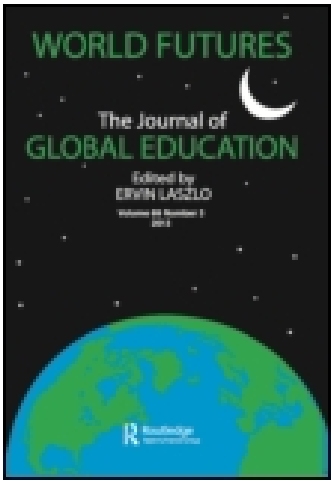

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TRANSDISCIPLINARITY AND CONCEPTUAL CHANGE

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This article tenders an inaugural discussion of how conceptual change theory can contribute to deeper understandings of what is conceptually involved when people attempt (or succeed) to transition from multi- and interdisciplinarity to transdisciplinarity. After explaining the nuances of Newtonian thinking (framed as formal rather than postformal thinking), the article shares a comparison of multi-, inter-, and transdisciplinarity along four dimensions. Special attention is given to Nicolescuian transdisciplinarity, an approach predicated on the new sciences of quantum physics, chaos theory, and living systems theory (rather than Newtonian and Cartesian thinking). Nicolescuian transdisciplinarity is a new methodology for creating knowledge and it comprises three axioms: multiple Levels of Reality and the Hidden Third; the Logic of the Inclusive Middle; and, knowledge as complex, emergent, and embodied. The discussion then turns to an overview of three basic approaches to conceptual change theory: knowledge as theory, knowledge as elements, and knowledge as context. The author then applies conceptual change theory to understand what is involved in moving toward transdisciplinary thinking, including four elements necessary for conceptual change to occur (intelligibility, plausibility, fruitfulness, and dissatisfaction with existing conceptualizations and mental models). The article concludes with the idea that transdisciplinary thinking is a form of postformal thinking (especially paradigmatic order thinking) and suggests that future conceptual shifts toward transdisciplinarity involve achieving a transdisciplinary conceptual tipping point.

KEYWORDS: Conceptual change theory, formal and postformal thinking, multi- and interdisciplinarity, Newtonian, Nicolescu, tipping points, threshold concepts, transdisciplinarity.

INTRODUCTION

In the early seventies, people began to conceptually struggle with the need for a new approach to disciplinary scholarship to handle pressing human problems. Now called *wicked problems,*[1] it was agreed human problems had become so complex that approaching their solution from the confines of just one discipline

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was no longer sufficient, nor was multi- or interdisciplinarity (McGregor and Volckmann 2011). To address this lacuna, the new concept of transdisciplinarity was introduced to the world at an Organization for Economic Cooperation and Development (OECD) seminar in Paris, in 1972 (Apostel et al. 1972; Jantsch 1972; McGregor 2010). Transdisciplinarity is radically different from multi- and interdisciplinarity, the long standing conventional approaches to solving problems within higher education. Whereas multi means more than one discipline and inter means between disciplines, trans refers to going *beyond* disciplines to engage with civil society. This article draws on the idea of conceptual change to address the intellectual shift involved in adopting a transdisciplinary perspective.

This article focuses on what has to happen to people's mental models so they adopt a radically different way of approaching their scholarship and practice. What sort of conceptual change is involved? Shifting to transdisciplinarity (TD) would indeed involve a huge conceptual leap, although this is not impossible because it has happened before. Historically, every major scientific breakthrough (including the shift from Newtonian science to the new sciences, starting in the early 1920s) began with an idea that threatened to overturn existing beliefs, including what counts as knowledge, reality, logic, and the role of values. Eventually, the purveyor of the new idea(s) finds believers and the number of believers reaches a critical mass. People change their way of thinking about knowledge. This happened in the past because perceptions were transformed, conceptual shifts occurred, and a new approach to knowledge, reality, logic, and the role of values was born. Such will be the case for transdisciplinarity (McGregor 2011b).

Developing a *transdisciplinary sense* involves conceptual change, which entails changing one's orientation; that is, "being able to appreciate the limitations as well as the potential of a specific discipline, [and] being prepared to *transcend* [emphasis added] the confines of the discipline seeking the cooperation of others in employing and preserving plurality and relationality" (Franz and Lehmann 2004, 14). After providing a cursory overview of the *essence* of transdisciplinarity (which entails a comparative analysis with multi and interdisciplinarity and their grounding in the old Newtonian sciences), the article shifts to a discussion of the conceptual change theory of knowledge creation, and then uses conceptual change as a lens to explain what might be involved when asking people to embrace transdisciplinarity, to gain a *transdisciplinary sense*.

OVERVIEW OF MULTI-, INTER-, AND TRANSDISCIPLINARITY

After explaining Newtonian thinking, the core of most (not all) scholarship informed by multi- and interdisciplinarity, this section will differentiate between multidisciplinarity and interdisciplinarity, ending with an overview of transdisciplinarity as understood by Basarab Nicolescu. For clarification, two dominant approaches to transdisciplinarity have gained prominence (Klein 2004). One strand defines it as joint problem solving of problems pertaining to the science–technology–society triad (Gibbons et al. 1994; Klein et al. 2001; Nowotny 2003; *Zurich Manifesto* 2000). The other assumes transdisciplinarity strives to remove the boundaries between higher education *and* the rest of the world, to address

Table 1
Basic Tenets of Classical Newtonian Thinking

Main Ideas of Newtonian Classical Physics
Reality: there is one level of reality, the empirical (physical) reality, materialism
Determinism: if the initial state is known, one can *predict* the physical state at another moment of space-time; the classical object is localized in space-time, and is used to describe reality
Continuity: one cannot pass from one point of space and of time without passing through all intermediate points
Relativity: reality is single-referential—the doctrine that measurements and perceptions are true only in relation to a *given* observer at a given place and time; truth becomes what is meaningful or significant *within* a given context
Local causality (separability): every physical phenomenon can be understood by a continuous chain of cause and effect; the laws of physics determine everything that happens and the causation percolates upward, determining what happens all the way up to the top
Completeness: the world is causally closed at the level of a small number of purely physical forces and types of energy; a complex system can be reduced to a description of primary, fundamental entities
Resistance: to oppose, to experience unwillingness and/or unresponsiveness to movement (resist change in state of motion or rest); to resist is to withstand, struggle against or prevent an action or argument
Reductionism: an approach to understanding the nature of complex things by reducing them to the interactions of their parts, or to simpler or more fundamental things; the intent is to finally and absolutely capture reality; view complex systems from a *linear perspective* disregarding complex phenomena (develop understandings sequentially, from the obvious, leading to no in-depth understanding)
Fragmentation: focus is on the parts but not on the relationships between the parts (no focus on the whole)
Dualism: any two sorts of reality (opposites) cannot communicate or act upon each other. One reality has nothing to do with the other—they are totally separate (especially body and mind or soul); reflected in binary *and/or*, *either/or* thinking (one best way)

Source: McGregor (2011a).

the wicked problems of the world (most notably Nicolescu 1985, 2002, 2013). The latter approach informs this article (see Tanya Ausburg's article in this issue for a richer discussion of the former approach).

Newtonian Thinking

Disciplinarity, multidisciplinarity, and interdisciplinarity are based on the precepts of Newtonian thinking (Nicolescu 2010b). McGregor (2011a) shared an overview of the basic tenets of Newtonian thought (Table 1). Heylighen (2006) explained that those who embrace Newtonian thinking assume everything that exists now (i.e., all matter) has existed since the beginning of time and will continue to exist, *just in* different configurations (due to forces and repositioning in time and space). Through the process of analysis or reductionism, people can precisely separate the parts from the whole, leading to clear *distinctions* among all components under observation. More so, once these distinct entities are identified and set aside,

Newtonian thinking presumes they *remain* distinct, meaning they cannot merge, divide, appear or disappear (Heylighen 2006) (this is called atomistic thinking). Reductionism ignores the synergy inherent between interacting parts, the energy that emerges from complex interactions within an integrated whole (Bullard 2011).

The Newtonian approach to the world also leaves no room for novelty or creation because it is presumed that the building blocks for everything already exist, just waiting for someone to *reconfigure* them. "Discovery [of new knowledge] is not a creative process; it is merely an 'uncovering' of distinctions that were waiting to be observed" (Heylighen 2006, 3); knowledge is *out there,* waiting to be discovered. The principles of distinction and determinism (and predictability) led to the philosophy of dualism; that is, while material objects obey mechanical laws (motion, force, and resistance), the mind does not. Hence, this worldview presumes the mind is independent of the body and vice versa. It holds that two sorts of reality (e.g., mind and body, but there are others) should not be able to communicate with or act on each other. In other words, one reality has nothing to do with the other because one is superior to the other, or more *real* (McGregor 2011c; Wilber 2001).

As well, the principle of determinism (aiding predictability) holds that any event is completely determined by previous events (cause and effect); that is, reality follows a predetermined path. This principle rids people of any agency or free will (i.e., purposeful actions or conscious participation). Determinism is reflected in phrases like "I had no choice. It was fate or happenchance. It was just a coincidence" (Bullard 2011). "There is simply no place for [ethics, values, norms] or purposeful actions in the Newtonian world view" (Heylighen 2006, 3).

Not surprisingly then, Newtonian thinking severely shackles the creative solution of emergent, complex, wicked problems. Thinking is restricted to narrow notions of reality, confining linear thinking, dualism and exclusion, predictability and control, and reducing everything to its simplest parts, negating the power of context and the whole. Resistance to change is expected, because order already exists and disorder is not welcomed. By not skipping any steps in a process, Newtonian thinking assumes that linear (cause and effect) progress leads to increases in knowledge. Most significantly for this article, focusing on the parts gives rise to disciplinary specializations and restricted assumptions about what knowledge is needed to address problems. And, even if multi*disciplin*arity and inter*disciplin*arity do manage to arise, they are still confined to the disciplines (with no links to non-academic actors), requiring bridges or facilitation for exchanges and collaborative work, mainly because of the Newtonian principles of separation and dualism (opposites cannot connect).

Multi-, Inter-, and Transdisciplinarity

Disciplines are solitary endeavors intent on carving out autonomous domains of action in which partitioners (disciplinarians) apply specialized techniques, concepts, and approaches. Disciplines strive to prepare specialists in relatively narrow domains, in which their specialized knowledge can be brought to bear (Geisler 2002). These comparatively self-contained and isolated domains of learning

possess their own community of experts, jargon, and ways of doing things (Nissani 1997). And, although single disciplinary work has its place, it *is* limiting when trying to address complex societal problems, because only one lens is brought to bear on the dynamics inherent in the complexity (McGregor 2007). A multi-, inter-, and, better yet, transdisciplinary perspective is required to deal with complexity.

