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Review:

Transdisciplinarity: A Review of Its Origins, Development, and Current Issues

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Abstract

Transdisciplinarity originated in a critique of the standard configuration of knowledge in disciplines in the curriculum, including moral and ethical concerns. Pronouncements about it were first voiced between the climax of government-supported science and higher education and the long retrenchment that began in the 1970s. Early work focused on questions of epistemology and the planning of future universities and educational programs. After a lull, transdisciplinarity re-emerged in the 1990s as an urgent issue relating to the solution of new, highly complex, global concerns, beginning with climate change and sustainability and extending into many areas concerning science, technology, social problems and policy, education, and the arts. Transdisciplinarity today is characterized by its focus on “wicked problems” that need creative solutions, its reliance on stakeholder involvement, and engaged, socially responsible science. In simultaneously studying multiple levels of, and angles on, reality, transdisciplinary work provides an intriguing potential to invigorate scholarly and scientific inquiry both in and outside the academy.

Index Terms: transdisciplinarity; knowledge practice; socially responsible science; integration of knowledge; wicked mess

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Transdisciplinarity represents a change in thinking about research and education challenging the division of academic labor into traditional disciplines such as English, sociology, or geology. Not only ought scholars to study across the disciplines, nor should disciplinary crossing be limited to joint and cooperative work on projects of mutual

interest across disciplines, but a reliance on disciplinary paradigms and an acceptance of disciplines as a basis for organizing knowledge, inquiry, and teaching needs somehow to be transcended. In their place, transdisciplinary theorists propose new principles and criteria for furthering knowledge. First articulated at the tail end of what with hindsight can be called academia's golden age (Freeland, 1992) and filled in incrementally as the twentieth century drew to a close, transdisciplinarity has become an important presence on the landscape of higher education. The advent and development of transdisciplinarity demonstrate emerging ways not only of organizing but thinking about knowledge and inquiry in a world that has become "too big to know" (Weinberger, 2011). As Alfonso Montuori (2008, p. ix) writes in his foreword to a recent book on the subject, "Transdisciplinarity is perhaps above all a new way of thinking about, and engaging in, inquiry."

1. Origins

The word *transdisciplinarity* appears to have been introduced in 1970 at a seminar on interdisciplinarity in universities held at the University of Nice and jointly sponsored by the Organisation of Economic Cooperation and Development and the French Ministry of Education. The eminent Swiss psychologist Jean Piaget is generally credited with coining the term (e.g., López-Huertas, 2013; Nicolescu, 2010; Padurean & Cheveresan, 2010). The conclusion of Piaget's (1972) essay on various kinds of interaction between the disciplines mentions transdisciplinarity offhand, as a kind of an aside, as a "higher stage succeeding interdisciplinary relationships . . . which would not only cover interactions or reciprocities between specialised research projects, but would place these relationships within a total system without any firm boundaries between disciplines" (Piaget, 1972, p. 138). Presentations by the French mathematician André Lichnerowicz and the Austrian astrophysicist Erich Jantsch at the same event elaborated on Piaget's insight, Lichnerowicz's relating it to logic and set theory and Jantsch's to issues of education and planning. In Jantsch's system, transdisciplinarity is the most complex and abstract synthesis of disciplines, surpassing multidisciplinary, pluridisciplinary, crossdisciplinarity, and interdisciplinarity. Jantsch provides a detailed analysis of the nascent concept of transdisciplinarity in terms of "the co-ordination of all disciplines and interdisciplines in the education/innovation system on the basis of a generalized axiomatics (introduced from the purposive level down) and an emerging epistemological ('synepistemic') pattern" (Jantsch, 1972a, p. 106). Jantsch's study is oriented toward the planning of future curricula in the context of emerging ideas about science as a source of innovation (see also Jantsch, 1972b for a somewhat different presentation covering his vision for transdisciplinarity in the university of the future, integrating education, research, and service).

Astonishingly, the same year that noted senior European academics pioneered the concept of transdisciplinary at the OECD conference in France, Jack Lee Mahan, Jr., a 28 year-old American graduate student in human behavior at the United States International University, independently produced a doctoral dissertation with the title, *Toward Transdisciplinary Inquiry in the Humane Sciences*. Mahan makes similar points to Jantsch's about the synthesis and integration of knowledge but adds ethical considerations: the need for "reverence of life, man, and the human condition" (Mahan,

1970, p. 21). Mahan goes further than Jantsch, whom he does not cite, criticizing both the compartmentalization of the traditional disciplines and ideals of detachment and aloofness associated with disciplinary inquiry. Mahan's study of the literature in the philosophy of the social sciences indicates that although transdisciplinarity may have been a new term, the concerns giving rise to such a notion were already present as undercurrents in the writings of the mid-twentieth century scholars he cites. Although he does not provide a concise definition of transdisciplinarity, the following gives a sense of what he thinks it means and how it can improve the quality of academic work.

Transdisciplinary inquiry would be characterized by a common orientation to transcend disciplinary boundaries and an attempt to bring continuity to inquiry and knowledge. Other characteristics would be: attention to comprehensiveness, context and frame of reference of inquiry and knowledge; interpenetration of boundaries between concepts and disciplines; exposing disciplinary boundaries to facilitate understanding of implicit assumptions, processes of inquiry, and resulting knowledge; humanistic reverence for life and human dignity; desire to actively apply knowledge to the betterment of man and society. (Mahan, 1970, pp. 194-195)

With hindsight, we can find significance in the optimistic origin of transdisciplinarity in terms of the possibility for a new synthesis in higher education, technology, and science. The timing was appropriate, since academic and government science had received a boost of glory in public opinion with the success of the Apollo program of manned moon landings. With funding at a peak and conditions of growth, the time was right for thinking big and imagining what the university could be in a perfect world. New discoveries on many fronts were also leading scholars and scientists to think big in terms of macro systems (including notions of "Spaceship Earth" and the "Global Village") and develop meaningful linkages between subjects superficially kept far apart. The notion of the interconnectedness of many seemingly disparate things was thematic in the writings of systems theorists such as R. Buckminster Fuller, Kenneth Boulding, E. F. Schumacher, René Dubos, Ludwig von Bertalanffy, Marshall McLuhan, Ervin Laszlo, and C. West Churchman, who were among the leading public intellectuals of the time.

The period was also marked by student unrest and a conflict between the generations (Feuer, 1969): the counterculture, which had put forward creative if radical and generally unworkable alternatives to the status quo (Roszak, 1969), had peaked, and dissatisfaction with the university as an arm of "the establishment" lingered. Many professors sympathized with the radical students and identified with their idealism. Perhaps a side-effect or after-effect of the counterculture was some utopian speculation about the future possibilities for universities, and some of this was expressed in the first writings on transdisciplinarity. Indeed, new colleges and universities were established based on some of these new theories. The glorious moment, forever defined by the spectacular accomplishment of man's landing on the moon in 1969, was all too brief, as it was bracketed only four years later with the first OPEC oil crisis. This set in motion a rapid withdrawal of heretofore massive government funding of higher education beginning in the United States and had the effect of putting on hold all promises for the continuation,

much less the expansion, of idealistic plans for educational systems based on emerging concepts about knowledge.

Interdisciplinary co-operation and collaboration, long established in higher education in the United States, continued apace, with advances in the 1970s in women's (and later gender) studies, environmental science, urban studies, and cognitive science (J. T. Klein, 1996). Later on, other splinters of interdisciplinary innovation could be seen in new specialties including disability studies and peace and conflict studies, to name two successes. To the extent that courses and academic programs were created around these new concentrations, curricula needed to be defined and ratified, and resources needed to be allocated. Yet the notion of transdisciplinarity introduced at the beginning of the 1970s remained undeveloped and almost uncited until the early 1990s.

A rare discussion of transdisciplinarity appearing in this mainly dormant period was a chapter contributed by Joseph J. Kockelmans (1979), a Dutch-born and European-trained but US-based philosopher working in the continental tradition, to a book he edited on interdisciplinarity and higher education. Kockelmans, one of the few to cite Mahan (1970) as well as the better known CERI conference proceedings that included Jantsch's (1972a) essay, defines transdisciplinarity as "scientific work done by a group of scientists . . . with the intention of systematically pursuing the problem of how the negative side effects of specialization can be overcome so as to make education (and research) more socially relevant" (Kockelmans, 1979, p. 128). For Kockelmans, the purpose of transdisciplinary work is not so much to find a reasonable solution to a given problem under study as to develop a larger, unifying, all-encompassing theoretical framework for scholarly and scientific work.

Several developments not necessarily related to each other brought transdisciplinarity back into the limelight not only as an interesting philosophy of education and science but as an urgent matter. One was a renewed awareness of the problem of disciplinarity as a mode of structuring knowledge, put forth chiefly in the writings of Ellen Messer-Davidow, David Shumway, and David Sylvan (Messer-Davidow, Shumway, & Sylvan, 1993; Shumway & Messer-Davidow, 1993). The very phenomenon of dividing knowledge into separate disciplines, each with its own personnel, modes of work and thought, and pathways toward accomplishment was previously so taken for granted as to be almost unrecognized, although some, like Donald T. Campbell (1969), had warned earlier of redundancy and gaps in the prevailing system of disciplinary specialization in the social sciences. Earlier writings on the nature of disciplines as intellectual structures by educational theorists Philip H. Phenix (1964) and later Paul Dressel and Dora Marcus (1982) analyzed the dimensions of meaning embraced by the various disciplines. The new work, by contrast, has looked at disciplines as social constructs, questioning in the process the validity of customary practices surrounding the disciplinary segmentation of knowledge and pointing out the drawbacks inherent in the system of disciplinarity (see Lattuca, 2001, pp. 23-54 for a fine review of concepts pertaining to disciplinarity, and see also Stark & Lattuca, 1997, pp. 141-176).

Another key factor was the end of the Cold War and the concomitant dismantling of the Iron Curtain, creating some of the conditions for a new so-called globalized workforce.

The end of the Cold War meant the end of certain tensions and conflicts but the beginning of others. There was a growing realization that globalization was not necessarily a good thing. First recognized in the early 1980s, what soon became the AIDS pandemic was an example of a quickly moving problem that knew no boundaries and could not be contained (Engel, 2006). New incarnations of global capitalism in the form of multinational corporations facilitated new forms of labor exploitation as inhumane as any that had existed during the earlier industrial age (N. Klein, 2000). Of course, we no longer lived in the industrial age but in the post-industrial, information age with an economy characterized by the production of knowledge and services rather than the manufacture of physical objects (Kumar, 1995). An entirely new way of thinking about culture and society, called postmodernism or postmodernity, based on dislocation and a sense of ultimate placelessness, appeared on the horizon, and it had great influence on thought in the social sciences, humanities, and arts beginning in the 1990s (Harvey, 2004). Warnings about looming environmental collapse were not new, as witnessed in the 1972 Club of Rome Report, *The Limits to Growth* (Meadows, Meadows, Randers, & Behrens, 1972), and even earlier in Rachel Carson's classic, *Silent Spring* (Carson, 1962). Nevertheless, with heightened awareness of global connectedness brought about by sociopolitical change came a new recognition of the vulnerability of planet earth as an environment (including not only landmasses but all bodies of water and atmospheric layers), in particular, the looming threat of catastrophic climate change induced by human activities. Climate change is predicted to cause not only unprecedented rises in temperature affecting agriculture and the human habitability of land but also rising sea levels and mass extinctions.

Therefore, although the words *transdisciplinarity* and *transdisciplinary*, with their basic meanings involving transcending the established framework of traditional academic disciplines were first used around 1970, the conditions for beginning transdisciplinary work in earnest did not fall into place for at least two more decades (see also Kessel & Rosenfield, 2008). Themes of sustainability and global environmental crisis were watchwords in moving the heretofore little-used concept of transdisciplinarity to the foreground of debates about science and planning. Julie Thompson Klein (2001), herself a key interlocutor in debates about new combinations of disciplines in education, pinpoints the United Nations Earth Summit in Rio de Janeiro in 1992 as the turning point of awareness about a need for action in the academic and scientific communities. Shortly thereafter, in 1994, the First World Congress on Transdisciplinarity was held in Convento da Arrábida, Portugal, producing a Charter of Transdisciplinarity, attributed to the Romanian theoretical physicist Basarab Nicolescu along with the Portuguese artist Lima de Freitas and the French transdisciplinarian Edgar Morin (de Freitas, Morin, & Nicolescu, 1994). Nicolescu's views are evident in the Charter, and he has taken the lead in developing a theory and program for transdisciplinary work.

In this and other works, Nicolescu (e.g., 2002, 2010) explicitly describes transdisciplinarity as complementing the disciplinary approaches. His concept of transdisciplinarity focuses on complexity as a fundamental feature of reality, on the premise of different levels and dimensions of reality, and on what he calls the logic of the *included middle*, in defiance of the Aristotelian axiom of the *excluded middle*, suggesting that Nicolescu, in the spirit of quantum mechanics, wants scientists to "rethink" the traditional absolute separation of the

subject and the object (Nicolescu, 2010). