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The emergence of transdisciplinary methodology in western science

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Publishers notes: This report draws on the narrative of a report first published in October 2005 as a written commentary on the 2nd World Congress on Transdisciplinarity held in Vitoria, Vila Velha, Brazil. Key findings of this earlier report for the New Zealand Ministry of Economic Development and Te Puni Kōkiri have been rewritten into this much longer and more detailed report so that the important knowledge contribution of this World Congress can be made available to academic, Māori community, public and industry audiences who are interested in better understanding: (i) emerging international developments in transdisciplinary methodology, (ii) the implications of these developments for New Zealand's innovation system.

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1. Introduction

This report provides an outline of key theoretical and methodological developments in transdisciplinary methodology that emerged from the 2nd World Congress on transdisciplinarity (2005) along with an assessment of just how these developments could benefit New Zealand's innovation systems. In addition, the content of this report provides a concise outline of emerging developments in transdisciplinary methodology that are further elaborated in a more recent international journal publication by Cole (2017) that attempts to culturally, theoretically and methodologically position the existence of a distinctive indigenous (Māori) transdisciplinarity.

The 2nd World Congress on Transdisciplinarity was held in Vitoria/Vila Velha, a small city on the eastern sea-board of Brazil, geographically located between Rio de Janeiro (to the North) and São Paulo (to the south). The Congress ran from 6th to 12th September, 2005 and was based on a range of activities including: plenary sessions (by leading international transdisciplinary theorists); paper sessions (by leading international transdisciplinary practitioners); dialogue sessions (on emerging areas global concern), and workshops. The official language of the Congress was Portuguese with English and French translation provided by United Nations translators.

The theoretical and methodological developments that emerged at this Congress maybe of interest and importance to our Māori pūkenga within the western academy (specifically) and Māori communities (more generally) for a couple of reasons. First, the emergence of a distinctive methodology of transdisciplinarity in western science builds on an insightful, historically detailed and theoretically robust critique of classical western scientific method (the primary methodological basis of disciplinarity). This critique will be of interest to our Māori pūkenga within the western academy as a basis for furthering decolonising methodology (L. T. Smith, 2012) through the development of critical theory (G. Smith, Hoskins, & Jones, 2012; G. H. Smith, 2003).

Second, in intervening years it has become apparent that academic discourse on emerging transdisciplinary methodology has emerged in virtual isolation from the academic discourse of indigenous peoples in the area of decolonising methodology (Abdi & Richardson, 2008; Adams & Mulligan, 2003; Apffel-Marglin, Marglin, & World Institute for Development Economics Research., 1996; Bruchac, Hart, & Wobst, 2010; Gutiérrez Rodríguez, Boatcă, & Costa, 2010; Harrison & Association of Black Anthropologists., 1997; Mohanty, 2003; Mutua & Swadener, 2004; Pahuja, 2011; Linda Tuhiwai Smith, 1999). The isolation of these two conversations is of concern. This is because while the international transdisciplinarity project seeks to address and remedy key limitations of classical western scientific method, it does this in a way that tends to assume theoretical and methodological superiority (Cole, 2017) over culturally-based knowledge traditions as almost … *axiomatic.* The emergence of transdisciplinarity assists in moving classical western science closer to indigenous knowledge traditions via a stronger focus on system complexity. However, at the same time there is currently a very real risk that these important 'methodological' and 'method' developments in western science will become yet another instrument of colonisation (Annabel Mikaere, 2003; A. Mikaere, 2011; Pihama & Perana, 1997). Given that the Ministry for Business, Innovation and Employment (MBIE) in New Zealand has adopted the emerging Zurich model of transdisciplinarity (McGregor, 2015) as a basis for contestable science funding, it is important that the implications of such developments are brought to the attention of Māori pūkenga and communities.

Finally, the cultural, theoretical and methodological positioning of an 'indigenous (Māori) transdisciplinarity' by Cole (2017) is not a theoretical or methodological end in itself. It is one small

written contribution towards what ideally needs to be an ongoing, collective kōrero on this important matter which is aimed at:

> *(i) reclaiming the knowledge development kawa, kaupapa and tikanga of our tūpuna,*
> *(ii) reframing this unique Māori cultural approach to knowledge development in a modern-day economic and professional research/innovation context aimed at*
> *(iii) reinstating the mana and mauri of Māori communities.*

Given the findings of Cole (2017), it seems likely that the critical theory underpinnings of transdisciplinary methodology (in particular) will constitute an important contribution towards this ongoing reclaiming, reframing and reinstatement challenge.

1.1 A brief history of the emergence of transdisciplinarity

The word 'transdiscipline' comes from two Latin root words (i.e. trans- and disciplina). In their modern-day English usage, the prefix 'trans-' refers to that which is across, between and beyond while the addition of the word 'discipline' (in this context) refers to academic disciplines. Thus, the word 'transdiscipline' literally refers to that which is across, between and beyond academic disciplines. In its modern usage, the word 'transdiscipline' is more commonly expressed as (i) the noun 'transdisciplinary' and (ii) the verb 'transdisciplinarity' (Nicolescu, 2005).

Nicolescu (2005) credits Jean Piaget (1896-1980) with the idea of transdisciplinarity and notes that academic use of the word 'transdiscipline' first appeared in France in the 1970s in connection with presentations by Jean Piaget, Erich Jantsch and André Lichnerowicz at the international workshop "Interdisciplinarity - teaching and research problems in Universities" (Jantsch, 1972; Lichnerowicz, 1972; Piaget, 1972) and according to Nicolescu (2005) has since that time, generally been associated with the complexity dimension of real-world problem solving (i.e. that which is now considered to be 'between' and 'across' western academic disciplines). A more complete picture of the etiology of transdisciplinarity awaits further investigation and linguistic clarification. For example, it seems quite likely that 17th century pansophic scholars may have a valid claim to transdisciplinary thinking (Comenius, 1998; Sadler, 1966, 1969). More careful consideration of the intellectual contributions of indigenous knowledge traditions is also needed.

The dimension of transdisciplinary endeavour belonging to that which is 'beyond' academic disciplines found explicit written expression in 1985 in the writings of Basarab Nicolescu (1985). In addition, in 1994, participants of the 1st World Congress on transdisciplinarity adopted a charter – the 2nd article of which gave formal recognition to the existence of 'levels of reality' (Freitas, Morin, & Nicolescu, 1994) – an idea that implied the existence of knowing that is beyond the current axiomatic foundations of disciplinarity. Between 1996 and 2004, the significance of this emerging body of theory appears to have remained relatively unrecognised by the international scientific community.

Ever since the 1970s, the response of the international science community to growing awareness of the existence of real-world complexity has been a re-orientation of disciplinary endeavour based on that which is between and across the disciplines. Some scientists referred to the coordination of knowledge development in this way as 'mode-2 science' … implying the extension of classical western scientific methodology into a new mode of operation (Castree, Kitchin, & Rogers, 2013; Faggiolani, 2014; Msomphora, 2016; Thorén & Breian, 2016). In more recent times, this approach to transdisciplinary endeavour is generally known as the Zurich model (McGregor, 2015).