Schneider (2003) referred to multi-, inter-, and transdisciplinarity as "close cousins" (p. 13). Bruun, Hukkinen, Huutoniemi, and Klein (2005) called them "neighbors" (20). Mittelstrass (2011) claimed pure forms of disciplinarity are very rare because they are usually realized and understood in the context of their neighbors. Nonetheless, for the sake of the argument presented in this article, an attempt is made to briefly distinguish among them, both for conceptual clarity, and for truly setting transdisciplinarity apart as a powerful new approach to creating knowledge, which necessitates a conceptual change in people's minds. Table 2 is drawn from Franz and Lehmann (2004), Geisler (2002), Paretti (2011), McGregor (2007, 2010), McGregor and Volckmann (2011), and Stock and Burton (2011). Stock and Burton (2011) recognized that confusing and incorrectly labeling these three approaches to integrated research is one of the key barriers to knowledge integration, with transdisciplinarity "as the holy grail" (1102). They coined the term "MIT disciplinarity" to capture the moniker "multi-inter-transdisciplinarity" (Stock and Burton 2011, 1093).

NICOLESCUIAN TRANSDISCIPLINARITY

While multi- and interdisciplinarity are mainly based on Newtonian science, transdisciplinarity, as understood by Basarab Nicolescu (a quantum physicist), is based on quantum physics, chaos theory, and living systems theory. This collection of new sciences rejects the basic laws and tenets of classical Newtonian physics and thinking (Table 1) (Nicolescu 2010a). He maintained that "modern [Newtonian] science ... is not valid in the field of the transdisciplinarity" (2012, 2). He believed it is essential to seek multiple perspectives on any human problem because the intent is to integrate many levels of truth while generating new TD knowledge. But he proposed this idea about 30 years ago, at a time when Newtonian thinking still reigned, informed by dualism (separatism), linear, cause and effect thinking, determinism, and reductionism (Nicolescu 2006).

To offset this ideological limitation to integrative problem solving and the creation of integrative knowledge, his approach to transdisciplinarity constituted an entirely new methodology for creating knowledge. Nicolescu "worked out" a transdisciplinary methodology with three main pillars (axioms) (Figure 1): (a) Multiple Levels of Reality whose integration is mediated by the Hidden Third (ontology); (b) the Logic of the Included Middle; (c) knowledge as emergent, complex, embodied, and cross-fertilized (epistemology) (Nicolescu 1985, 2002, 2012, 2013). In particular, his approach to transdisciplinarity hinges on the prefix *trans*, which means crossing over, *going beyond*, moving back-and-forth, and/or moving into another state or to another place (Harper 2013). The notion of iterative interactions leading to *a new state* is key to the process of transdisciplinarity. It involves taking down boundaries among disciplines and taking down boundaries

Table 2
MIT Disciplinarity—A Comparison of Multi-, Inter-, and Transdisciplinarity

	Multidisciplinarity *Juxtaposition of Disciplines*	**Interdisciplinarity** *Integration and Collaboration*	**Transdisciplinarity** *Transcendence*
Nature of the problem	Everyone in the discipline studies the same problems, couched *within* the purview of the discipline Issue remains within the domain of the one discipline	Striving to address pressing problems situated at the *intersection* of the disciplines; those involved assume they can solve the problem using only disciplinary knowledge, without consulting non-academic sectors Focus is on the dialogic connections across the disciplines, with the issue acting as the intersection anchor, anticipating cognitive advancement through epistemological openness	Goal is to understand the world and to address wicked, messy problems (characterized by emergence, complexity and plurality), *beyond* disciplinary boundaries Issues *span and go beyond* the boundaries and borders of academic and other sectors (community, industry, state)
Disciplinary Orientation	Disciplines *remain distinct* while people mingle (sit down at table together) but do not linger Each individual acquaints him or herself with more than one discipline, although no connections are made among the disciplines Members of a team, representing different disciplines, work in a self-contained manner (often isolated from the team), while working on a problem of common interest; when each person's work is done, it is handed off to the group Entails co-contributions (protecting one's discipline while respecting others' unique views)	Intent is disciplinary *renewal* and *evolution* Disciplines actually change their concepts due to interacting with other disciplines; they may even change their structure and aims; new disciplines can even emerge (e.g., bioethics), with the original disciplines remaining intact (e.g., biology and philosophy) Want to be able to transfer learnings but not to dismantle disciplinary boundaries; generates new applications, new analyses Expands the multidisciplinary process by both (a) increasing the level of coordination and collaboration of expertise and communication amongst team members and (b) integrating the team's findings (individuals remain within their areas of expertise)	Intent is to establish a new set of axioms related to but *beyond traditional disciplines*; objective is to ensure the integration of as many perspectives as possible (academic and non-academic) Opens up to all disciplines and non-academic actors to what they have in common and what lies beyond respective boundaries and sectors Through increased levels of trust, blurring of disciplinary boundaries and escalating valuing of each other's knowledge and perspectives, transdisciplinary agents become a *community working for a common cause* rather than just a collection of people (like multi and inter)

(Continued on next page)

Table 2
MIT Disciplinarity—A Comparison of Multi-, Inter-, and Transdisciplinarity *(Continued)*

	Multidisciplinarity *Juxtaposition of Disciplines*	**Interdisciplinarity** *Integration and Collaboration*	**Transdisciplinarity** *Transcendence*
	Many perspectives are heard (while respecting each other's disciplinary bases) but intent is to serve disciplinary needs		Intent is creation of transdisciplinary knowledge to address wicked, messy, complex problems
State of Boundaries	Boundaries are *maintained* BUT because there is no mutual understanding of specialized disciplinary approaches, people from each discipline must be willing to chase into each other's territory and also be prepared to explain, defend even yield their own approach to another's	Boundaries between disciplines are temporarily bridged to enable collaborative work	Boundaries among disciplines and between higher education and non-academic sectors are *blurred, distorted, dismantled, even transcended*
Concepts	Concepts are confined within the disciplines and are not integrated	Disciplinary concepts, methods and epistemologies are explicitly exchanged, transferred and integrated	*New trans* disciplinary concepts are created through the fusion of disciplinary and non-disciplinary contributions; these concepts are called embodied knowledge, owned by everyone who co-created them using inclusive logic while integrating many perspectives

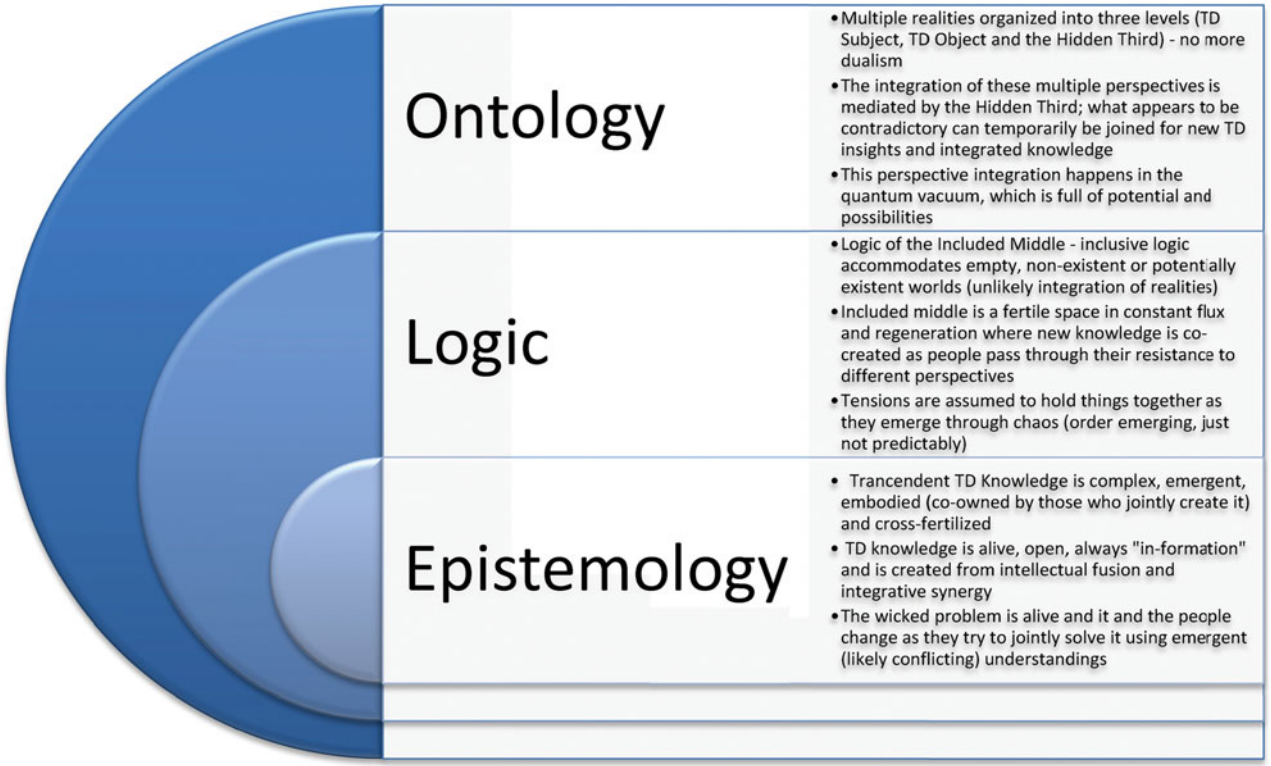

Figure 1. Three axioms of transdisciplinary methodology.

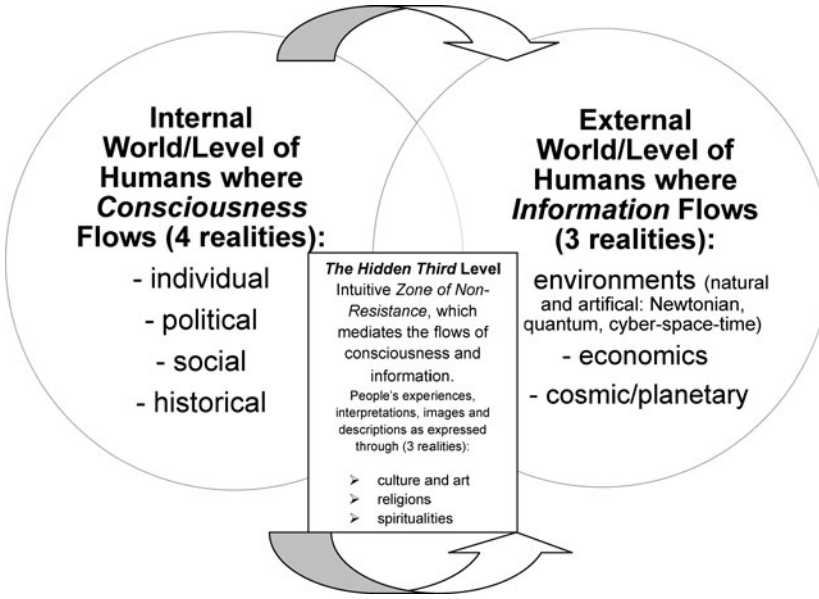

Figure 2. Three levels of transdisciplinary reality.

between the university and the rest of the world, leading to cross-sectoral problem solving. The creation of "small, adaptive 'inter-spaces' between higher education and other societal sectors" (Hampson and Assenza 2012, 11) is the essence of Nicolescuian transdisciplinarity.

Ontology (Reality)

In a major push-back against Newtonian dualism and the singular notion of matter-based reality, Nicolescu proposed that TD ontology encompasses at least 10 different realities (perspectives and view points), aside from just the physical, material reality. These 10 realities are organized along three levels. Level one is the internal world of humans, where *consciousness* and *perspectives* flow—the TD-Subject (comprising political, social, historical, and individual realities). Level two is the external world of humans where *information* flows—the TD-Object (comprising environmental, economic, and cosmic/planetary realities). Level three is the Hidden Third. Peoples' experiences, intuitions, interpretations, descriptions, representations, images, and formulas meet on this third level. Three realities exist on this level, this intuitive zone of non-resistance to other's ideas, this mediated interface: culture and art, religions, and spiritualities (Nicolescu 1985, 2002); see Figure 2.

The author understands the Hidden Third to represent people's sensibilities to what it means to be humans living together on the earth, and how hard it is to problem solve when ideologies, interests, positions, and values are in conflict, yet the problem dearly needs to be solved. It serves as the mediating grease for

interactions when solving seemingly intractable problems. Of deep significance to Nicolescu's approach to transdisciplinarity is that while each of the 10 realities is characterized by its incompleteness, in *unity*, they generate new, infinite transdisciplinary knowledge (Nicolescu 2006). This approach to reality (ontology) is profoundly different from the Newtonian notion of *one* level of reality, the empirical (physical) reality, materialism, predicated on the notion of *matter.* TD transreality includes matter *as well as* consciousness, perspectives, emotions, and various approaches to what counts as knowledge and ways of knowing (far beyond Newtonian exclusionary dualism).

More about the Hidden Third. At a time when it was counterintuitive to engage in any sort of cross-disciplinary work (the late '70s), let alone cross-sectoral work, Nicolescu needed a concept to accommodate people resisting other people's worldviews, and a way to allow for the integration of these worldviews to create new knowledge. Being a quantum physicist, he was inspired by the quantum vacuum, which is not empty, just at its lowest energy point, ready for emergence and potential. With this inspiration, he coined the term the Hidden Third. The word "hidden" obviously means it is invisible. The word "third" typically refers to someone playing a mediating role between two entities. Succinctly, Nicolescu (2011a) suggested that the Hidden Third (the quantum vacuum) refers to a zone of non-resistance to other's views on reality that plays the mediating role of a third between information and consciousness and perceptions. It acts like a *secretly included* middle agent that allows for temporary unification of, what are normally, contradictory ideas. Because Newtonian thinking assumes object (information) and subject (consciousness/mind) cannot connect (dualism), Nicolescu argued that in order to address humanity's pressing problems, different perspectives "have to meet in a least one point **X**" and they are able to do so because meditation of the interactions between them happens via the Hidden Third (Nicolescu 2005, 9).

Still inspired by the quantum vacuum, Nicolescu (1985, 2011a) posited that the Hidden Third is a way to conceive of people moving to a place where they become open to others' perspectives, ideologies, value premises and belief systems, inherently letting go of aspects of how they currently *know* the world. To that end, he assumed Reality is always in flux, that it is plastic (Cillier and Nicolescu 2012; Nicolescu 2011b), meaning it is malleable and pliable. Transdisciplinarity is deeply concerned with the dynamics created by the simultaneous action of several Levels of Reality; that is, the *movement* of Reality, facilitated by the lubricating role of the Hidden Third (Nicolescu 1999). The result of this transmovement is the emergence of new TD knowledge, possible because people's eyes and minds have been opened to other points of view, which can be integrated using the Logic of the Included Middle.

Logic

Multi- and interdisciplinarity stem from classical physics and the modern sciences (Newtonian thinking) (Nicolescu 2008). He posited that transdisciplinarity requires a different kind of logic when operating in the *secretly included middle*

(the Hidden Third, the quantum vacuum). Logic is concerned with the habits of the mind that are acceptable for inference and reasoning when arguing one's position on an issue. Instead of the Logic of Exclusion (exclusionary dualism and separatism) used in Newtonian thinking, transdisciplinarity requires the Logic of Inclusion—the *Logic of the Included Middle*. Nicolescu clarified that "the logic of the included middle does not abolish the logic of the excluded middle: it only constrains its sphere of validity" (2000, 6). Both logics are needed to address wicked problems.

The Newtonian logic of exclusion assumes the space between objects or people is empty, flat, static, and void of life (much like the space between the balls on a billiard table). In academic life, this logic manifests as separate departments, journals, library holdings, conferences, and professional associations. It is also evident in the familiar intellectual actions of: deduction (cause and effect), linear thinking, reductionism (breaking things down into parts to understand the whole from which they come), and either/or approaches (dualism) with no room for contradictions (Table 1; McGregor 2007, 2011c).

In stark contrast, the Logic of the Included Middle draws on inclusive logic. Inclusive logic permits (a) empty domains, (b) worlds that do not exist, and (c) worlds that might eventually exist (Nolt 2010). This logic accommodates the eventual, possible, creation of new, integrative knowledge that does not yet exist. Inclusive logic enables people to imagine that the space between things is alive, dynamic, in flux, moving, perpetually changing, and full of potential and eventualities (like a lava lamp). It is in this *fertile middle space* that transdisciplinary manifests itself (Figure 3, a light hearted representation of this powerful dynamic). Transdisciplinarity has people from all walks of life stepping through the zone of non-resistance (away from one worldview and one notion of reality toward others) onto a fertile, moving floor of the *included middle,* where, together, they generate new TD intelligence and knowledge (where previously there was none, or its potential had not been realized). When people from different disciplines and sectors come in contact with each other and are motivated, an energizing force is generated—a synergy is created. This synergy leads to the generation of *embodied knowledge* created from the energy emanating from *intellectual fusion.* Everyone involved now owns the new TD knowledge because it was co-created (McGregor 2004, 2009).

The Logic of the Included Middle requires scholars to create a space for dialogue and knowledge generation and for transintegration. In this space, attempts would be made to reconcile different logics for the sake of addressing wicked problems facing humanity (achieving non-dualism wherein contradictory ideas are temporarily reconciled). Using inclusive logic to move through the different types of reality (by making space for reconciling contradictions) creates the *permanent possibility* for the eventual evolution of TD knowledge unique to the wicked problem and the actors involved in its solution (McGregor 2011b).

Epistemology (Knowledge)

Disciplinary, multi- and interdisciplinary research happen within the confines of academic disciplines, with no intention of integrating knowledge or of engaging

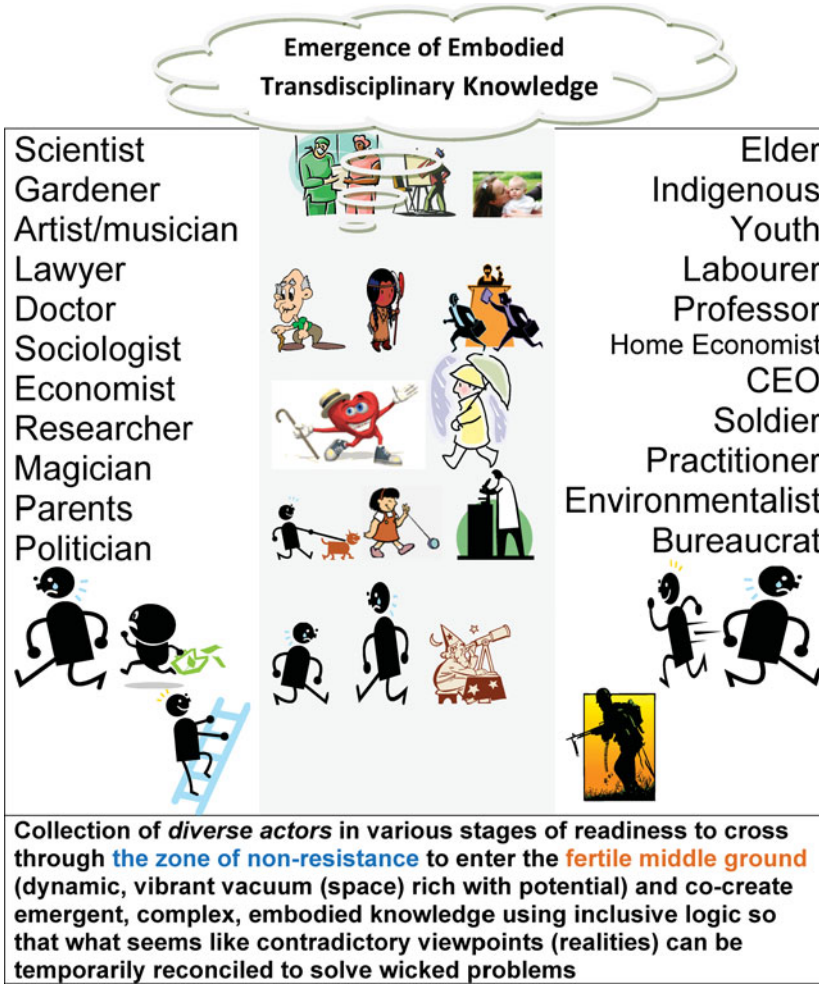

Figure 3. Whimsical representation of the logic of the included middle.

with people outside of the university (Table 2). In contrast, Nicolescu (2002, 2008) posited that TD knowledge is based on cross-fertilization, and is characterized by complexity, emergence, and embodiment (McGregor 2011b). Horlick-Jones and Sime (2004) coined the phrase *border-work* to refer to the intellectual work that occurs when people living on the borders of the academy (university disciplines) and other sectors (civil society, industry, government) engage in knowledge generation to address wicked problems.

Nicolescu (2010a, 2011a, 2012) draws on Morin's (1999, 2005) approach to complexity. TD methodology assumes that everything is *complexus*—woven into a web, where the focus is on the relationships (links), not on the separate parts.

Emergence refers to novel qualities, properties, patterns, and structures that appear from relatively simple interactions among people in this web, qualities that did not exist when presented in isolation. These new qualities are layered in arrangements of increased complexity (Morin 2005; Nicolescu 2008). The process of emergence manifests when people pass through the zone of non-resistance (accepting there are many realities) and enter the fertile middle ground to problem solve using inclusive logic (Figure 3). The resultant TD knowledge is characterized as embodied, a part of everyone who co-created it, rather than discipline-bound or sector-bound.

Knowledge as emergent also means wicked problem(s) *continually change* as people try to jointly solve them. Each wicked problem (e.g., poverty) is a rich weave of societal structures and functions. The *weave of poverty* (and people's understandings of it) keeps changing because new and coherent structures, patterns and properties *emerge* as a result of iterative interactions among people while engaged in intellectual border work within the web of changing relationships. Original perceptions of the problem are left behind, transformed, even transcended, as new understandings of the problem take shape and as synergistic energy is generated via intellectual fusion (McGregor 2004, 2009). The resultant TD knowledge is open and alive because the wicked problem the knowledge addresses is alive, emerging from the life world (Max-Neef 2005; McGregor 2009; Nicolescu 2005). When people accept the world and everything in it as dynamic, evolving and always *in-formation*, their knowledge, explanations, and definitions gain nonpermanent status, thereby rendering TD knowledge as always in-formation, emergent, and vibrant (McGregor 2004; Nicolescu 2005).

Finally, cross-fertilization of TD knowledge results from the iterative convergence of different actors and their fuzzy-edged balls of knowing, shaped by their respective disciplinary or sectoral expertise. TD cross-fertilized knowledge emerges through the process of transintegration, understood to mean opening things up to all disciplines and to civil society- and other sector-knowing so that something new can be created via synthesis and the harmonization of ideas and perspectives (Nicolescu 1997). Cross-fertilized TD knowledge is transcendent in that those involved give up sovereignty of their domain to create a space for the emergence of new knowledge (Somerville and Rapport 2002). Cross-fertilization (transcending disciplines) takes us far beyond the multidisciplinary stance of juxtapositioning separate disciplines and interdisciplinarity's attempt to collaborate and integrate while not dismantling disciplinary boundaries (Table 2).

In summary, if academics were to employ a transdisciplinary approach, they (a) would crisscross disciplinary and sub-disciplinary boundaries with the intent to change (or remove) the borders while integrating theories, policies, and practices emanating from this disciplinary migration and integration. (b) They would then recognize that leadership for humanity happens in the fertile middle ground within the academy *and* among higher education, civil society, and other sectors. (c) This leadership would be informed by the logic of inclusion and the mediated interaction and transintegration among multiple levels of transreality. They would find new respect for tension and chaos (d) especially as they manage the value-laden transdisciplinary dialogue inherent in intellectual fusion and perspective integration. (e) Academics would appreciate that resultant TD knowledge is complex,

emergent, cross-fertilized, and embodied. Finally, (f) they would integrate the many realms of reality (multiple perspectives and logics) as they work with other disciplines *and* members of civil society in intellectual border-work to generate TD knowledge to address the wicked context of twenty-first-century humanity.

The next section provides an overview of conceptual change theories followed with inaugural speculation as to how this phenomenon might play out when academics are asked to embrace a more holistic and transintegrative approach to address the problems of the world through a transdisciplinary lens. As an interesting sidenote, transintegrative has been described as an approach that helps people gain new frames of reference through awareness of archetypal or universal concepts that underlie all human feeling and thinking. These concepts create bridges to help people move from old to new frames of reference (MacLean et al. 1961); in this case, *to cross over* to transdisciplinarity.

CONCEPTUAL CHANGE THEORIES

Originally conceived by Posner and colleagues (1982), conceptual change has evolved into a thriving line of inquiry, rich with nuanced, ongoing debate among proponents of the theory (Özdemir and Clark 2007). Conceptual change is concerned with "the process by which people's central organizing concepts change from one set of concepts to another, incompatible with the first. [That] is, how concepts change under the impact of new ideas or new information" (Posner et al. 1982, 211). There are no widely accepted, well-articulated, and tested theories of conceptual change (diSessa 2006), but there are many perspectives that can inform the line of thinking shared in this article; that is, how do disciplinarians and those bridging disciplines (multi and inter) shift conceptual frameworks (ideologies and philosophical methodologies) to value transdisciplinarity, moving beyond disciplines?

The article began with a discussion of Newtonian thinking, which is one of the prevailing ideologies shaping the twenty-first century (Kincheloe and Steinberg 1993; McGregor 2013). This ideology is deeply evident within higher education. Ideologies are successful when they become so commonplace that no one questions them or their influence on interpreting the world. They become, in effect, the basis for everyday life and the cornerstone of lay culture. Conceptual change researchers use the idea of *naivety* to refer to people's reliance on lay notions of their world (Vosniadou 2007), of which ideologies, like Newtonian thinking, play a central role. Vosniadou (2007) acknowledged the new trend of understanding conceptual change in relation to reconciling ideological differences.

Conceptual change theories normally help educators understand how *students* move from *naive* conceptualizations of ideas to those that are more sophisticated and reflective of normative (some say correct) approaches (e.g., from thinking the earth is flat to thinking the earth is round). Conceptual change theories are most common within science and mathematics education (especially as it is informed by history, philosophy, and cognitive developmental psychology), as well as by health, social sciences, and design education. These theories offer insights into how *students* learn new, abstract concepts and how concepts change with learning

and development (Mason 2007; Vosniadou 2007; 2013; Wikipedia Encyclopedia 2013).

In this article, conceptual change is used differently than above, which focused on students. Instead, it is used to shed insights into what might be involved in *academics* shifting from sole reliance on *naive* disciplinary ways of knowing (informed by Newtonian thinking) to more complex and sophisticated approaches to creating knowledge and using said knowledge to address wicked problems. Naive usually means unaffected simplicity, lack of guile, ignorance of life. In this article, a generous helping of creative license was employed, whereby naivety is presumed to mean one's wisdom or judgement is confined by particular worldviews (Oxford Dictionary). Naivety can thus refer to being ignorant of more sophisticated perspectives and alternatives to the longstanding, narrow disciplinary approaches informed by Newtonian thinking.

Perhaps another way to conceive this naivety is to view it as an ideological or conceptual *blind spot*. Blind spots refer to conventional wisdom that no longer holds true but still guides thinking (Porter 1980). Tuchman (1985) claimed these blind spots impair people's ability to see reality for what it is. Roth (2001) explained that as people are enculturated into specific disciplines, they acquire "the blind spots, ideologies and prejudices of the field" (6). Through this enculturation process, people, ofttimes unaware, pick up prejudices and common-sense notions of what counts as knowledge, reality and logic in their field. Roth (2001) referred to these as conceptual blind spots and epistemological prejudices.

Wagner (1993) believed disciplinarians can fill in *blank spots* in their knowing by drawing on their "collective ignorance" (16), or as Kincheloe and Steinberg (1993) called it, their "gravitational field" (300). However, *blind spots* are areas in which "existing theories, methods, and perceptions actually keep [people] from seeing phenomena as clearly as [they] might" because blind spots represent what they "don't know enough to even ask about or care about [i.e., ignorance]" (Wagner 1993, 16). Indeed, von Forrester (2003) referred to cognitive blind spots. People often do not know they have a blind spot; that is, "we do not see that we do not see" (von Forrester 2003, 284). These blinders make it very difficult to accept there are multiple realities (Meyerson and Martin 1987). Ideological blind spots mean other perspectives (realities) may not even be considered when engaging with wicked problems.

This begs the question, "What is involved in academics undergoing conceptual change as they move towards transdisciplinarity, from naive to more sophisticated notions of what is knowledge, reality and logic?" As a caveat, in the spirit of this imaginative undertaking, no intellectual disrespect or violation of the cited authors' original ideas about conceptual change theory is intended; rather, their ideas served as deep sources of inspiration for the ideas in this article, as conceptual stepping stones. Now to a discussion of the three main approaches to conceptual change theory (Figure 4).

Özdemir and Clark (2007) suggested that two dominant threads of thought run through the conceptual change research domain. Some focus on *knowledge as theory* and others focus on *knowledge as elements*. The former assumes people's

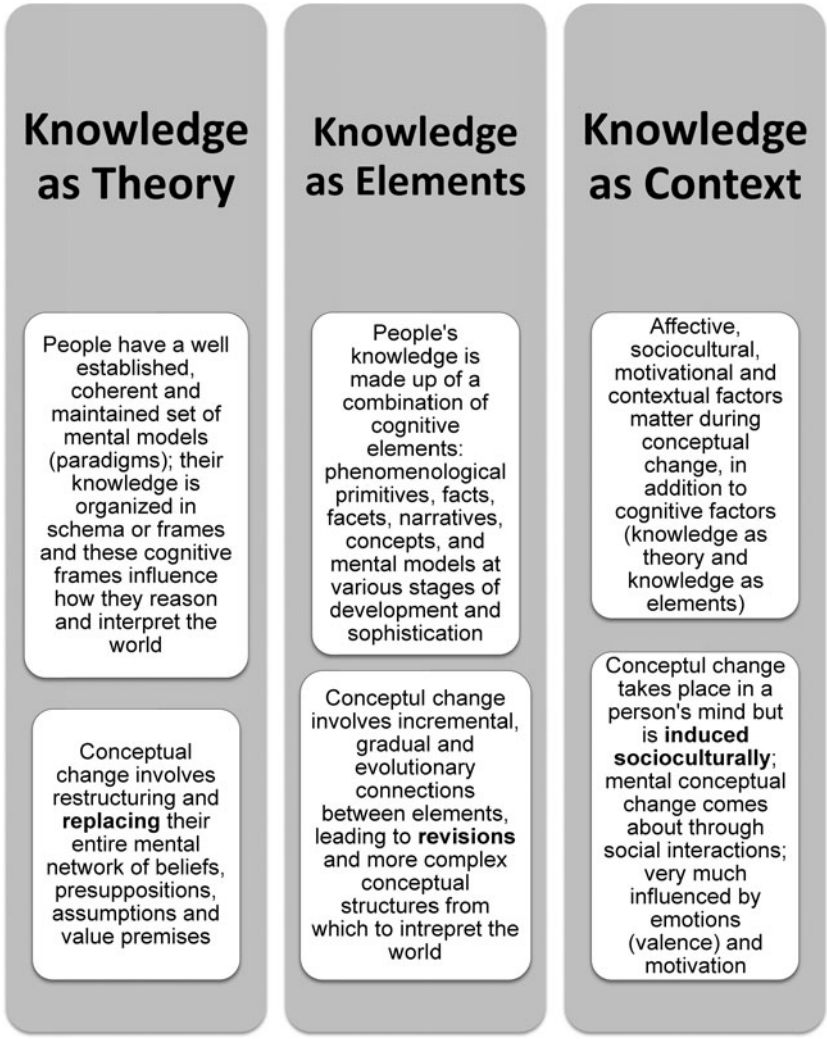

Figure 4. Three aspects of conceptual change theory.

knowledge is most accurately represented as a "coherent, unified framework of theory-like character" (Özdemir and Clark, 351). People's knowledge reflects an "overarching hierarchal conceptual structure" (352), which can only change if they experience a radical paradigm shift (mental models and belief systems) wherein they assimilate and accommodate new ideas. In contrast, the knowledge as element approach assumes people understand things in terms of a "collections of multiple quasi-independent elements" including but not limited to "phenomenological primitives [p-prims], facts, facets, narratives, concepts, and mental models

at various stages of development and sophistication" (Özdemir and Clark,354). A third challenge to these two approaches has emerged in the form of *emotional, social and contextual* conceptual change (Mason 2007; Vosniadou 2007). Each is now briefly addressed.

Knowledge as Theory

Posner et al. (1982) proposed that a person's current concepts, their "conceptual ecology" (212), will influence their receptiveness to and selection of new concepts. As well, prior conceptions are extremely resilient and highly resistant to change because concepts are so dependent upon the cognitive artifacts within a person's *conceptual ecology* comprising their constituent ideas (parts of the whole), ontological categories (notions of reality) and epistemological beliefs (what counts as knowledge and truth). Their conceptual ecology highly influences their interactions and receptiveness to new ideas, to new concepts (Davis 2001; Özdemir and Clark 2007; Posner et al. 1982).

To complicate the situation, the knowledge as theory approach assumes conceptual change is a gradual process because it occurs at the level of individual concepts. This process is even more entangled because some concepts are attached to others. With this web-based relationship between concepts, a revision of one requires revisions to others. For example, if a person was able to replace the concept of dualism (exclusion) with non-dualism (inclusion), they would also have to revise their notion of separability so it accommodated interconnectedness. As well, concepts are connected through people's belief system, meaning that for conceptual change to occur, people's ontological commitments must be open to revision and radical change (see Özdemir and Clark 2007; Vosniadou 2013). Chi (2008) agreed that conceptual change requires an ontological shift.

Davis (2001) and Özdemir and Clark (2007) explained that conceptual change is often likened to Kuhn's (1970) idea of a paradigm shift. At any given point in time, people maintain a small number of well-developed coherent mental models (ideologies and theories) that give them consistent predictions and explanations across significant domains in their life (Özdemir and Clark). These entrenched paradigms (worldviews, like the aforementioned Newtonian worldview) constrain future learning of new concepts, making the conceptual change process difficult because people must revise and restructure an *entire* mental network of beliefs, presuppositions, assumptions, and value premises (Chi 2008). "Ontological and epistemological presuppositions form the foundations of our knowledge base and their revision is likely to have serious implications for all the subsequent knowledge structures which have been constructed on them" (Vosniadou 1994, 49).

Knowledge as Elements

Whereas knowledge as theory viewed conceptual change as a "broad, theory-replacement process," knowledge as elements involves "a piecemeal evolutionary

process" by which "elements and interactions between the elements are revised and refined through addition, elimination, and reorganization [of the elements] to strengthen the network" (Özdemir and Clark 2007, 355). The knowledge as theory approach assumes knowledge is organized in schema or frames, and changes to concepts are *re*volutionary (dramatic change or innovation). In contrast, the knowledge as elements approach assumes conceptual change is incremental, gradual and evolutionary, with times when conflicting ideas can co-exist within a person's conceptual ecology (Özdemir and Clark 2007). To reiterate, the elements making up a person's knowledge include phenomenological primitives [p-prims], facts, facets, narratives, concepts, and mental models at various stages of development and sophistication.

Leading up to conceptual change within a person, implicit presumptions influence people's reasoning when they interpret the world (Özdemir and Clark 2007). People assume things happen in life just because that is the way things are. These unquestioned beliefs emerge from people's experiences, observations and abstractions of phenomena. Over a period of time, people's concepts will change due to the "gradual accretion and piecemeal eliminations, additions and organization of elemental knowledge pieces" (357). Where once they spontaneously connected and activated these knowledge pieces, "during the conceptual change process, the elements [pieces] and interactions between the elements are revised and refined through addition, elimination, and reorganization to strengthen the network" (355). In this process, small elements (be they beliefs, facts or narratives) get connected to create more complex conceptual structures. The result is a more *complex base* from which to interpret the world; one might say, more explicit assumptions to inform reasoning and logic.

Knowledge in Context

diSessa (2002) cautioned against underestimating the complexity and diversity of conceptual change phenomena. Indeed, more recent thinking posits that conceptual change is not solely influenced by cognitive factors (theory-like or elements). Affective (emotional), social–cultural, motivational and contextual factors can also contribute to conceptual change (Davis 2001; Mason 2007; Sinatra and Pintrich 2003; Wikipedia Encyclopedia 2013). Jovchelovitch (2007) coined the term *knowledge in context* to account for the cognitive and social nature of conceptual change.

Thagard and Zhu (2003) explained that adoption of alternative viewpoints that are very contradictory to existing stances requires cognitive changes in beliefs and concepts as well as changes to the valences people hold for the new idea. Valence means chemistry—a visceral reaction to an idea. Valence also refers to the capacity of one thing to affect another in a special way. "Emotional conceptual change is a change of valence from positive to negative or vice versa" (Thagard and Zhu 2003, 100). To illustrate, in order for people to accept transdisciplinarity, those embracing Newtonian thinking would not only have to change their beliefs about cause and effect and the role of complexity, they would have to change the valence they have for these concepts. "Entrenched emotional attitudes [i.e., valences] may be

a substantial barrier to ... largescale cognitive-emotional shifts" (Thagard and Zhu 2003, 101). Therefore, they concluded, holding an intention to understand and evaluate alternative points of view makes it easier for emotional conceptual change to occur (see also Sinatra and Pintrich 2003).

In contrast to the cognitive approach to conceptual change (knowledge as theory or knowledge as elements), the social–cultural approach maintains that "conceptual change cannot be seen as an individual, internal, cognitive process but as a social activity that takes place in a complex sociocultural world and that the surrounding situational, cultural and educational context should be taken into account" (Vosniadou 2007, 58). Conceptual change involves people doing more than relacing an incorrect conception with a correct one. It also entails taking different points of view and understanding when different conceptions are appropriate depending upon the context. The sociocultural perspective assumes that affective, motivational, and personal variables matter during conceptual change.

Indeed, Mason (2007) explained that from a cognitive perspective, knowledge is an entity in someone's head and knowing means possessing that knowledge. From the sociocultural approach, knowledge is an activity that cannot be considered separately from the context in which it takes place; hence, knowing means belonging, participating, and communicating during a process of enculturation into a learning community. He further explained that conceptual change goes beyond modifications of one's conceptual structures to a concern for the embeddedness of these same structures. Second, concepts are more than mental entities; they are tools people use when thinking and communicating, serving as modes of reasoning and logic (Mason 2007).

Third, hard-core sociocultural scholars believe that concepts cannot be transferred from one situation to another because they are context-specific (Mason 2007), although this assumption is being challenged. To illustrate, Greeno (1997) posited that what is transferred is more than a concept. He conceived transfer in terms of "transformations of constraints, affordances, and attunements" (Greeno 1997, 12). As people experience "improved participation in interactive systems" (Greeno 1997, 12) more and more things can be transferred, leading to conceptual change.

In summary, the sociocultural approach assumes that conceptual change takes place in an individual's mind but it is induced socioculturally. Concepts are viewed as existing *between* minds with conceptual knowledge being inseparable from the social practices of communication and discourse (context) (Mason 2007). While the cognitive approach to conceptual change embodies the acquisition metaphor (individual minds can *acquire*, develop, and change concepts), the contextual approach uses the participation metaphor (concepts are gained through knowing and doing, through participating in social and cultural activities as apprenticeships in thinking) (Sfard 1998). Conceptual change is a mental change that comes about because of social interactions, and this process of change is greatly influenced by motivation and emotions. The latter determine when someone adopts a new frame of mind or remains entrenched in their previous frame of mind (Thagard 2003) (Figure 4).

CONCEPTUAL CHANGE APPLIED TO UNDERSTAND TRANSDISCIPLINARITY

In a general sense, *trans* means moving between, across, and beyond one state to a new state. More specifically, trans*disciplinarity* means moving back and forth between disciplines as well as moving across and beyond disciplines to engagement with the rest of the world, to a new state or a new place. Moving beyond mono, multi and interdisciplinarity to transdisciplinarity is a profound conceptual shift. The former are mainly predicated on Newtonian thinking while transdisciplinarity is based on the new sciences of chaos, quantum physics, and living systems— understanding the dynamic unfolding of life at the infinitesimal level. Such a conceptual shift entails profound and far reaching change from one way of thinking to another, despite that "the transdisciplinary way of understanding rests on the traditional and newly developing disciplines or regions of research and knowledge generation" (Weislogel 2013, 80). When moving toward the new state of transdisciplinarity, mental thresholds have to be crossed and threshold concepts must be mastered.

Mastering threshold concepts is central to shifting to any new worldview. Nicolescuian transdisciplinarity is rich with threshold concepts. Threshold is Old English *perxold*, point of entry (Harper 2013). Threshold concepts represent a transformed way of understanding, interpreting or viewing something. They represent troublesome knowledge (conceptually difficult). They are alien ideas, often counterintuitive and often described as inaccessible or supercomplex. As disquieting as they are, threshold concepts instigate new learning and new ontological possibilities. Once people comprehend a threshold concept, they experience a transformed internal view of the thing in question, including worldviews and methodologies for creating new knowledge (Land 2010). Transdisciplinary threshold concepts include the Hidden Third, inclusive logic, emergence, embodiment, the included middle, the zone of non-resistance, and multiple levels of reality. They also include the idea that knowledge is alive, that it is always in-formation (a counterpoint to Newtonian static information) and that it is created through intellectual fusion. I could go on.

Massive conceptual change is involved before people can gain a sense of "what is transdisciplinarity"? But, the more one accepts Newtonian physics, the harder it is to imagine a world in which other postulates are true (Posner et al. 1982). Therein lies the challenge of shifting to a transdisciplinary perspective. Multidisciplinarity and interdisciplinarity rely on the tenets of Newtonian thinking while transdisciplinarity is predicated on the new sciences, the antithesis to Newtonian thinking (Nicolescu 2010b).

In more detail, multi- and interdisciplinarity have enjoyed far reaching, pervasive success because their philosophical core, Newtonian thinking, "is compelling by its simplicity, coherence and apparent completeness [and it is] largely in agreement with intuition and lay common-sense" (Heylighen 2006, 1). Unfortunately, the new sciences, which are challenging Newtonian thinking, "lack this simplicity and intuitive appeal, and are still plagued with paradoxes, confusions and multiple

interpretations" (Heylighen 2006, 1). Transdisciplinarity, by virtue of its grounding in the new sciences, also experiences challenges with being accepted as a new paradigmatic approach to addressing global problems. What is involved in getting people to embrace the new concepts entailing transdisciplinarity? Posner et al. (1982) suggested that accommodating conceptual change entails intelligibility, plausibility, and fruitfulness of the new approach (i.e., transdisciplinarity) along with some level of dissatisfaction with one's existing conceptual framework (i.e., multi- and interdisciplinarity). Each is now discussed.

Intelligibility

For starters, only if people can psychologically construct a coherent, meaningful mental representation of a new idea can it become a tool of thought (Posner et al. 1982). Such is the case for transdisciplinarity. In order for people to consider any alternative conception (e.g., transdisciplinarity), they must find it *intelligible*, be able to *internally represent* it in their mind (Figures 2 and 3). *Intelligibility* requires more than just knowing what the words mean and what any associated symbols mean. It also involves grasping "the intelligibility of the whole" and not just "the intelligibility of the parts" (Posner et al. 1982, 218). This learning is a very demanding psychological and intellectual task (see next section on postformal thinking) because it is very easy to simply use the alterative ideas in a superficial way without the necessary revisions to one's conceptual ecology (i.e., one's current collection of concepts) (Posner et al. 1982). For transdisciplinarity, this plays out in people's assumptions that it means *beyond disciplines*, which is partially true, but TD's grounding in the new sciences takes *beyond disciplines* to a whole new level. It becomes a "philosophy of the beyond" (Weislogel 2013, 92), not just movement to the other side.

Plausibility

Another challenge to embracing conceptual change is the *plausibility* of what one is being asked to accept. If the new idea is counterintuitive to one's long established way of knowing, there will be much resistance and implausibility (it is unreasonable to accept the new idea) (Posner et al. 1982). A prime example of this with Nicolescuian transdisciplinarity is the notion that there are multiple levels of reality, not just one physical, material reality (Newtonian thinking). It goes against people's intuitive senses to ask them to accept that there is more than one type of reality. And, as long as people remain committed to their epistemological beliefs (what counts as knowledge and truth), their cognitive blind spots, they will find any new conceptualizations counterintuitive and implausible. To shift to a TD perspective, to place less energy on "protecting [one's] metaphysical commitments" (Posner et al. 1982, 220), people have to delve deeply into self reflection to determine the strength and depth of their metaphysical beliefs because this determines the extent to which they can move past the implausibility of the new idea of transdisciplinarity (Kincheloe and Steinberg 1993).

Fruitfulness

Posner et al. (1982) also suggested that accepting a new concept is contingent on the *fruitfulness* of the new conception. For people to embrace a new conceptualization of a phenomenon, they must be convinced of its potential. If, when they attempt to interpret their world and experiences using the new conception, they realize new insights and discoveries, "then the new conception will appear fruitful and the accommodation of it will seem persuasive" (222). A plausible conception must first be intelligible, and a fruitful conception must be intelligible and plausible (Duit and Treagust 2003). This means that people have to find transdisciplinarity both intelligible and believable before they will ever consider using it to see if it is fruitful. This indeed *is* a conceptual challenge given trandisciplinarity's grounding in the new sciences, which are *so* different from the familiar ideology of Newtonian thinking, which shapes most day-to-day, lay thinking, even within the academy.

Dissatisfaction with Existing Conceptions

Finally, based on Kuhn's (1970) idea of paradigm shifts, Posner et al. (1982) proposed that in order for people to become open to a new conceptualization (e.g., transdisciplinarity), they "must first view an existing conception with some dissatisfaction before [they] will seriously consider a new one" (220). In this case, the long established conceptions *are* disciplinarity, multidisciplinarity, and interdisciplinarity, all grounded in Newtonian thinking (Nicolescu 2010b). Posner et al. actually queried, "Why consider alternatives to a Newtonian view (or whatever view they hold) when they are unconvinced of the inadequacy of their convictions?" (1982, 221). Although many agree that disciplinary-based approaches to addressing the world's wicked problems are insufficient, most scholars are tenaciously hanging onto their disciplinary knowledge, or to multi and interdisciplinarity, their cognitive blind spots (McGregor and Volckmann 2011). This tenacity is unfounded. Nicolescu (2005) recognized that all four types of knowledge creation are absolutely necessary, asserting that "transdisciplinary research is clearly distinct from disciplinary [and multi-and interdisciplinary] research, even while being entirely complementary" (3).

EASE OF TRANSITION TO TRANSDISCIPLINARITY

When transitioning from one methodology to another, it is worth noting that conceptual change involves revolutions (revolving) in that concepts change places in an hierarchy (Thagard 2003). In this case, hierarchy means an arrangement according to relative inclusiveness, not order of importance (Oxford Dictionary). It could be suggested that while mono-, multi-, and interdisciplinarity are still needed, they change places in the MIT hierarchy (Stock and Burton 2011), with transdisciplinarity moving closer to the top.

This reordering begs the question, "How easy will it be for mono-, multi-, and interdisciplinary-oriented scholars to accommodate, to transition to, the transdisciplinary perspective?" Posner et al. (1982) shared some intriguing insights into this query. First, when an idea is very complex, such as transdisciplinarity,

it is likely that people will accommodate certain parts of it but not others. For example, they may be open to complex and emergent knowledge but balk at the idea of multiple levels of reality mediated by a Hidden Third. People may be receptive to blurring or dismantling boundaries among disciplines but not to cross-sectoral engagement. Accommodating such complex new conceptualizations will probably involve accepting some of the claims and then generally modifying other ideas, as people more fully realize the meaning and implications of their new conceptual commitment to transdisciplinarity (Posner et al. 1982).

Posner et al. (1982) further explained that initial conceptual adjustments lay the ground work for further adjustments, resulting in a substantial reorganization or change in people's central concepts. And, even though shifting from disciplinarity to trandisciplinarity is a *radical* change, Posner et al. do not understand radical to mean abrupt. For them, radical actually means departing from the traditional way of doing things and of seeing the world; that is, change at the root level. Shifting to transdisciplinarity entails changing one's *fundamental,* root, assumptions about what counts as reality, logic and knowledge, far beyond Newtonian thinking laid out earlier in the article (one reality, exclusionary logic and knowledge as static and fixed). People require time for any substantial reorganization of their worldviews.

It might also be the case that people may accept some postulates from Nicolescuian transdisciplinarity as described in this article but understand them from a non-Nicolescuian fashion (Posner et al. 1982). For example, people may accept the idea of multiple levels of reality from a numeric perspective (more than one) but not understand the role of consciousness and information flows as an inherent part of Nicolescu's approach to transdisciplinarity (Figure 2). Or, they may accept the idea of inclusion (wanting to include as many perspectives as possible) but not understand the idea of Nicolescuian inclusive logic informed by quantum physics. They may relate to the idea of needing a third person to mediate contradictory ideas, but be unable to accept the idea that a vacuum is full of potential, rather than empty (the mediating Hidden Third). Given all of these threshold concepts and dimensions of accommodating conceptual change, Posner et al. (1982) described transitioning from one conceptual framework to another as "fumbling about, many false starts and mistakes, and frequent reversals in direction" (223).

POSTFORMAL THINKING AND CONCEPTUAL CHANGE

Recognizing this conceptual slippage, Mason (2007) described conceptual change as moving toward *changes in ways of thinking* about knowledge, an idea that resonates with the intent of this article, which proposed people could embrace transdisciplinarity as a new way to think about knowledge, moving beyond the long established *formal* logic, ontology, and epistemology attendant to Newtonian thinking. Consider that until fifty years ago, it was accepted that people's cognitive abilities (their ability to gain intelligence) evolved through four stages, culminating in *formal operations*, wherein people are able to solve problems using empirical or *logical* evidence, and are able to think in an abstract manner, combining and classifying items using higher order reasoning. They can think in absolutes, make decisions based on linear logic, do things systematically (rule out things and

Figure 5. Elements and stages of postformal thinking.

see relationship among them), and think about things they have not experienced (hypotheticals) (per Jean Piaget).

Eventually, cognitive psychologists began to appreciate that humans are capable of engaging in much more complex, "sophisticated thinking" (Kincheloe and Steinberg 1993, 298), beyond the *formal operations* stage. This form of thinking became known as *postformal thinking* (*post* means after) (Kegan 1994). Gidley (2010) linked postformal thinking with transdisciplinarity, identifying several features of postformal reasoning: complexity, dialectics, dialogue, imagination, reflexivity, paradox, pluralism, and wisdom. In particular, Kincheloe and Steinberg (1993) identified four key features of postformal thinking: etymology, process, patterns, and context, while Commons (2008) and Commons and Richards (2002) tendered a Model of Hierarchical Complexity, wherein they conceived of systematic, metasystematic, paradigmatic, and cross-paradigmatic order thinking (Figure 5). These two approaches are now explained to illustrate how postformal thinking does indeed reflect the conceptual nuances of transdisciplinarity, delving into powerful hidden perspectives to reveal synergy and possibilities for knowledge critique and integration.

Etymology

First, *etymology* entails "thinking about thinking" through the exploration of the forces that produce what a culture validates as knowledge. It encompasses the origins of knowledge, the origins of consciousness, and problem detection and asking unique questions (problematization and problem posing) (Kincheloe and Steinberg 1993). The process of problematization refers to how and why certain behaviors, phenomena, or processes become a problem (a situation that presents difficulty, uncertainty, or perplexity). Problematizing calls into doubt a matter previously taken for granted, and presents it as an issue requiring great mental demands, one that is hard to comprehend and to solve. Once conceived as a problem, people begin to feel the need for some form of collective action to deal with the matter. Whom ever gets to identify a problem has a lot of influence over the situation because they are shaping what should be thought about in society.

Patterns

Second, postformal thinking is also concerned with *patterns*, the interconnections and relationships that undergird the lived world. A pattern is a regular, repeatable order in which things occur. Patterns can be visible or non-discernible. Conventionally, patterns are understood to be activities done without thinking. But, they can also serve as templates that help people find similarities and make connections among things they would not normally connect. As do those engaged in transdisciplinarity (McGregor 2004), those engaged in postformal thinking look for common, predictable patterns instead of separate ideas and events. Revealing patterns involves (a) uncovering tacit forces and hidden assumptions (exploring deep patterns and structures); (b) metaphoric cognition, meaning being able to see relationships between ostensibly different things; and (c) uncovering the larger patterns of life forces, especially levels of connections between minds and ecosystems (Kincheloe and Steinberg 1993).

Process

Third, postformal thinking focuses on the cognitive *process*, the cultivation of new ways of *reading the world*, which includes (a) deconstructing the world (seeing it as a text to be read and decoded to reveal blind spots), (b) stretching the boundaries of consciousness by connecting logic (reason) with emotions, and (c) employing nonlinear holism so people can challenge Newtonian thinking and transcend simplistic notions of cause and effect. Postformal cognitive processes embrace reciprocity and holism; appreciate that phenomena creatively unfold (rather than sequentially accumulate); and value the role of emotions, which become powerful thinking mechanisms when conjoined with linear logic, helping people extend their ability to make sense of the universe. Postformal cognitive processes represent a union of reason, emotion and creativity grounded in organic holism and simultaneity (Kincheloe and Steinberg 1993).

Contextualization

Finally, postformal thinking is all about *context*, the appreciation that knowledge can never stand alone (i.e., it is alive and always in-formation). Because context means "that which is braided together" (Kincheloe and Steinberg 1993, 314), *contextualization* involves examining "the ecology of everything" to discern meaning (314). Also, people would focus on the particulars and the subtle interaction between particulars and generalizations to discern the rhythm of everyday life. Most significantly, contextualization involves uncovering ideologies and the power they have to shape the world and people's (in)ability to critically live in the world. Together, "operating at a meta-cognitive level" (Kincheloe and Steinberg, 317), the postformal notions of etymology, patterns, process, and context serve as a powerful way for people to "think about thinking" and knowledge creation. These four aspects of postformal thinking deeply resonate with Nicolescuian transdisciplinarity, as explained in this article.

Commons and Richards (2002) provided further insights into postformal thinking, with their premise that adult thinking evolves according to successful performance of complex tasks (not just intellectual maturity with age). They conceptualized four stages of increasingly complex behavior, beyond Piaget's *formal operations* level. In their Model of Hierarchical Complexity, they conceived of systematic, metasystematic, paradigmatic and cross-paradigmatic order.

Systematic Order Thinking

First, by discerning the relationships between variables, those thinking at the level of *systematic order* are able to create new systems (about 20% of the population have this ability, mostly those engaged in scientific endeavors) (Commons and Richards 2002). People are able to situate events, ideas, and relationships in a large context and they can form or conceive systems out of these relations: legal, societal, corporate, economic, national systems. Using this order of thinking, people are able to view a phenomenon as an "interlocking set of relationships, with the truth of each relationship in interaction with embedded, testable relationships" (Commons and Ross 2008, 325). Transdisciplinarity entails deep systems thinking.

Metasystematic Order Thinking

Second, when people are able to discern similarities and difference between systems, they are thinking at the *metasystematic* order of complexity (*meta* means "with"—with other systems). As an example, most university professors are able to both examine the sets of rules and logics used by their own discipline and understand the assumptions and methods used by other disciplines, thereby constructing metasystems out of disparate systems (Commons and Richards 2002). Using metasystematic thinking, people can "act on systems [using] metasystematic actions [of] compare, contrast, transform, and synthesize" (Commons and Ross 2008, 325). They estimate that 1–2 percent of the U.S. population functions at this order of thinking. Transdisciplinarity involves attempts to integrate diverse

systems into new wholes, to gain deeper insights into how to address wicked problems.

Paradigmatic Order Thinking

Third, when people (a) have the complex acuity to understand how others see the world (their paradigms), (b) can see the relationships between large and disparate bodies of knowledge (metasystems), and (c) can actually create new fields of study out of these multiple metasystems, they are functioning at the *paradigmatic order*. As an example, in the 1800s, Clark Maxwell created a new paradigm (classical electromagnetism) by showing that fields and waves are united, and did so by fitting together the already existing metasystems of electricity and magnetism (Commons and Richards 2002). Commons and Ross (2008) estimated that fewer than .05 percent of people are able to engage in paradigmatic thinking. Transdisciplinarity most assuredly requires people to try to appreciate others' perspectives and the paradigms and ideologies underlying their cognitive processes, thereby creating possibilities for intellectual fusion and integration.

Cross-Paradigmatic Order Thinking

Even fewer people can function at the fourth level, the *cross-paradigmatic order*, wherein they integrate paradigms into an entire new field of study (in fact, most people struggle with understanding what a paradigm is let alone integrating it with other paradigms). Cross-paradigmatic skills change the course of civilization; yet, *so few* people have these skills that societies do not have mechanisms to encourage their activities (Commons and Richards 2002). They asserted there is little support for major innovations in culture; often, those engaged in such activities are viewed as eccentric geniuses and radicals. Examples include celestial mechanics (Nicolaus Copernicus), classical mathematical physics (Isaac Newton), evolution (Charles Darwin), relativity (Albert Einstein), and quantum mechanics (Max Planck). Indeed, "this stage has not been examined in much detail because there are very few people who can solve tasks of this complexity" (Commons and Ross 2008, 327). Because the intent of trandisciplinarity is to understand the world, to change civilizations (Nicolescu 1985), those engaged in addressing wicked problems must remain open to being and/or supporting any and all transdisciplinary radicals who are trying to engage in cross-paradigmatic thinking.

TRANSDISCIPLINARY CONCEPTUAL TIPPING POINT

On a final note, it is likely that transdisciplinary radicals are indeed engaged in paradigmatic and maybe even cross-paradigmatic thinking. Eventually, the increasing complexity of their thoughts will inspire others to undergo *conceptual change* as their worldviews evolve and shift from formal to postformal cognitive processes using a Nicolescuian transdisciplinary methodology. This conceptual change will involve some combination of knowledge as theory, knowledge as elements, *and* knowledge as context (Figure 4), depending on each person's proclivity to embrace intellectual change. Respectively, some people may experience

a radical shift in worldview (a paradigm shift toward transdisciplinarity) leading to changes in their overarching conceptual structures. Others may experience incremental conceptual shifts, gradually revising their long standing worldview, progressively moving beyond Newtonianism to Nicolescuian transdisciplinarity. In both instances, conceptual change theorists now believe any conceptual change toward transdisciplinarity would take place in a person's mind *but* be deeply influenced by the context, emotions, and social interactions while addressing wicked problems.

In an interview with Volckmann (2010), Ken Wilber referred to the *tipping point* to capture the process inherent in people's conceptual acceptance of new ideas, in this case, transdisciplinarity. A tipping point is a point in time when a growing number of people rapidly and dramatically change their behavior by widely adopting a previously rare practice. Wilber asserted that when the leading edge of the development of a new idea reaches 10 percent of the population, a transformation occurs, and the idea becomes diffused throughout the entire culture. If just 10 percent of the world's academics were receptive to the idea of transdisciplinarity, a tipping point could be achieved. There are over 1.5 million academics in North America alone. Ten percent amounts to just 150,000 people. "Even though only about 10% will actually be embracing [the new ideas], that 10% will profoundly alter social institutions as we know them, and that impact is going to occur worldwide" (Volckmann 2010, 3). Civilizations will be affected.

Conceptual change is being experienced by entire industries and communities of professional practice (Davis 2001); hence, it stands to reason it can be expected of academics in higher education. To that end, this article proposed a link between conceptual change and transdisciplinarity such that understanding conceptual change "might be considered a research project at the service of a deeper understanding of transdisciplinarity" (Weislogel 2013, 81). Weislogel called the new approach of transdisciplinarity "a philosophy of the *beyond*" (92), one that challenges people to expose the contradictions, ambiguities, and partialities of Newtonian thinking. Through the lens of "a philosophy of the *beyond*," people could "become aware of their own ideological inheritance and its relationship to their beliefs, value structures, and interests" (Kincheloe and Steinberg 1993, 302). Once people have moved *beyond* Newtonian thinking, they can better *read* the everyday world and more holistically co-address wicked problems.

In conclusion, new approaches often have very different conceptual systems from the ones they replace (Kuhn 1970), meaning moving from one to the other requires conceptual change (Thagard 2003). Shifting from Newtonian-informed multi- and interdisciplinarity to transdisciplinarity involves deep conceptual change (as illustrated in this article). This conceptual change needs to be understood in order to comprehend how people might lose the conceptual blind spots entrenched with Newtonian thinking, opening pathways to paradigmatic and (ideally) cross-paradigmatic, sophisticated, complex transdisciplinary thinking. Shifting to a transdisciplinary stance means leaving behind one's *formal* Newtonian cognitive past and embracing a new *postformal* conceptualization of knowledge creation grounded in the new sciences of chaos, quanta, and living systems.

NOTE

1. For clarification, wicked problems are incredibly hard to solve (if not impossible) (McGregor 2012), and include but are not limited to poverty, the increasing gap between rich and poor (uneven income and wealth distribution, inequality), inequity and injustice, uneven and unsustainable development, production and consumption, declining mental health and well-being (depression, denial, lost hope), terrorism, violence and conflict, racial and religious intolerance, food insecurity, water shortages, land loss and misappropriation, global warming, ozone depletion, warming oceans, and declining ecological diversity (Paige, Lloyd, and Chartres 2008).

REFERENCES

Apostel, L., S. Berger, A. Briggs, and G. Machaud. ed. 1972. *Interdisciplinarity, problems of teaching and research in universities*. Paris, France: OECD, CERI.

Bruun, H., J. Hukkinen, K. Huutoniemi, and J. T. Klein. 2005. *Promoting interdisciplinary research: The case of the Academy of Finland*. Helsinki: The Academy of Finland. http://www.aka.fi/Tiedostot/Tiedostot/Julkaisut/8_05%20Promoting%20Interdisciplinary%20Research_%20The%20Case%20of%20the%20Academy%20of%20Finland.pdf. Accessed December 3, 2013.

Bullard, T. 2011. The problems with Newtonian thinking [Video]. *A presentation at the International Alchemy Conference.* Long Beach, CA. http://quantumleapalchemy.com/node/76. Accessed December 3, 2013.

Chi, M. T. H. 2008. Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In *International handbook of research on conceptual change*, ed. S. Vosniadou, 61–82. Hillsdale, NJ: Erlbaum.

Cillier, P., and B. Nicolescu. 2012. Complexity and transdisciplinarity: Discontinuity, levels of reality and the Hidden Third. *Futures* 44:711–718.

Commons, M. 2008. Introduction to the model of hierarchical complexity and its relationship to postformal action. *World Futures* 64 (5–7):305–320.

Commons, M., and F. Richards. 2002. Four postformal stages. In *Handbook of adult development*, ed. J. Demich, 199–219. New York: Kluwer Academic/Plenum.

Commons, M., and S. M. Ross. 2008. What postformal thought is, and why it matters. *World Futures* 64 (5–7):321–329.

Davis, J. 2001. Conceptual change. In *Emerging perspectives on learning, teaching and technology*, ed. M. Orey. Bloomington, IN: Association for Educational Communications and Technology. E- book entry at http://epltt.coe.uga.edu/index.php?title=Conceptual_Change. Accessed December 3, 2013.

diSessa, A. A. 2002. Why "conceptual ecology" is a good idea. In *Reconsidering conceptual change*, ed. M. Limón and K. Mason, 28–60. Dordrecht, The Netherlands: Kluwer.

———. 2006. A history of conceptual change research: Threads and fault lines. In *Cambridge handbook of the learning sciences*, ed. K. Sawyer, 265–281. New York: Cambridge University Press.

Duit, R., and D. Treagust. 2003. Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education* 25 (6):671–688.

Franz, J., and S. Lehmann. 2004. Side-by-side: A pedagogical basis for (design) transdisciplinarity. *The IDEA Journal* 5:9–30. http://idea-edu.com/wp-content/uploads/2013/01/2004_IDEA_Journal.pdf. Accessed December 3, 2013.

Geisler, C. 2002. *Multidisciplinarity: The renewal of the university and its curriculum*. Invited talk at Dialogues Between Two Cultures NEH Seminar. Boulder

CO: University of Colorado at Boulder. http://pages.uoregon.edu/idd/interdesign/Multidisciplinary_Renewal.html. Accessed December 3, 2013.

Gibbons, M., C. Limoges, H. Nowotny, S. Schwartzman, P. Scott, and M. Trow. 1994. *The new production of knowledge*. London: Sage.

Gidley, J. N. 2010. Globally scanning for "megatrends for the mind": Potential *futures* of futures thinking. *Futures* 42 (10):1040–1048.

Greeno, J. 1997. On claims that answer the wrong question. *Educational Researcher* 26 (1):5–17.

Hampson, G. and G. Assenza. 2012. *Transformative higher education for humanity and biosphere: An introduction*. Olomouc, Czech Republic: Palacky University, School for Transformative Leadership.

Harper, D. 2013. *Online etymology dictionary*. Lancaster, PA. http://www.etymonline.com/. Accessed December 3, 2013.

Heylighen, F. 2006. The Newtonian world view. In *Principia cybernetica Web*, ed. F. Heylighen, C. Joslyn, and V. Turchin. Brussels, Belgium: Principia Cybernetica. http://pespmc1.vub.ac.be/NEWTONWV.html. Accessed December 3, 2013.

Horlick-Jones, T., and J. Sime. 2004. Living on the border: Knowledge, risk and transdisciplinarity. *Futures* 36 (4):441–456.

Jantsch, E. 1972. Towards interdisciplinarity and transdisciplinarity in education and innovation. In *Interdisciplinarity problems of teaching and research in universities*, ed. L. Apostel, S. Berger, A. Briggs, and G. Machaud, 97–121. Paris, France: OECD, CERI.

Jovchelovitch, S. 2007. *Knowledge in context*. Cambridge, England: Cambridge University Press.

Kegan, R. 1994. *In over our heads*. Cambridge, MA: Harvard University Press.

Kincheloe, J., and S. Steinberg. 1993. A tentative description of post-formal thinking. *Harvard Educational Review* 63 (3):296–320.

Klein, J. T. 2004. Prospects for transdisciplinarity. *Futures* 36 (4):515–526.

Klein, J. T., W. Grossenbacher-Mansuy, R. Häberli, A. Bill, R. Scholz, and M. Welti, eds. 2001. *Transdisciplinarity: Joint problem solving among science, technology, and society*. Berlin, Germany: Birkhäuser Verlag.

Kuhn, T. S. 1970. *The structure of scientific revolutions (2*nd ed.*)*. Chicago, IL: University of Chicago Press.

Land, R. 2010. *Threshold concepts and troublesome knowledge*. Keynote address at the New Zealand Association of Bridging Educators' national conference. Wellington, NZ. http://www.utdc.vuw.ac.nz/events/RayLand/201009RayLandSlides.ppt. Accessed December 3, 2013.

MacLean, J., D. MacDonald, U. Bryne, and A. Hubbard. 1961. The use of LSD-25 in the treatment of alcoholism and other psychiatric problems. *Quarterly Journal of Studies on Alcohol* 22:34–45.

Mason, L. 2007. Introduction: Bridging the cognitive and sociocultural approaches to research on conceptual change: Is it feasible? *Educational Psychologist* 42 (1):1–7.

Max-Neef, M. A. 2005. Foundations of transdisciplinarity. *Ecological Economics* 53:5–16.

Meyerson, D., and J. Martin. 1987. Cultural change: An integration of three different views. *Journal of Management Studies* 24 (6):623–647.

McGregor, S. L. T. 2004. The nature of transdisciplinary research and practice. *Kappa Omicron Nu Human Sciences Working Paper Series*. http://www.kon.org/hswp/archive/transdiscipl.html. Accessed December 3, 2013.

———. 2007. Consumer scholarship and transdisciplinarity. *International Journal of Consumer Studies* 31 (5):487–495.

———.2009. Integral leadership's potential to position poverty within transdisciplinarity. *Integral Leadership Review* 9(2). http://integralleadershipreview.com/4758-feature-article-integral-leadership%E2%80%99s-potential-to-position-poverty-within-transdisciplinarity1. Accessed December 3, 2013.

———. 2010. Historical notions of transdisciplinarity in home economics. *KON FORUM* 16(2). http://www.kon.org/archives/forum/16–2/mcgregor.html. Accessed December 3, 2013.

———. 2011a. Demystifying transdisciplinary ontology: Multiple levels of reality and the hidden third. *Integral Leadership Review* 11(2). http://integralleadershipreview.com/1746-demystifying-transdisciplinary-ontology-multiple-levels-of-reality-and-the-hidden-third. Accessed December 3, 2013.

———. 2011b. Knowledge generation in home economics using transdisciplinary methodology. *Kappa Omicron Nu FORUM* 16(2). http://www.kon.org/archives/forum/16–2/mcgregor2.html. Accessed December 3, 2013.

———. 2011c. The Wilberian integral approach. *Kappa Omicron Nu Human Sciences Working Paper Series*. http://www.kon.org/hswp/http://www.kon.org/hswp/archive/mcgregor_2.htm. Accessed December 3, 2013.

———. 2012. Complexity economics, wicked problems and consumer education. *International Journal of Consumer Studies* 36 (1):61–69.

———.2013. *Fostering ideological awareness for consumer professionals [Monograph Series No. 201301]*. Seabright, NS: McGregor Consulting Group. http://www.consultmcgregor.com/documents/publications/ideological-reframingfor-consumer-professionals.pdf. Accessed December 3, 2013.

McGregor, S. L. T., and R. Volckmann. 2011. *Transversity: A study of transdisciplinarity and higher education*. Tucson, AZ: Integral Publishers.

Mittelstrass, J. 2011. On transdisciplinarity. *TRAMES* 15 (4):329–338.

Morin, E. 1999. *Seven complex lessons in education for the future*. Paris, France: UNESCO. http://unesdoc.unesco.org/images/0011/001177/117740eo.pdf. Accessed December 3, 2013.

———. 2005. Restricted complexity, general complexity. In *Worldviews, science and us: Philosophy and complexity*, ed. C. Gershenson, D. Aerts, and B. Edmonds, 5–29. London: World Scientific Publishing. E-chapter retrieved from http://www.worldscibooks.com/chaos/etextbook/6372/6372_chap01.pdf. Accessed December 3, 2013.

Nicolescu, B. 1985. *Nous, la particule et le monde [We, the particle and the world]*. Paris, France: Le Mail.

———. 1999. *The transdisciplinary evolution of learning*. Paper presented at the American Educational Research Association conference. Montreal, Quebec. http://www.learndev.org/dl/nicolescu_f.pdf. Accessed December 3, 2013.

———. 2000. Levels of reality as source of quantum indeterminancy. In *Determinism and complexity*, ed. F. T. Arecchi, 127–158. Rome, Italy: Nova Spes Foundation and Armando Publishing. http://arxiv.org/pdf/quant-ph/0012007.pdf. Accessed December 3, 2013.

———. 2002. *Manifesto of transdisciplinarity* (Karen-Claire Voss, Trans.). Albany: State University of New York Press.

———. 2005. Towards transdisciplinary education and learning . Paper presented at the Metanexus Institute conference on Science and religion: Global perspectives. Philadelphia, PA, June 4–8. http://www.metanexus.net/archive/conference2005/pdf/nicolescu.pdf. Accessed December 3, 2013.

———. ed. 2008. *Transdisciplinarity: Theory and practice*. Creskill, NJ: Hampton Press.

———. 2010a. *Disciplinary boundaries—What are they and how they can be transgressed?* Paper prepared for the International Symposium on Research Across Boundaries.

Luxembourg: University of Luxembourg. http://basarab-nicolescu.fr/Docs_articles/Disciplinary_Boundaries.htm. Accessed December 3, 2013.

———. 2010b. Methodology of transdisciplinarity. *Transdisciplinary Journal of Engineering and Science* 1 (1):19–38.

———. 2011a. Methodology of transdisciplinarity—Levels of reality, logic of the included middle and complexity. In *Transdisciplinarity: Bridging science, social sciences, humanities and engineering*, ed. A. Ertas, 22–45. Austin, TX: TheAtlas Publishing.

———. 2011b. Transdisciplinarity: The Hidden Third, between the subject and the object. In *Ştiinţă, Spiritualitate, Societate [Science, Spirituality, Society]*, ed. I. Chirilă and P. Bud, 11–34. Cluj-Napoca, Romania: Eikon.

———. ed. 2012. *Transdisciplinarity and sustainability*. Austin, TX: TheAtlas Publishing.

———. 2013. Methodology of transdisciplinarity. *World Futures* (this issue).

Nissani, M. 1997. Ten cheers for interdisciplinarity [Electronic version]. *Social Science Journal* 34 (2):201–216.

Nolt, J. 2010. Free logic. In *Stanford encyclopedia of philosophy*, Ed. E. N. Zalta. Stanford, CA: Stanford University. http://plato.stanford.edu/entries/logic-free/#incl. Accessed December 3, 2013.

Nowotny, H. 2003. The potential of transdisciplinarity. In *Rethinking interdisciplinarity*, 48–53. Paris, France: Interdisciplines Project. http://www.interdisciplines.org/medias/confs/archives/archive_3.pdf. Accessed December 3, 2013.

Özdemir, G., and D. Clark2007. An overview of conceptual change theories. *Eurasia Journal of Mathematics, Science & Technology Education* 3 (4):351–361.

Paige, K., D. Lloyd, and M. Chartres2008. Moving towards transdisciplinarity. *Asia-Pacific Journal of Teacher Education* 36 (1):19–33.

Paretti, M. 2011. Interdisciplinarity as a lens for theorizing language/content partnerships. *Across the Disciplines* 8(3). http://wac.colostate.edu/atd/clil/paretti.cfm. Accessed December 3, 2013.

Porter, M. 1980. *Competitive strategy*. New York: Free Press.

Posner, G. J., K. A. Strike, P. W. Hewson, and W. A. Gertzog1982. Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education* 66 (2):211–227.

Roth, W.-M. 2001. "Enculturation": Acquisition of conceptual blind spots and epistemological prejudices. *British Educational Research Journal* 27 (1):5–27.

Schneider, B. 2003. Knowledge beyond disciplines. *The Flame: Claremont Graduate University Magazine* 4 (3):12–17. http://www.cgu.edu/include/news/flame/The_Flame_WINTER_2003.pdf. Accessed December 3, 2013.

Sfard, A. 1998. On two metaphors for learning and the danger of choosing just one. *Educational Researcher* 27 (2):4–13.

Sinatra, G., and P. Pintrich. ed. 2003. *Intentional conceptual change*. Mahwah, NJ: Lawrence Erlbaum.

Somerville, M. A., and D. Rapport2002. *Transdisciplinarity: reCreating integrated knowledge*. Montreal, QU: McGill-Queens University Press.

Stock, P., and R. Burton2011. Defining terms for integrated (multi-inter-transdisciplinary) sustainability research. *Sustainability* 3:1090–1113.

Thagard, P. 2003. Conceptual change. In *Encyclopedia of cognitive science* (Vol. 1), ed. L. Nadel, 666–670. London: Macmillan.

Thagard, P., and R. Zhu2003. Acupuncture incommensurability and conceptual change. In *Intentional conceptual change*, ed. G. Sinatra and P. Pintrich, 81–103. Mahwah, NJ: Lawrence Erlbaum.

Tuchman, B. 1985. *The march of folly*. New York: Ballantine Books.

Volckmann, R. 2010. The state of integral: A conversation with Ken Wilber. *Integral Leadership Review* 10(5). http://www.integralleadershipreview.com/archives-2010/2010–10/ILRkenruss.pdf. Accessed December 3, 2013.

von Forrester, H. 2003. *Understanding understanding*. New York: Springer-Verlag.

Vosniadou, S. 1994. Capturing and modeling the process of conceptual change. *Learning and Instruction* 4:45–69.

———. 2007. The cognitive-situative divide and the problem of conceptual change. *Educational Psychologist* 42(1):55–66.

———, ed. 2013. *International handbook of research on conceptual change* (2nd ed.). New York: Routledge.

Wagner, J. 1993. Ignorance in educational research. *Educational Research* 22 (5):15–23.

Weislogel, E. 2013. On the relationship of metaphysics and transdisciplinarity. *Transdisciplinary Journal of Engineering & Science* 4:79–93.

Wilber, K. 2001. *The theory of everything*. Boston, MA: Shambhala.

Wikipedia Encyclopedia2013. *Conceptual change*. San Francisco, CA: Wikipedia Foundation. http://en.wikipedia.org/wiki/Conceptual_change. Accessed December 3, 2013.

Zurich Manifesto: Statement on a Broader View of Transdisciplinarity2000, Feb.–March. http://www.ecuad.ca/∼eburnett/communications.html. Archived at http://www.webcitation.org/5o9msKle5. Accessed December 3, 2013.