and product from the perspective of the researcher/s.

Fig. 2 shows the researcher/s actions as informed and shaped by the individual and collective researcher/s intentions. Intentions, in turn are founded on the researcher/s interpretation of their formal commitments or responsibilities within the research team ('responsibilities' in Fig. 2), what they feel is possible in the given team and context ('pragmatism') and the personal values or beliefs they hold about the research ('values and beliefs'). Actions are also constrained or afforded by the researcher/s individual and collective capacity (skills, knowledge, experience, resources). In other words, the actions taken as TD research process are a function of researcher/s intentions and researcher/s capacity. At the point where action is taken, context once again comes into play. TD research processes are enacted within real-world contexts that may distort actions in unforeseen or unintended ways. The outcomes of the actions taken by TD researcher/s constitute the TD research products.

The preceding discussion illustrates how the outcomes of TD research (products) may differ to what was intended due to the research (process) enacted. The point here is that in planning and evaluating TD research, a proposed or promised outcome (product) is likely to be substantially effected by the innate complexities of the TD research process. Specifically, process (and therefore product) will depend on the researcher/s skills (and luck) in negotiating and balancing: responsibilities, pragmatism, values and beliefs, and capacity to act, across research teams that cross discipline divides and likely involve extra-academic participants.

### 5.3. TD research product

The third element of TD research depicted in Fig. 1 is product. While the products of TD research have been described using a range of terms [13,17,28,31], we label them: peer approval, problem solving and mutual learning. *Peer approval* refers to traditional scholarly products such as publication in scholarly journals, conference participation, patents and citation. Criteria for judging the quality of these types of research products are usually constituted by the discipline-based peer community [31]. These quality criteria may be implicit or unspoken but tend to be broadly agreed and rigorously applied in well established disciplinary communities [34]. A challenge for TD research is that research products seeking peer approval from established disciplinary communities may need to withstand scrutiny from the multiple peer communities associated with the research problem and its context. These multiple peer communities may use quite divergent yardsticks for assessing quality [7].

The second research product, *problem solving*, requires that the research has made a manifest contribution to solving a practical, real-world problem [18,35,36,46]. Evidence for such a contribution might include: the implementation of new policy measures, a shift in public discourse or broader acceptance of new technologies. Some suggest that the quality and value of problem solving research products would most appropriately be judged by those with a stake in the problem [16]. There is also some debate as to the appropriate time-frame for evaluating problem solving, given

that the impact of recommendations for change might take years or decades to be fully implemented, felt and understood.

*Mutual learning*, the third product, is the idea that all collaborators in the research project experience some transformation in their knowledge or perspective [13,17,18]. This product of TD research includes a focus on the participating researcher/s', stakeholders' and community members' sense of self and interpretation of the problem context, and particularly, how these change as a function of involvement in the research. The distinction between researcher/s, stakeholders and the general community that inhabits the problem context is somewhat fuzzy and will depend on the aims and context of individual TD projects. This fuzziness has ramifications for TD research projects that might seek to generate or facilitate mutual learning. To prove and evaluate this product, participating researchers would need to agree on mechanisms to recognize, document and critically evaluate their individual and collective learning over the life of the research project.

Acknowledging the existence of three different types of product is important for crafting TD research and evaluating its quality. This is because TD research calls for research design and evaluation that enables and accounts for the multiple, distinctive research intentions and outcomes discussed above. TD project leaders need to make pragmatic decisions about what can be achieved within constraints of time and budget, and the forethought and resources needed to collect evidence of the development and delivery of each type of product.

## 6. The Transdisciplinary Wheel (TDW) animated and applied

### 6.1. Context, process and product

The TDW in Fig. 1 broadly outlines the relationship between three key elements of TD research (context, process, and product). Although this figure may infer that the elements of TD research are distinct or clearly separable, in practice, the boundaries between the elements are permeable (as indicated by the perforated lines delineating the various elements). This means that the boundaries between context, process and product leak and the elements infuse one another. This has implications for practice: TD researchers need to continuously circle through and physically or conceptually revisit each of these three elements. This necessary dynamism is represented by Fig. 3.

In Fig. 1 the researcher/s (R) were shown as static, somewhat arbitrarily positioned between process and product. In Fig. 3, the TDW is animated to represent research in motion. This second depiction shows the researcher/s as motile, cycling between all three elements with the intent of catalyzing infusion between the elements. As indicated by the arrows, the paths of movement are not necessarily prescribed or predictable, and movement may be different directions. As such, Fig. 3 characterizes the researcher/s' role in TD research as dynamic and non-linear, actively engaged with and iterating physically or conceptually between context, process and product.