Mode-2 western science resulted in the emergence of a new vocabulary in the educational and research lexicons of disciplinary science that described the coordination of knowledge development across and between academic disciplines (e.g. inter-disciplinarity, multi-disciplinarity, supra-disciplinary and cross-disciplinary). This same mode-2 complexity orientation is evident in the early papers of the 'Transdisciplinary' Journal of Ecological Economics which emerged in the early 1990s. This 'complexity' perception of transdisciplinarity was challenged in 2005 when Manfred Max-Neef published a paper in the Journal of Ecological Economics that drew attention to what he characterised as 'weak' and 'strong' versions of transdisciplinarity (Max-Neef, 2005). According to this system of classification, mode-2 science and the Zurich model could be characterised as a 'weak' version of transdisciplinarity because social engagement based on joint-problem-solving (Klein et al., 2001) is primary concerned with that which is across and between academic disciplines. By contrast, a strong version of transdisciplinarity can be characterised as being simultaneously concerned with that which is across, between and beyond academic disciplines.

Strong transdisciplinarity is essentially a theoretical critique and methodological remedy for perceived limitations in the axiomatic methodology of classical western science. According to Max-Neef, knowledge development that has moved 'beyond' disciplinarity can be based on the distinguishing characteristics of an axiomatic methodology of transdisciplinarity (Nicolescu, 1985, 1996, 2000, 2002, 2005, 2010, 2011, 2016).

From the time of its first published articulation in 1985, it has taken 20-years for what Max-Neef (2005) characterised as a 'strong transdisciplinarity' to mature and develop to a critical point where its introduction to the international science community could occur as a historically and theoretically grounded 'methodology of transdisciplinarity'. The public presentation of this strong transdisciplinary methodology at the 2nd World Congress on Transdisciplinarity in 2005 is, therefore, what could be described as a once in a 2,500-year event that is of tremendous significance to western science. During the last 2,500-years, Aristotelian logic has had a tremendous influence on 'cultural systems of knowledge development, including the emergence of classical scientific methodology (Nicolescu, 2005). Strong transdisciplinarity represents the emergence of an alternative to Aristotelian logic that has systemic, axiomatic implications and as such signals the beginnings of a very new era in western science. Given the significance of this historical event, this report provides a concise introduction to key theoretical and methodological characteristics of weak (report section 2) and strong (report section 3) transdisciplinary modalities and concludes with an exploration of the possible implications of these international developments for New Zealand's emerging knowledge economy and innovation systems (report section 4). For the convenience of the reader, and to avoid ambiguity, in the remainder of this report, use of the words 'transdisciplinary' and 'transdisciplinarity' will include an adjective (e.g. 'weak', or 'strong') so as to indicate whether a 'weak' or 'strong' *transdisciplinary* modality is being referred to (Max-Neef, 2005).

Finally, because aspects of this report draw on critical theory, it is important to note that perceived limitations of classical western scientific methodology do not in any way diminish the remarkable and breathtaking achievements of the disciplinary-based system of knowledge development over the last 250 years. However, while acknowledging such achievements, it would be equally wrong to ignore the contribution of disciplinarity to the creation of complex/wicked problems that now threaten human and ecological 'life on earth'. A critically important attribute of an emerging strong transdisciplinary critique of classical western scientific methodology is not that it is wrong, but in unhelpful ways … incomplete. The remainder of this report attempts to provide a concise introduction to, and outline of, the ontological, logical, complexity and real-world implications of such methodological

incompleteness. For the convenience of the reader and where possible, academic references are included to support a more detailed study of this matter.

2. Characterisation of weak transdisciplinarity

The literal English meaning of 'transdiscipline' which implies that which is across, between and beyond academic disciplines (M. A. Max-Neef, 2005; Nicolescu, 2005) has found expression in two different schools of transdisciplinarity. In the Zurich model of transdisciplinarity, the 'beyond' dimension of transdisciplinarity exists, but focuses only on the extension of cross-disciplinary knowledge development into the domain of joint problem-solving as part of the science-technology-society triad (Gibbons, Limoges, Nowotny, & Schwartzman, 1994; Klein et al., 2001). The Nicolescuian model of transdisciplinarity involves a methodological shift of attention from the 'social object' of joint problem-solving to the scientific 'subject-object' relationship (Nicolescu, 2005). Max-Neef (2005) further differentiates transdisciplinarity into what he has defined as 'weak' and 'strong' modalities (Max-Neef, 2004). A survey of the published journal literature using the keywords: 'transdiscipline', 'transdisciplinary' and 'transdisciplinarity' quickly indicates that most researchers still associate transdisciplinary activities with (i) the coordination of knowledge development between and across academic disciplines and (ii) an extension of the same into the domain of joint problem-solving. This is what Max-Neef (2005) calls weak transdisciplinarity, mainly because it is *an approach to knowledge development* that is primarily concerned with addressing the complexity dimension of real-world problem-solving.

2.1 Weak transdisciplinarity, mode-2 science and the Zurich model

The 'weak transdisciplinary' category of Max-Neef (2005), is more commonly known to researchers in the western scientific academy as 'mode-2 science' or 'the Zurich model' of transdisciplinarity. Weak transdisciplinarity addresses the problem of complexity through several levels of paradigmatic-operational organisation. By contrast, strong transdisciplinarity seeks to extend its reach through several levels of reality[1] using a dual theory of logic and a model of complexity that can include, but is not restricted to different levels of organisation. Most western scientists still associate transdisciplinary research and practice with weak transdisciplinarity (i.e. that which is across and between the disciplines). The persistence of this mode-2 orientation may be explained by the fact that the emergence of a distinct methodology of knowledge development 'beyond the disciplines' is as yet still unknown to most disciplinary scientists. In addition, weak transdisciplinarity is relatively easy to understand and operationalise (i.e. you simply bring different disciplinary experts together into a common research programme). By contrast, the application of a strong transdisciplinary approach requires intentional, persistent intellectual effort (over time) to develop requisite understanding as a basis for theoretically and methodologically robust practice. It seems unlikely that this is an intellectual pursuit that all disciplinary scientists will be interested in, or willing to take. Thankfully, this is probably not necessary. As Max-Neef (2005) has shown, disciplinarity and transdisciplinarity should be seen as complementary (i.e. 2-essential parts of a larger whole western scientific knowledge development system).

2.2 Limitations of a weak transdisciplinary approach

While a weak transdisciplinary approach is relatively easy to co-ordinate, it does have limitations. Some of these limitations have become more apparent over the 2 last decades in New Zealand as Government research funding agencies (MoRST, FRST, MSI and MBIE) have attempted to implement weak transdisciplinarity as a central pillar of government research funding policy (Cole, 2019). The

[1] Conceptually, a level of reality is a sphere or realm characterised by the operation of laws (quantum, macro-physical, mental and or spiritual) and the existence of concepts that are invariant (they do not change). In quantum physics, the laws that govern the behaviour of sub-atomic particles do not consistently hold up in the macro-physical world. This is an example of two different levels of physical reality. However, levels of reality are not confined solely to physical systems, but may be thought of as an attribute of all complex systems.

implementation of such policy has not been without problems. In particular, disciplinary specialisation is the result of lengthy education based on linguistic differentiation that constitutes a very real communication barrier, when attempts are made to get dissimilar disciplinary experts to work together. This communication barrier can be overcome given time, appropriate facilitation method and resourcing (Fenemor et al., 2011). But a deeper and more difficult problem to solve is associated with the contestable nature of research funding and emerging government policy requirements for cross-disciplinary knowledge development in a joint problem-solving (i.e. real-world) context.

Getting disciplinary scientists to work-together in a competitive, cross-disciplinary research programme necessitates the sharing of research budgets and public disclosure of individually held intellectual property, as a contribution towards the 'collective' or 'common good'. This is a valid and necessary aspiration - given the real-world, complex problems, society faces (Brown, Harris, & Russell, 2010; Funtowicz & Ravetz, 1993). However, in real-world practice, this approach to contestable funding and problem solving is not without very real-world, operational problems. In particular, it has resulted in the emergence of a diverse range of *adaptive behaviours* aimed at maximising the capture of shared research funding and avoiding the public disclosure of intellectual property.

Avoidance behavioural adaptations include the efforts of science leadership and institutions to rebrand themselves in response to central government, research funding, investment signals. While rebranding is not wrong, it is unhelpful when it involves attempts to re-orient existing disciplinary expertise towards a weak transdisciplinary investment signal, *without supporting training and skill development.* Scientists who have spent an entire career working in a disciplinary institutional context, struggle to move into a weak transdisciplinary, real-world, research modality. Transdisciplinary knowledge development requires learning and skill development consistent with any other branch of disciplinary scientific endeavour (Patricia, 2012; Penin, Staszowski, & Brown, 2015; Songca, 2006). When rebranding involves the movement of disciplinary scientists into weak transdisciplinary research programmes without requisite training, it tends to result in a situation in which individual scientists revert to working in their own disciplinary silos under an over-arching programme banner of 'transdisciplinary' endeavour.

Another reason for 'rebranding' avoidance behaviours is because science leadership who themselves are often unfamiliar with the difference between weak and strong transdisciplinary modality, tend to underestimate what is involved, practically speaking, in moving from mode 1 to mode 2 – let alone giving due consideration to a strong transdisciplinary approach. There is a tendency to view a 'rebranding' transition as just an expertise *management problem* needed to continue funding existing disciplinary research endeavour. In reality, nothing could be *further from the truth* than a perception of this kind.

Avoidance behaviours also contribute towards the problem of integrating different disciplinary contributions together to create synthesis. The creation of a 'collective' intellectual synthesis requires a certain coming together of academic minds and hearts (Senge, 2004). This is very difficult to achieve when western scientific funding is now 'competitive' and methodologically 'critique-based' in a way that is designed to support the creation of economically optimal outcomes (Cole, 2019). This disciplinary model of knowledge development works reasonably well in the creation of replicable, experimental theory. However, it breaks down in real-world, joint problem-solving context that introduces the murky complexity associated with what Manfred Max-Neef refers to as *social beings, institutions, history, culture, ethics, religion, human development and the indeterminacy that always accompanies individual freedom* (Max-Neef, 2012).

Finally, an unexpected consequence of the weak transdisciplinary coordination of knowledge development in New Zealand is that it has added yet another level of complexity to the already very difficult problem of legitimising and resourcing kaupapa Māori, Māori-centred and Māori community-based creative activities (Cunningham, 2000). In New Zealand at least, Government driven prioritising, funding, implementation and evidencing of the 'impact' of a weak transdisciplinary modality is still very much a project in the making. After more than a decade of central government funding and policy attention, this approach to real-world problem solving has not yet yielded the transformative outcomes anticipated as part of transdisciplinary endeavour (Nicolescu, 2005).

2.3 The coexistence of culturally-mediated knowledge development traditions

The emergence of a weak transdisciplinary knowledge development modality gives western science an appearance of 'holistic' authenticity. However, a strong transdisciplinary critique of classical western scientific method (i.e. the axiomatic basis of weak transdisciplinarity) indicates that there are limitations associated with an approach to complexity via a weak transdisciplinary modality. Unfortunately, questions concerning the validity of such a knowledge claim have resulted in the creation of two very different, emerging models of transdisciplinary endeavour (McGregor, 2015). The likely existence of a distinctive 'indigenous transdisciplinarity' (Cole, 2017) raises additional questions relating to the philosophical, epistemological and methodological basis upon which western scientific knowledge claims of theoretical and methodological superiority are based.

Questioning of this kind does not somehow imply that western science is wrong. Nor does it fail to acknowledge the remarkable, breathtaking achievements of western science over the last 250 years. However, questioning of this kind does suggest that western science is an *incomplete part* of what is in reality a global, culturally-mediated conception of, and discourse about reality. The free daily expression, resourcing and recognition of culturally-mediated knowledge development frameworks form an essential basis for achieving *the goals of cultural survival and well-being.* This is a problem context that is clearly 'beyond' the authoritative domain of western science, and as noted earlier in this report, so far, has not been factored into the thinking on which the emergence of 'weak' or 'strong' transdisciplinary practice is based. In a New Zealand context, western science is a very incomplete contribution towards the modern-day problem of Māori community well-being and cultural survival.

In 2016, as part of the Kīngitanga day celebrations at Waikato University, I was invited to give an academic presentation on the emergence of a distinctive transdisciplinary methodology in western science, and its relationship to what I characterised as an indigenous (Māori) transdisciplinarity. After this presentation, I was approached by Māori students who asked if I thought it was necessary to study and understand the history, theory and methodology of transdisciplinarity as part of their efforts to learn and practice kaupapa Māori research. I hesitated to answer this question at the time. In reflection, I think this is a really important question. The simple answer to this question is 'yes' and the reason for this affirmative answer follows from many of the key points already outlined in this report. Understanding the historical emergence, critical theory and methodology of transdisciplinarity is not essential as a basis for the expression of kawa, kaupapa and tikanga in Māori knowledge development. However, an understanding and experiential knowledge of this emerging, and rapidly changing methodological landscape in western science, forms an essential basis for (i) decolonising methodology and (ii) activism aimed at confronting and disempowering social structures that marginalise, oppress, repress and disempower indigenous communities. As such, the contents of this report, and related Te Toi Ōhanga publications on this matter could be thought of as a necessary and important contribution towards the development of *decolonising methodology and practice.*

3. Characterisation of strong transdisciplinarity

According to the classification of Max-Neef (2005), strong transdisciplinarity is simultaneously concerned with that which is across, between and *beyond* academic disciplines (Nicolescu, 2005). However, it is important to note that this does not diminish the importance of disciplinarity, or its taxonomy of collaboration in academic research (e.g. inter-disciplinary, multi-disciplinary, supra-disciplinary, cross-disciplinary). Given that Māori culture (specifically) and indigenous cultures (more generally) are clearly 'beyond' disciplinarity, it should now be evident that this new modality of knowledge development has moved, both theoretically and methodologically closer (than disciplinarity) to indigenous knowledge development traditions. This observation is explored in greater detail by Cole (2017).

Basarab Nicolescu (2005) has proposed three pillars, or axioms for what Max-Neef refers to as a strong transdisciplinarity. These axioms are defined below and elaborated in the remainder of this report section.

> ***(i) The ontological axiom*** *- there are in nature and in our knowledge of nature different levels of reality that correspond to different levels of perception,*
>
> ***(ii) The logical axiom*** *- the passage from one level of reality to another is insured by the logic of the included middle,*
>
> ***(iii) The complexity axiom*** *- the structure all levels of reality or perception is a complex structure. Every level is what it is because of its interdependency with all other levels of reality that exist at the same time (Nicolescu, 2005).*

As noted in the previous section of this report, weak transdisciplinarity is primarily concerned with addressing the problem of (system) complexity, an objective that is partly shared by the third axiom of a strong transdisciplinarity methodology. In addition to (system) complexity, strong transdisciplinarity acknowledges the existence of the human perception of reality as a constituent part of the complexity problem. While a weak transdisciplinary approach focuses its attention on the (axiomatic) observation, explanation and prediction of behaviour within a single level of reality, strong transdisciplinarity is simultaneously concerned with perceptual complexity, levels of reality and the logic of the included middle.

To better understand the basis for the axiomatic differences between weak and strong transdisciplinarity, it is necessary to offer a more detailed written explanation of the proposed axiomatic foundation of a strong transdisciplinary methodology. In this elaboration, it is important to maintain a clear distinction between: (i) weak transdisciplinarity which is based on the extension of *classical western scientific methodology* into the domain of 'cross' and 'between' disciplinary knowledge coordination aimed at 'jointly' addressing the complexity of real-world problems and (ii) strong transdisciplinarity which is based on an entirely new axiomatic methodology designed to remedy perceived limitations in classical western scientific methodology.

3.1 The ontological axiom

The ontological axiom of Nicolescu (2005) draws attention to the fact that there are in nature and in our knowledge of nature different levels of reality that correspond to different levels of human perception. Around the turn of the last century, Werner Heisenberg put forward the notion of 'levels of reality' in response to contradictions that arose between quantum physics and the theories of

Albert Einstein (Heisenberg, 1989). Unfortunately, these ideas remained buried from most English language speakers in German text (Heisenberg, 1942). More recently Basarab Nicolescu (2000) also acknowledged the existence of levels of reality in physics, suggesting that the laws governing the behaviour of quantum entities differ from those governing entities in the macro-physical world. According to Nicolescu (2005) "there are in nature and in our knowledge of nature, different levels of reality and correspondingly different levels of perception". Two levels of reality are different if, while passing from one level to the other, there is a discontinuity in laws and fundamental concepts like, for example, causality (Nicolescu, 2000, p. 11). Hierarchical levels of reality separated by zones of discontinuity in causal laws and logic appear to exist in the micro, macro and metaphysical realms of reality. Our perception of reality does not always involve hierarchical order, as expressed in the idea of 'levels' of reality. The different levels of reality are "… accessible to human knowledge through the existence of different *levels of perception* which stand in a one-to-one correspondence with levels of reality (Max-Neef, 2004, p. 13). For example, in the intellectual realm of knowledge development, Howard Gardner's theory of multiple intelligences (Gardner, 1993a) would be highly compatible with Nicolescu's levels of reality, even though it does not imply the existence of a hierarchy of human intelligence.

The first axiom of transdisciplinarity draws our attention to the fact that scientific models are far more than just simplifications of reality; they are constituent 'perceptual' parts of the sum total of reality. A model captures at best, only a few aspects of the totality of reality that exists. From a disciplinary perspective, we have tended to rely on these model simplifications as a basis for characterising reality in a way that is not wrong, but incomplete, and therefore unhelpful as a basis for plan-making, policy-making, decision-making and legislation. For example, in a disciplinary approach to reality of this kind, economic theory is based on an axiomatic fabrication of the real world that tends to be isolated from ecological, social and cultural levels of perception and reality. It is therefore, no surprise that the real-world implementation of conventional neo-liberal dominant market economic theories has resulted in systemic ecosystem decline, the unsustainable use of non-renewable resources, growing social inequality and a cultural extinction rate that is worse in percentage terms than current estimates of ecological species extinction. To complicate this matter, academic disciplines are generally not fully aware of the systemic limitations of the compartmentalised models of reality on which they base their thinking.

To substantiate the existence of levels of reality, Nicolescu (2005) turns to the quantum revolution (Southgate et al., 1999) to provide empirical evidence that the laws governing sub-atomic quantum entities differ from those that govern entities in the macro-physical world. It is also evident that similar worlds, governed by different laws and logic exist in complex social (Loisel, 2005) and cultural systems (Cole 2017). The sum totality of all reality is in some way dependent upon the co-existence of these distinctly different worlds, that are separated by zones of discontinuity in which there is a breakdown in fundamental laws, logic and causality as you move from one world to another. This inclusive model of reality indicates the existence of distinct zones or levels of reality, not all of which are amenable to epistemic access by the inquiring or observing human mind. Thus, in a visual depiction of classical scientific method, the existence of 'levels of reality' and corresponding 'levels of human' perception or consciousness (Figure 1) creates an interesting question about the assumed objective separation between scientific subject and object (refer sub-section 3.1.1).

Human ability to perceive different levels of reality has the potential to deeply enrich our understanding of complexity. The idea of developing knowledge across multiple levels of human

perception and corresponding levels of reality involves movement 'beyond' the axiomatic scaffold provided by classical western scientific methodology.

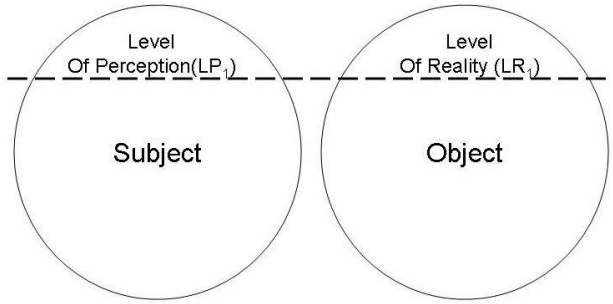

Figure 1 *A visual depiction of the one-to-one correspondence between levels of reality and levels of human perception in the well-known model of classical western science involving separation between an object (the entity of interest to the researcher) and a subject (the researcher).*

As noted earlier in this section, Howard Gardiner's theory of multiple intelligences is compatible with 'levels of reality'. Early educational psychologists considered that the subject of human intelligence was well-understood, rested principally upon linguistic and logical/mathematical ability and could be accurately measured using standardised IQ tests that produced a normal 'bell-shaped' statistical distribution (Murray and Hermstein, 1996). The primary weakness of this theory was the reduction of human cognitive ability to one level of perception and its subsequent use as an evidential basis for a 'dualistic classification' of students into one of two principle categories – *the haves and the have nots.* Howard Gardner challenged this conventional thinking by showing (1993b) that there were not just two, but at least eight, clearly distinguishable forms of human intelligence: linguistic; logical/mathematical; musical; spatial; bodily-kinaesthetic; intra-personal; inter-personal, and naturalist. In Frames of Mind, Gardiner also mentions the likely existence of religious and existential intelligence, both far more difficult to quantify (Gardner, 1983).

According to Gardiner (1983), each form of intelligence employs different sensory, intuitive and cognitive capabilities that combine to provide a range of tools for perceiving reality. Gardner points out that some aspects of learning may depend on multiple representations of reality (Gardner, 1999) linked with the use of multiple intelligences. In connection with our consideration of 'levels of reality', diverse perceptual blends of sensory-intuitive-cognitive intelligence (e.g. seeing, hearing, touching, feeling, intuition, bodily movements, musical intuition, artistic expression, writing) correspond with differing human perceptual levels of reality. Sensory-intuitive-cognitive blends of these perceptive faculties can only be defined or generalised in an individual student and cultural context and for this reason, no single system of education will suit all students or all cultures. This theory of multiple intelligences represents an important starting point for exploring the strong transdisciplinary idea of interdependency between scientific subject and object.

3.1.1 Inter-dependence of scientific subject and object

An implication of the ontological axiom is that the ability of the human 'subject', as defined in the classical model of science (Figure 1), to perceive *levels of reality* is related to sensory, worldview and intellectual capabilities. This implied interdependence between levels of perception and levels of reality poses a challenge to the classical model of science, which assumed an objective separation (Figure 2) between scientific subject and the object (Nicolescu, 2005). This reframing of the relationship between classical western scientific subject and object implies that the simultaneous (i)

study of researcher, human intelligence and learning is equally as important as (ii) the study of natural phenomena (i.e. the object). A strong transdisciplinary methodology re-draws the classical scientific 'object' boundary (Figure 1) so as to acknowledge subject-object interdependency and thus include both object and subject as foci for investigation (Figure 2). Thus, strong transdisciplinarity not only acknowledges complexity in the natural world around the observer (i.e. the object), it also acknowledges the observer's power of perception, current knowledge, systems of belief, worldview and values as constituent parts of system or scientific complexity.

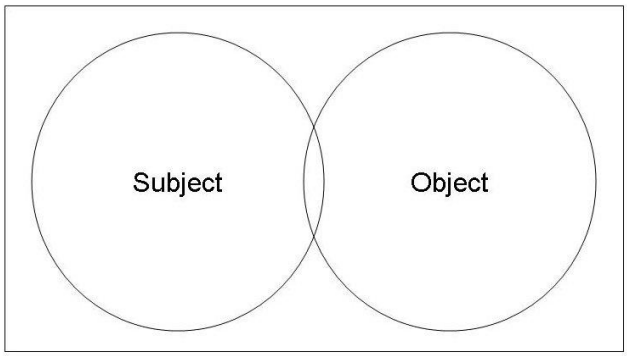

Figure 2 *A visual depiction of the object-observer model of classical science in a way that symbolically shows the transdisciplinary interdependency between scientific subject and object.*

If the ability of the human subject, as defined in the classical model of science (Figure 1) to perceive *levels of reality* is related to our sensory, worldview and intellectual capabilities, then there exists a need to rethink the role of 'rational objectivity' in complex, real-world (joint) problem-solving. The axiomatic foundation of classical western scientific methodology assumed the existence of universal laws, that could be mathematically characterised with the aid of experimental replication (Galilei 1953). However, as Basarab Nicolescu (2005) notes, human ontologies can include, but are not limited to mathematical characterisation. Thus, a transdisciplinary methodology cannot be used to approach the totality of human knowledge, if limited to the language of mathematics. Also, the existence of levels of reality implies that *rational objectivity* is a level of human perception that has a corresponding level of reality, and as such, it cannot provide epistemic access to all levels of reality.

When viewing reality from a single discipline, we tend to be unaware that logical-mathematical intelligence determines to some extent what we are capable of perceiving. For example, economists who are remarkably gifted (analytically), tend not to see the ecological consequences of their theoretical constructions of reality. This is both a complexity problem (i.e. the disciplinary isolation of economics from ecology) and a methodological problem (i.e. attempts to verify and falsify economic theory within a single level of reality in a way that relies heavily on rational objectivity). Blends of rational objectivity with other more subjective-intuitive-sacred perceptive faculties would provide access to different levels of reality. As Howard Gardiner has shown, human intelligence is based on both logical-mathematical (i.e. objective) and more intuitive sensory (i.e. subjective) capabilities. This suggests that the particular mix of perceptive intelligence that a subject has, will provide access to different levels of reality. For example, musical intelligence may provide access to levels of reality that are more difficult to access using, for example, logical-mathematical intelligence. Thus, this ontological axiom challenges the long-held classical western scientific assumption that reality is open to the investigator *at a single level of reality*.

3.2 The logical axiom

The logical axiom of Nicolescu (2005) proposes that the passage from one level of reality to another is insured by the logic of the included middle. With an orientation towards the development of objective knowledge, classical western science employed exclusive logic as the basis of its systems of categorical classification and symbolic communication of 'laws of a universal nature' (i.e. the language of mathematics). Exclusive logic also supports reduction of the sum-total of reality into constituent parts (i.e. the process of model-building or abstraction). A shift in thinking that challenged the supremacy of exclusive logic in western science began to emerge during the quantum revolution of the 1920s. More recently, Nicolescu (2005) has argued the case for a transdisciplinary methodology that recognises the essential and simultaneous role of both exclusive and inclusive logics. His 'logic of the included middle' responds to the logical contradictions that exist because of the scientific tendency to misapply exclusive logic in the domain of complex, real-world problem-solving. By employing inclusive logic, and introducing levels-of-reality, potential exists to create new knowledge that transcends the contradictions caused by strictly exclusive logic. It thus becomes possible to move between different levels of reality through the logic of the included middle.

> *The logic of the included middle is not a metaphor. It is, in fact, a logic of transdisciplinarity and complexity, since it allows, through an iterative process, to cross different areas of knowledge in a coherent manner, and generating a new simplicity (or simplexity). It does not exclude the logic of the excluded middle; it just limits its boundaries and range of influence. Both logics are complementary (Max-Neef, 2004, p. 13).*

Classical logic based on Aristotelian traditions still dominates modern scientific thinking and is based on 3 fundamental axioms.

The axiom of identity:

A is A

The axiom of non-contradiction:

A is not non-A

The axiom of the *excluded* middle:

There exists no third term T, that is simultaneously A and non-A

This classical Aristotelian logic of western science allows no outcome for the contradictory pairs A and non-A other than exclusion. In this logic, there exists no possibility of a third term 'T'. However, the problem of the excluded middle may be overcome if we introduce the notion of levels of reality. That which in the same level of reality would appear as contradictory and/or antagonistic (A and non-A), ceases to be so when a third element, the T state (Figure 3) is introduced from a neighbouring level of reality (Max-Neef, 2004). Figure 3 portrays two levels of reality (LR_1 and LR_2). Each of these levels of reality are associated with multiple levels of organisation (LO_1 … LO_4). Classical western scientific method focuses attention on levels of organisation within a given level of reality. A strong transdisciplinary methodology implies the need to research across (i) levels of organisation (LO_1 … LO_4) and (ii) levels of reality (LR_1 and LR_2) at the same time and in so doing opens enormous possibilities for knowledge discovery and unification through the logic of the included middle.

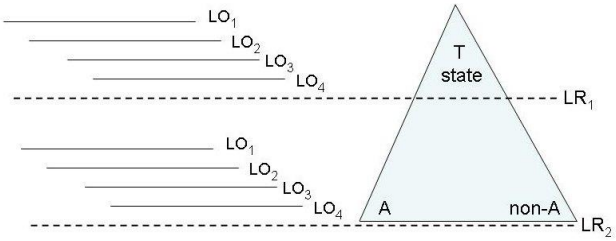

Figure 3 *A visual depiction of the logic of the included middle showing how logical contradictory pairs (A and non-A) are reconciled in a T-state at a neighbouring level of reality.*

Figure 3 also portrays the classical Aristotelian logic of exclusion with its logical contradictory pairs A and non-A. Nicolescu proposes that A and non-A result from viewing the scientific 'object' (Figure 1) at a single level of reality and that it is thus possible to reconcile contradictory or antagonistic pairs of this kind by moving to a new, or neighbouring level of reality in search of a T-state. It seems likely that the reconciliation of A and non-A will be a temporary phenomenon as the new T-state eventually becomes linked with a new pair of contradictory phenomena, A' and non-A', and their reconciliation through the discovery of a new state T'. This implies a type of iterative knowledge development. This included middle term (T) embraces that which is at the same time A and non-A, as well as new knowledge that is neither A or non-A. The emergence of a new T state achieves more than the building of consensus between the contradictory terms A and non-A, it facilitates knowledge discovery.

Our current systems of social organisation are based principally on consensus building. A strong transdisciplinary methodology suggests that while consensus building has served us well in the past, it is still an incomplete approach to problem-solving because it is typically constrained by the methodological (i.e. ontological and logical) limitations of weak transdisciplinary knowledge coordination. Furthermore, the very need for 'consensus building' is a consequence of a logic of exclusion that does not allow for logical reconciliation between A and non-A. A strong transdisciplinary methodology implies that it is possible to build new knowledge across levels of reality. This outcome provides hope for breaking the self-reinforcing cycle of contradictory logic so often associated with attempts at cross-cultural dialogue and complex problem-solving in public policy. From a strong transdisciplinary point of view, the three processes of understanding, problem-solving and the unification of knowledge are inextricably linked. Finding solutions that support human-ecosystem well-being and survival depend on our ability to work with complexity, which in turn is dependent on unified knowledge.

3.2.1 The limitation of classical scientific logic

The axiomatic foundation of classical western scientific methodology assumed the existence of universal laws (i.e. an optimal, superior or preferred level of reality), that could be mathematically characterised (i.e. understood using a categorical classification based on exclusive logic) with the aid of experimental replication (i.e. an agreed method of independent verification and falsification). This prescription for knowledge development relies on rational objectivity as a basis for the mathematical characterisation of universal laws. As Basarab Nicolescu (2005) notes, human ontologies can include, but are not limited by mathematical characterisation. Thus, a transdisciplinary methodology cannot be used to approach the totality of human knowledge, if limited to the language of mathematics. It is important to note that this is not the only limitation on knowledge development created by a scientific methodology based on the classical Aristotelian logic of the excluded middle.

The very *existence of an* objective separation between scientific object (the entity being observed) and subject (the observer) is itself a product of exclusive logic that has contributed to the creation of

some 8,000-10,000 academic disciplines (i.e. A and non-A entities). Exclusive logic supports *knowledge compartmentalisation* and while this is maybe considered as an essential part of a human intellectual approach to complexity, it is *knowledge unification* that is required to address, understand and remedy complex real-world problems. Exclusive logic is a limiting assumption because it is not the only logic that can be used as a basis for knowledge development and real-world problem-solving. For example, Cole (2017) has shown that inclusive logic plays in central role in indigenous (Māori) cultural knowledge development, Māori community wellbeing and cultural survival. From a methodological perspective, if we are going to assume (axiomatically) that exclusive logic is the only logic necessary for knowledge development and real-world problem-solving, then we also need to be able to explain why we are preferencing the use of exclusive logic in this way, when other perfectly valid logics also exist – *many of which are culturally defined and mediated.*

A strong transdisciplinarity seeks to move beyond the limitations of supposedly objective, categorical logic in the same way that the theory of multiple intelligences has moved education beyond the limitations of a 'human IQ' based solely on linguistic and logical-mathematical intelligences. A logic of the included middle opens the way for collective intelligence (Spariosu, 2004) and the reunification of disciplinary knowledge across levels of reality, levels of organisation and levels of human perception. In theoretical terms at least, it is difficult to see just how the coordination of knowledge development across and between the disciplines can overcome the methodological limitations of knowledge development based *only on a classical logic of the excluded middle.* Exclusive logic is not wrong, but it is by very nature totally 'intolerant' of inclusion and hence an epistemological limitation when the complex, real-world problems we face ideally require the unification of knowledge, skills, institutions, religions, cultures and individuals.

3.2.2 Real-world consequences of exclusive logic

Aristotelian logic and a failure to acknowledge the existence of levels of reality has led to attempts to build models of the world from the supposed vantage point of superior perceptions of reality. These models of reality (the identity entity 'A') seem elegant and attractive because they result in an internally consistent system of logic that provides certainty, fixed reference points, comparative, predictive and explanatory power. However, the fundamental problem with such linguistically closed entities is that they exclude the possibility of co-existence with any other entities (non-A) derived from alternative disciplinary, institutional, political, religious or cultural perceptions of reality. This in turns leads to the existence of logical contradictory pairs (A and non-A) sustained by an internally consistent logic, but for which there is no 'closed form' or 'systemic' solution that makes coexistence possible. This outcome has spelled disaster for the unification of knowledge, while at the same time contributing to human-ecosystem destruction, decline and collapse, along with ecological species and human cultural extinction rates that are so high they are a cause for grave concern.

The contradictory logic of economic growth (A) and no economic growth (non-A) is a good example of this dilemma. The entity A in this case is the logical argument that economic growth is directly related to human welfare, and that no growth (non-A) will result in unemployment and scarcity that leads to social disorder. What makes the argument for continue economic growth contradictory is that we know that macro-scale (global) economic growth is destroying planetary life support systems. This seems to provide a strong and convincing argument for no-growth or alternative development strategies that are qualitative in nature. The problem is, the no-economic-growth and qualitative economic growth entities are non-A, and there currently exists no third term T that reconciles the inherent contradiction between A and non-A. We cannot do without economic growth and we equally cannot have more prolonged economic growth. There is a real sense in which both A and non-A are

absolutes. Finding a way out of this logical contradiction constitutes an enormous challenge for western science, one that a weak transdisciplinary approach to the coordination of knowledge development has so far failed to remedy.

3.3 The complexity axiom

The complexity axiom of Nicolescu (2005) is a direct consequence of introducing levels of reality and inclusive logic:

> *(i) The structure all levels of reality or perception is a complex structure and …*
> *(ii) every level is what it is because of its interdependency with all other levels of reality that exist at the same time (Nicolescu, 2005).*

Levels of reality and corresponding levels of human perception cannot exist in isolation. The human perception of reality is a constituent part of what western science has previously categorised as system complexity that was assumed to be external to the observer. Systemic interdependency of this kind implies that science and education are complementary and essential as a basis for knowledge development. The former seeks to explore reality. The latter helps us to better understand how humans learn about and perceive reality, as mediated by developmental and psychological state changes.

A strong transdisciplinary typology of complexity (Figure 4), thus acknowledges the existence of (i) 'transversal' (organisational) complexity (ii) 'vertical' human perceptual complexity associated with different levels of reality, (ii) 'horizontal' complexity embracing the classification of reality associated with the use of exclusive logic in classical scientific methodology and (iv) zones of non-resistance (Nicolescu, 1996).

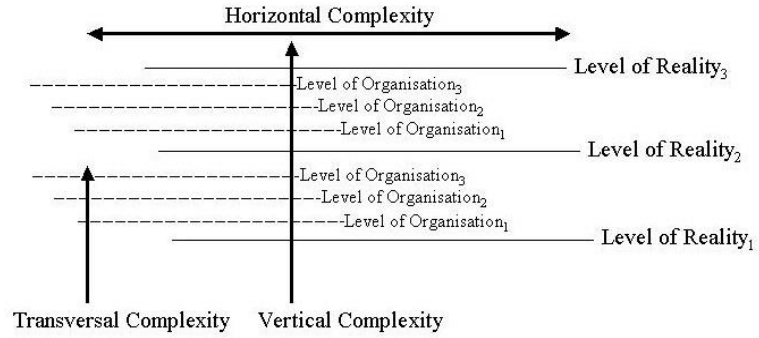

Figure 4 *A visual depiction of different three types of strong transdisciplinary complexity*

The existence of multiple levels of reality means that it is important to differentiate between horizontal complexity (i.e. complexity within a single level of reality) that may include multiple levels of organisation (i.e. transversal complexity), and vertical complexity, which can include several levels of reality - *depending on the levels of human perception available to a human observer or collective of observers (Nicolescu, 2005).* Complex reality resists our knowing because the approach to levels of reality involves passage across zones of non-resistance (Nicolescu, 2005). According to Nicolescu (2005), zones of non-resistance may correspond to the sacred or metaphysical dimension since they seem not submit to rational logic (Nicolescu, 2005). Through the disciplinary assumption of a single level of reality we effectively eliminate zones of non-resistance (i.e. the sacred) and the role of levels of human perception as aids to a cognitive-sensory-intuitive approach to reality. This is a very new model of complexity for western science that moves closer to centuries old indigenous knowledge

traditions in which subject-object-and-sacred have always been one and accessible via cognitive-sensory-intuitive and sacred forms of intelligence (i.e. ritual).

> *From a transdisciplinary point of view, complexity is a modern form of the very ancient principle of universal interdependence (Nicolescu, 2005, p. 22).*

3.4 The emergence of strong transdisciplinary practice

The axiomatic methodology of strong transdisciplinarity is now well-developed implying that the emergence of strong transdisciplinary method is now an important stage in further development. However, there is also need for caution in drawing a conclusion of this kind because in strong transdisciplinarity, method is context dependent (row 4, Table 1).

In a disciplinary-based (experimental, applied), or weak transdisciplinary (joint problem-solving) research project (rows 2-3, Table 1), the professional researcher is typically the expert, who seeks the support of public stakeholders to participate in the application of well-established research methods – often in new or novel applied domains. Disciplinary and weak transdisciplinary modalities focus attention on a single level of reality (column 2, rows 2-3, Table 1) that supports the exploration of real-world or social scientific objects (column 4, rows 2-3, Table 1) within, across and between disciplinary boundaries (column 5, rows 2-3, Table 1). The dominant logic of disciplinary and mixed disciplinary modalities is the logic of the excluded middle (column 3, rows 2-3, Table 1).

Table 1 *A comparison of key characteristics of disciplinary, weak and strong transdisciplinary and indigenous (Māori) transdisciplinary modalities*

Modality	Levels of reality	Logic	Scope of concern	Means of knowledge coordination	Method
Disciplinarity	reality	exclusive	object	within	experimental, applied
Weak transdisciplinarity	reality	exclusive	social object	across-between-beyond (joint problem-solving)	joint problem-solving
Strong transdisciplinarity	reality-perception	dual logic	subject-object	across-between-beyond (subject|object)	contextual
Indigenous (Māori) transdisciplinarity	reality-perception	dual logic +	subject-object-sacred	Tua-uri, Te Aronui, Te Ao Tua Ātea	socially-mediated

In strong transdisciplinarity, the research question and the problem of how to best investigate this question are both unknowns. Solutions to these investigative questions are 'contextual' (column 6, row 4, Table 1) in a research process that is mediated by a research team that blurs the traditional lines of distinction between scientific subject and object (column 4, row 4, Table 1). The research team is likely to be composed of representative community members affected by the outcomes of an investigation, supported by disciplinary experts including educators who provide the 'collective' - levels of human perception - that are needed to explore new levels of reality (column 2, row 4, Table 1) in search of a T-state, through the logic of the included middle (column 3, row 4, Table 1). In this model of strong transdisciplinarity, to use a well-known metaphor, the research team could be likened to a symphony orchestra in which the music score for all of the different instruments is being written and played – simultaneously (column 5, row 4, Table 1).

An indigenous (Māori) transdisciplinarity (Cole, 2017) shares both similarities and differences with a strong transdisciplinary approach (rows 4-5, Table 1). These distinguishing characteristics are difficult to linguistically define using the English language because this modality moves well-beyond an axiomatic and linguistic (disciplinary) fabrication of reality (column 5, row 5, Table 1). Key differences include: (i) the use of multiple theories of logic (column 3, row 5, Table 1), (ii) explicit recognition of the inextricably interdependent relationship between subject-object and sacred (column 4, row 5, Table 1) and (iii) the social mediation of what western science generally refers to as method (column 6, row 5, Table 1).

While quite an extensive applied research literature exists in the area of what this report defines as weak transdisciplinarity, a survey of papers presented at the 2nd World Congress on transdisciplinarity (e.g.: Bambara, 2005; Bertea, 2005; Brink, 2005; D'Ambrosio, 2005; Loisel, 2005; Ribeiro & Pratschke, 2005; Voss, 2005) indicates that comparatively little work is being done on moving strong transdisciplinarity from methodology to practice. However, based on the content of this report, it is also evident, that the connection between methodology and practice is currently an area where ground-breaking discoveries are likely to be made. Furthermore, while a paucity of strong transdisciplinary research on the one hand limits the extent to which we can draw learning from best practice, this can also be seen as an opportunity. In particular, centres of international research where strong transdisciplinarity is currently being developed could be viewed as being of strategic importance to New Zealand. Furthermore, not only is the potential for new knowledge discovery in this area is high, New Zealand would seem to be strongly positioned to take advantage of this opportunity for a number of reasons.

First, our environmental and local government legislation aspires to be stakeholder mediated in a way that is consistent with the intent of contextual method development (Klein et al., 2001). Second, our government-based, science funding system and small population provides enormous scope for the establishment of strong transdisciplinary research activities that are inter-agency and cross-culturally-based. Third, a strong transdisciplinary methodology could dramatically empower, expand and enhance the New Zealand knowledge economy (Colmar Brunton, 2000) and innovation systems (Prime Ministers Office, 2001). Fourth, as Cole (2017) has shown, a strong transdisciplinary methodology effectively moves western science closer to what can be characterised as an indigenous (Māori) transdisciplinarity. Finally, as noted earlier in this report, the critical theory on which a strong transdisciplinary methodology is based has the potential to strengthen and enhance discourse associated with decolonising methodology (Smith, 2012).

Given the potential that exists for systemic knowledge, economic, social, ecological and cultural benefits from a strong transdisciplinary approach, the final section of this report is devoted to a more detailed elaboration and consideration of this day of opportunity.

4. Strong transdisciplinarity: a day of opportunity

This report section explores the implications of adopting a strong transdisciplinary methodology for science, technology, economics and policy development in New Zealand. A strong transdisciplinary methodology involves quite complicated, subtle and new ideas that will not be easily grasped by non-scientific audiences. The problems associated with communicating these new ideas, even in writing means that it is difficult to arrive at coherent policy implications from the somewhat brief outline of strong transdisciplinarity provided in this report. For these reasons, there is a risk that any effort to explore the (potential) beneficial implications of a strong transdisciplinary methodology, in an applied context, may be criticised as being speculative and pre-emptive. This is a valid point. However, it would be equally wrong to fail to consider the opportunities that could follow from a momentous knowledge development event of this kind. A risk averse, conservative position might fail to recognise and take advantage from genuine strategic opportunities for New Zealand. Thus, the following narrative attempts to explore the fine-line between over confident speculation and risk-aversion in order to outline a vision of the future informed by what we currently know about a strong transdisciplinary approach. This vision needs to be based on the assumption that strong transdisciplinarity itself is not beyond critique or further development.

4.1 Envisioning the coexistence of disciplinarity, weak and strong transdisciplinarity

It is possible to envision a future in which disciplinarity will be complemented by the continued emergence of weak and strong transdisciplinary modalities that are collectively concerned with that which is within, between, across and beyond disciplinarity. Disciplinary science has at times, stumbled on discoveries that are 'accidentally' beyond disciplinarity. An emerging transdisciplinarity will assist in moving western science beyond this modality of 'getting it right by accident' to a systematic method of 'getting it right by investigative inquiry'. This will be accomplished by a gradually growing (collective) awareness of the fact that the creation and unification of knowledge are inextricably connected with education and the acquirement of human perception that corresponds to different levels of reality. The creation of new disciplines will continue to contribute to the fragmentation of knowledge, while an emerging science of strong transdisciplinarity will seek to mediate their unification, principally through the logic of an included middle.

Disciplinarity has primarily viewed the world from a single level of reality and this has been appropriate for the study of natural phenomena across levels of organisation that exist within that same level of reality. An emerging strong transdisciplinarity will seek to work simultaneously across multiple levels of reality and organisation to achieve the unification of knowledge across the same, in recognition of the fact that (i) every level of reality is what it is because all other levels of reality are interdependent and exist at the same time, (ii) no one level of reality constitutes a privileged position from which to view all other levels of reality, and (iii) the laws governing a given level of reality are only a sub-set of all laws that can only be defined simultaneously across all levels of reality (Nicolescu 2005).

Disciplinarity assumed that it was possible to view the world from a single level of human perception and its corresponding level of reality aided by linguistic and logical-mathematic intelligences that support rational objectivity. An emerging science of strong transdisciplinarity will seek to better understand the corresponding relationship between human sensory, intuitive, sacred, conceptual and logical forms of intelligence and access to differing levels of reality. Knowledge of this kind will fundamentally change the way that we think about, initiate, embed and benefit from knowledge development and innovation activities.

Disciplinarity will continue to find expression in applied and fundamental modalities. An emerging science of strong transdisciplinarity will not neglect joint problem-solving, but will concentrate on 'subject-object' interdependency that is simultaneously concerned both with the intellectual and

sensory role of the observer in seeking to understand natural phenomena (i.e. the scientific object). Strong transdisciplinarity will contribute to ground-breaking achievements in technology that will be made in relation to that which is good for ecosystems, society, culture, institutions and religions via the unification of knowledge (e.g. economics and ecology). This is an emerging future in which the role of strong transdisciplinarity in mediating social change, discovery, innovation and synthesis involves a form of practice, or expression, that increasing blurs the (currently) sharp lines of distinction between professional scientists and community-business members. In this emerging future, society will become an active participant in the object-subject interdependency that underpins joint-problem-solving, knowledge acquirement and discovery.

Disciplinarity expresses its identity in the classical separation of subject and object that supports rational objectivity. Strong transdisciplinarity implies that rational objectivity needs to be complemented by a far more dynamic and complex human perception of reality that will be needed to: (i) establish dialogue across differing levels of human perception and corresponding levels of reality, while (ii) simultaneously exploring reality from rational, relational and metaphysical perspectives. This will in turn necessitate simultaneous consideration of the theoretical, phenomenological and process dimensions of strong transdisciplinary inquiry.

Disciplinary perceptions of reality have led to the development of logical contradictory and sometimes antagonistic pairs (A and non-A) that cannot be reconciled at the same level of reality at which they were created. An emerging science of strong transdisciplinarity will seek the reconciliation of contradictory pairs (A and non-A) across levels of reality (i.e. complexity) through the logic of the included middle. As such, strong transdisciplinary inquiry and practice will become a science of simultaneous knowledge discovery, knowledge unification, and understanding.

Strong transdisciplinarity not only implies a dramatically different future for knowledge creation, learning and unification, it invites exploration of a transdisciplinary approach to economics based on (i) the unification of academic and culturally-mediated knowledge traditions (ii) the central role of a dual theory of logic, (ii) ability to move beyond the logical contradictory alternatives created by overdependence on exclusive logic, (iv) a fundamental shift in the way society perceives reality and (v) a recognition of the fact that economic growth is not the same as development, and that development does not necessarily require economic growth. More than any other potential contribution of a strong transdisciplinary methodology, a transdisciplinary economy could finally open a space for the peaceful coexistence of ecosystems, humans, culture, ethics, religion, social beings, and institutions along with respect for collective and individual freedom.

4.2 Technology, innovation and the knowledge economy of the future

The emergence of an alternative to the classical western scientific logic of exclusion has interesting implications for technology, innovation systems and a knowledge economy. Innovation occurs principally as a result of the discovery, prototyping, real-world testing and commercialisation of new ideas. How might a strong transdisciplinary perspective help in the design and operation of a highly successful innovation system?

First, from a strong transdisciplinary perspective, the discovery of new knowledge, understanding and the unification of knowledge are inextricably connected. For this reason, education must become a central pillar of an innovation system connected with: (i) training in strong transdisciplinary capability and (ii) support for the growth of knowledge associated with subject-object interdependency. A disciplinary-based approach to innovation is methodologically bounded or limited in its ability to discover new knowledge because of the limitations: (i) placed on human perception working from a single level of reality and (ii) associated with an approach towards reality based only on exclusive logic.

This is not where the most advanced and ground-breaking discoveries are likely to be made. The logic of the included middle implies that the discovery of knowledge currently beyond disciplinarity, exists at levels of reality beyond the reach of disciplinary methodology. A strong transdisciplinary methodology could dramatically change this situation.

Second, a strong transdisciplinary perspective on innovation would re-draw the system boundary around both innovation object (the domain of knowledge discovery) and innovation subject (i.e. the innovation team). By building an innovation team across all multiple intelligences, the potential for viewing a problem across multiple levels of reality would be maximised. This implies that joint-problem-solving is also an essential ingredient of effective innovation that will ensure that new discoveries are delivered where they are needed most in ways that avoid spatial discontinuities.

Third, ecological sustainability is an area that currently requires the development of a highly effective innovation system. To date, our efforts to move neo-liberal dominant market economic activity towards sustainability have tended to focus on negotiating consensus across logical contradictory pairs (growth/no-growth, single-goal/multiple-goal focus, collective/private use, self-interest/mutual-interest, etc.). However, as indicated earlier this is report, this is an incomplete and ineffective way of resolving logical contradictions because it is ultimately based on the necessity for exclusion. Joint-problem-solving of the most persistent problems facing a sustainable future, based on a logic of the included middle, represents one of the most fertile domains for ground-breaking discoveries.

Finally, in a strong transdisciplinary model of innovation, education will no longer be considered as a discrete period of progressive, abstracted learning that prepares a student for emergence into the 'real-world' of work and employment. A strong transdisciplinary methodology suggests that it could be possible build a knowledge economy that is more than just an adaptation of market economics designed to reap the monetary and intellectual benefits of knowledge capital via innovation, research, technology and commercialisation. A strong transdisciplinary methodology could reposition the idea of economic activity in a very new, transdisciplinary basin of knowledge attraction. This would dramatically change the societal role and contribution of education in a way that promotes a process of life-long learning, embedded in real-world joint problem-solving classrooms, supported by virtual institutions of learning, through unifying transdisciplinary knowledge management systems that we can at present - only begin to imagine. Educational curricula will no longer (only) focus the attention of students on analysis and specialisation at single levels of reality. Students will enjoy the benefits of a truly 'pansophic' education – something envisioned by the father of modern education (i.e. Jan Amos Comenius) more than 300 years ago (Comenius, 1998). Students will obtain instantaneous access to unified knowledge spanning multiple levels of reality, organisation and perception across the temporal and spatial horizons of human existence, through a cyber-space-time interface that seamlessly matches their varied intelligences to differing levels of learning potential and innovation.

While acknowledging the somewhat blurry nature of this vision of a strong transdisciplinary contribution to our collective futures, this would seem to be a vision worthy of investment and academic endeavour.

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