### 6.2. TDW as a guide to practice

The TD Wheel can be applied in different ways across three broad research phases: at project initiation; when the project is in-train; and as a prompt for evaluation at project completion. In an initiation phase, the model could play a *shaping* role as a guide to project design. At this stage, the heuristic would support analysis of what processes and products are desirable, as

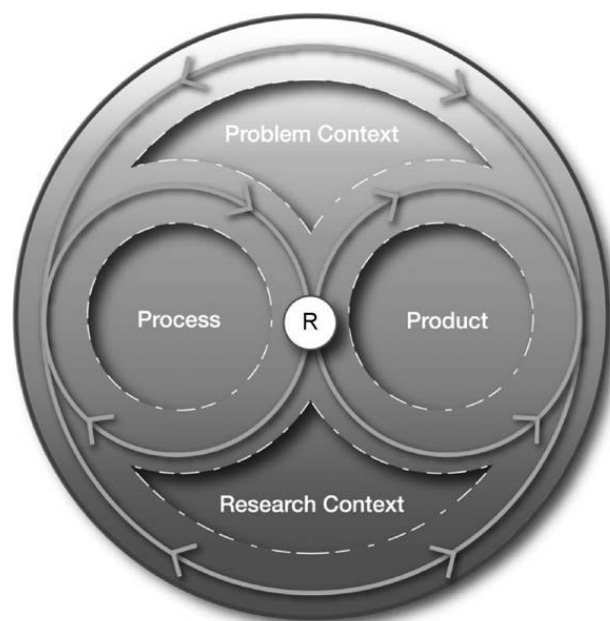


Fig. 3. The Transdisciplinary Wheel (TDW) in motion.



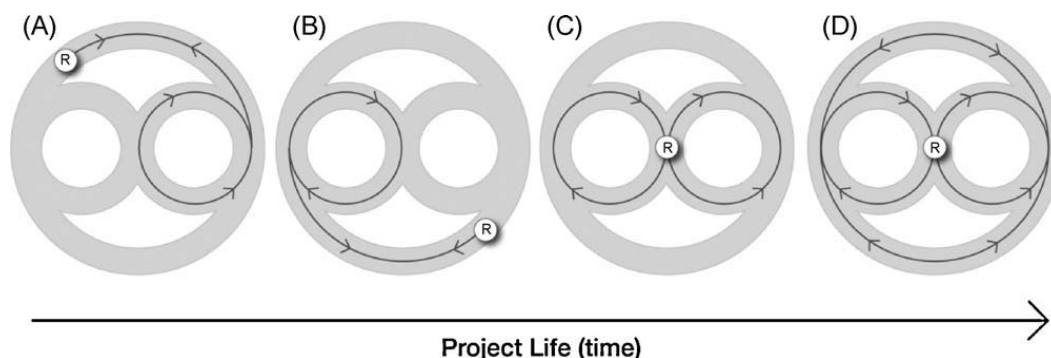


Fig. 4. Traces of the Transdisciplinary Wheel (TDW) in application.

well as how these might be approached within the given problem, research and researcher/s context. When a TD project is in-train, the detail of TDW (as suggested in Table 1) offer a *supporting* role by guiding researcher/s' critical reflection, and assisting in the identification of potential hindrances, obstacles and opportunities. At the close of a TD research project, the model has application for *evaluating* quality. It emphasizes, for example, that research products must be judged in light of the shifting opportunities and constraints afforded by the various elements of context, over the life of the project (Fig. 2).

One of the concrete ways the TDW might be utilized is in documenting and tracking the pattern of researcher/s movement over its various elements. Using the model in this way would allow for periodic reflection on the research process and the illumination of those elements that are either being continuously circled or neglected. We call the documentation of a pattern of researcher/s movement a 'trace'.<sup>4</sup> Each specific trace would be uniquely shaped by the particular research project's context, evolution of method and ongoing negotiation over the desired products. Fig. 4 provides examples of what such traces might look like. Trace A in Fig. 4 depicts a pattern of research observed in a project initiation phase where the researcher/s are actively engaging those in the problem context to negotiate and draft project objectives. In contrast, trace B depicts a phase focused intensely on negotiating process according to the opportunities afforded by the researcher/s, and research context (i.e. institutional and interpersonal factors). The third trace, C, shows researcher/s cycling between process and product, without substantial engagement in context.

The notion of traces allows that TD research patterns will vary by project and shift over time. Multiple traces can be created over the life of a TD research project to document and evaluate the project's evolution. Fig. 4 represents traces as project snapshots taken over time. In Fig. 4, trace A represents a pattern of research that might be observed at the beginnings of a project, traces B and C represent successive interim points over the life of the project. On completion of a TD project, given the stated need for this approach to be responsive, negotiated and dynamic, the researcher/s would ideally need to have documented cumulative movement that traversed all three elements of the TDW (e.g. trace D in Fig. 4).

Specific criteria, such as those presented in Table 1, offer dual utility for creating a trace. For researcher/s comfortable with meta-thinking, the manifestations in Table 1 could be used to flesh out the meaning of a trace with project-specific detail. For those less accustomed to analyzing their research practice at this level of abstraction, the factors offer a means to initiate discussion about the pattern of research, with a view to creating a trace. Depicting TD research as traces shows how the TDW could be used as a reflective tool. Reflecting in this way offers means to analyze, comment on and critique a project's execution, progress and quality.

## 7. Conclusion

TD research is increasingly recommended as a model of research practice suited to the intractable problems of our time. A principle barrier to a broader uptake of TD research is a lack of clarity on what good quality TD research looks like. We have reviewed literature and described a flexible framework that explores this problem. Our review of the intricacies of context helps to make these elements explicit and thereby support TD researcher/s in planning for success by enabling conscious analysis of context. The TDW explains TD research as a coalescence between three key elements of context, process and product. The Wheel depicts the dynamic interrelationship between the elements, and offers a means to discuss, envision and plan the processes and products of TD research, in relation to the opportunities and constraints afforded by context.

We have argued that immersion in and responsiveness to context, and evolution and negotiation on process are fundamental to TD research. As such, TD research cannot be adequately evaluated by frameworks that focus on research outputs alone. The quality of TD research depends on, and needs to be judged in relation to, the interplay between context, process and product. The TDW can support this approach to understanding and evaluating quality through, for example, clarity in describing and nominating the type of research product intended (i.e. peer approval, problem solving, mutual learning) and through the use of traces to document the evolution of research process and product in relation to context.

<sup>4</sup> We use the term 'trace' in its literal sense "a course or path that one follows: a mark, line or discernible effect left by something that has passed" [47], rather than after Derrida's [48] use of 'trace' to denote the non-existent or self effaced; what is left after the present has been accounted for.

Part of the value of TDW is that, as an heuristic, it can be debated, pulled apart and remade to better represent the conceptualization of TD that underpins the practice of individuals and groups. In offering this model to shape TD practice, as a tool to support reflection on TD research, and as a means to negotiate on evaluation and communicate the quality of TD research, we invite the researcher to try it on and adapt it until the fit is right for the specific messy problem being addressed by the given TD research endeavor.

## References

- [1] P. Dickens, Changing our environment, changing ourselves: critical realism and transdisciplinary research, *Interdiscipl. Sci. Rev.* 28 (2003) 95–105.
- [2] S. Jasanoff, Technologies of humility: citizen participation in governing science, *Minerva* 41 (2003) 223–244.
- [3] A.J. McMichael, C.D. Butler, C. Folke, New visions for addressing sustainability, *Science* 302 (2003) 1919–1920.
- [4] W. Gold, K. Ewing, J. Banks, M. Groom, T. Hinckley, D. Secord, D. Shebitz, Collaborative ecological restoration, *Science* 312 (2006) 1880–1881.
- [5] N. Lane, Alarm bells should help us refocus, *Science* 312 (2006) 1847.
- [6] J.D. Sachs, W.V. Reid, Investments toward sustainable development, *Science* 312 (2006) 1002.
- [7] J.F. Spaapen, F. Wamelink, H. Dijstelbloem, Towards the evaluation of transdisciplinary research, in: B. Tress, G. Tress, A. Van der Valk, G. Fry (Eds.), *Interdisciplinary and Transdisciplinary Landscape Studies: Potential and Limitations*, DELTA SERIES 2, Wageningen, Netherlands, 2003, pp. 148–159.
- [8] R.J. Lawrence, C. Despres, Introduction: futures of transdisciplinarity, *Futures* 36 (4) (2004) 397–405.
- [9] M. Max-Neef, Foundations of transdisciplinarity, *Ecol. Econ.* 53 (2005) 5–16.
- [10] G.H. Hadorn, D. Bradley, C. Pohl, S. Rist, U. Wiesmann, Implications of transdisciplinarity for sustainability research, *Ecol. Econ.* 60 (2006) 119–128.
- [11] F. Wickson, A.L. Carew, A.W. Russell, Transdisciplinary research: characteristics, quandaries and quality, *Futures* 38 (2006) 1046–1059.
- [12] A.W. Russell, F. Wickson, A.L. Carew, Transdisciplinarity: context, contradictions and capacity, *Futures* 40 (5) (2008) 460–472.
- [13] R.W. Scholz, D. Marks, Learning about transdisciplinarity: where are we? Where have we been? Where should we go?, in: J. Thompson Klein, W. Grossenbacher-Mansuy, R. Häberli, A. Bill, R.W. Scholz, M. Welti (Eds.), *Transdisciplinarity: Joint Problem Solving among Science, Technology and Society*, Birkhäuser Verlag, Basel, Switzerland, 2001, pp. 236–252.
- [14] R. Defila, A. Di Giulio, Evaluating Transdisciplinary Research, Newsletter of the Swiss Priority Program Environment, Swiss National Science Foundation, 1999.
- [15] T. Ramadier, Transdisciplinarity and its challenges: the case of urban studies, *Futures* 36 (2004) 423–439.
- [16] T. Aenis, U.J. Nagel, Impact indicator definition within a transdisciplinary research group, in: B. Tress, G. Tress, A. Van der Valk, G. Fry (Eds.), *Interdisciplinary and Transdisciplinary Landscape Studies: Potential and Limitations*, DELTA SERIES 2, Wageningen, Netherlands, 2003, pp. 160–169.
- [17] R. Häberli, W. Grossenbacher-Mansuy, J. Thompson Klein, R.W. Scholz, M. Welti, Synthesis, in: J. Thompson Klein, W. Grossenbacher-Mansuy, R. Häberli, A. Bill, R.W. Scholz, M. Welti (Eds.), *Transdisciplinarity: Joint Problem Solving among Science, Technology and Society*, Birkhäuser Verlag, Basel, Switzerland, 2001, pp. 6–22.
- [18] C. Pohl, Transdisciplinary collaboration in environmental research, *Futures* 37 (2005) 1159–1178.
- [19] A. Wiek, Challenges of transdisciplinary research as interactive knowledge generation—experiences from transdisciplinary case study research, *GAIA* 16 (1) (2007) 52–57.
- [20] D. Marinova, N. McGrath, A transdisciplinary approach to teaching and learning sustainability: a pedagogy for life, *Teaching and Learning Forum*, Available at <http://lsn.curtin.edu.au/tlft/tf2004/marinova.html> 2004 (accessed on 29-04-2008).
- [21] G.N.R. Cundill, C. Fabricius, N. Marti, Foghorns to the future: using knowledge and transdisciplinarity to navigate complex systems, *Ecol. Soc.* 10 (2005) 1–8.
- [22] W. Zierhofer, What makes a project a better project? Reflections on the assessment of transdisciplinary research, in: B. Tress, G. Tress, A. Van der Valk, G. Fry (Eds.), *Interdisciplinary and Transdisciplinary Landscape Studies: Potential and Limitations*, DELTA SERIES 2, Wageningen, Netherlands, 2003, pp. 170–174.
- [23] R.L. Flood, *Rethinking The Fifth Discipline: Learning within the Unknowable*, Routledge, London, United Kingdom, 1999.
- [24] M. Hammer, T. Söderqvist, Enhancing transdisciplinary dialogue in curricula development, *Ecol. Econ.* 38 (2001) 1–5.
- [25] C. Haugaard Jakobsen, T. Hels, W.J. McLaughlin, Barriers and facilitators to integration among scientists in transdisciplinary landscape analyses: a cross country comparison, *Forest Policy Econ.* 6 (2004) 15–31.
- [26] S. Maasen, O. Lieven, Transdisciplinarity: a new mode of governing science? *Sci. Public Policy* 33 (6) (2006) 399–410.
- [27] M. Gibbons, C. Limoges, H. Nowotny, S. Schwartzman, P. Scott, M. Trow, *The New Production of Knowledge: The New Dynamics of Science and Research in Contemporary Societies*, Sage Publications, Stockholm, Sweden, 1994.
- [28] V. Boix Mansilla, H. Gardner, Assessing Interdisciplinary Work at the Frontier: An Empirical Exploration of 'symptoms of quality', *Interdisciplines*, Available at <http://www.interdisciplines.org/interdisciplinarity/papers/6> 2003 (accessed 29-04-2008).
- [29] B. Tress, G. Tress, G. Fry, Clarifying integrative research concepts in landscape ecology, *Landscape Ecol.* 20 (2004) 479–493.
- [30] B. Blättel-Mink, H. Kastenholz, Transdisciplinarity in sustainability research: diffusion conditions of an institutional innovation, *Int. J. Sustain. Dev. World Ecol.* 12 (2005) 1–12.
- [31] T. Becher, P. Trowler, *Academic Tribes and Territories: Intellectual Enquiry and the Cultures of Disciplines*, Open University Press, Buckingham, United Kingdom, 2001.
- [32] J. Lave, E. Wenger, *Situated Learning: Legitimate Peripheral Participation*, Cambridge University Press, New York, 1991.
- [33] C. Kueffer, G. Hirsch Hadorn, G. Bammer, L. van Kerkhoff, C. Pohl, Towards a publication culture in transdisciplinary research, *GAIA* 16 (2007) 22–26.
- [34] J.T. Klein, Afterword: the emergent literature on interdisciplinary and transdisciplinary research evaluation, *Res. Eval.* 15 (1) (2006) 75–80.
- [35] P.W. Balsiger, Supradisciplinary research practices: history, objectives and rationale, *Futures* 36 (2004) 407–421.
- [36] B. Tress, G. Tress, G. Fry, Integrative studies on rural landscapes: policy expectations and research practice, *Landscape Urban Plan.* 70 (2005) 117–191.
- [37] L. Grigg, R. Johnson, N. Milsom, *Emerging Issues for Cross-Disciplinary Research: Conceptual and Empirical Dimensions*, Department of Education, Science and Training, Canberra, Australia, 2003.
- [38] M. Mitrany, D. Stokols, Gauging the transdisciplinary qualities and outcomes of doctoral training programs, *J. Plan. Educ. Res.* 24 (2005) 439–447.
- [39] M. Bergmann, Quality Criteria for Transdisciplinary Research: A Guide for Formative Evaluation of Research Projects, Institute for Social-Ecological Research, Frankfurt am Main, Germany. Available at [http://www.downloads.iso.de/reloadie.htm?..literatur/evalunet\\_e.htm](http://www.downloads.iso.de/reloadie.htm?..literatur/evalunet_e.htm) 2005 (accessed 29-04-2008).
- [40] D. Stokols, R. Harvey, J. Gress, J. Fuqua, K. Phillips, In vivo studies of transdisciplinary scientific collaboration: lessons learned and implications for active living research, *Am. J. Prev. Med.* 28 (2005) 202–213.
- [41] A. Klamor, T.C. Leonard, So what's an economic metaphor? in: P. Mirowski (Ed.), *Natural Images in Economic Thought: Markets Read in Tooth and Claw*, Cambridge University Press, Cambridge, UK, 1994, pp. 20–51.
- [42] S. Funtowicz, J. Ravetz, Science for the post-normal age, *Futures* 25 (1993) 739–755.
- [43] M. Gibbons, H. Nowotny, The potential of transdisciplinarity, in: J. Thompson Klein, W. Grossenbacher-Mansuy, R. Häberli, A. Bill, R.W. Scholz, M. Welti (Eds.), *Transdisciplinarity: Joint Problem Solving among Science, Technology and Society*, Birkhäuser Verlag, Basel, Switzerland, 2001.
- [44] J.M. Nash, B.N. Collins, S.E. Loughlin, M. Solbrig, R. Harvey, S. Krishnan-Sarin, J. Unger, C. Miner, M. Rukstalis, E. Shenassa, C. Dube, A. Spirito, Training the transdisciplinary scientist: a general framework applied to tobacco use behavior, *Nicotine Tob. Res.* 5 (2003) S41–53.
- [45] L.J. Bracken, E.A. Oughton, 'What do you mean?' The importance of language in developing interdisciplinary research, *Trans. Inst. Brit. Geogr.* 31 (2006) 371–382.
- [46] J.D. Aram, Concepts of interdisciplinarity: configurations of knowledge and action, *Hum. Relat.* 57 (2004) 379–412.
- [47] Merriam-Webster Online Dictionary, Available at (<http://www.merriam-webster.com/>) (accessed 29-04-2008).
- [48] J. Derrida, *Of Grammatology* (G.C. Spivak, Trans.), The John Hopkins University Press, Baltimore, Maryland, 1976.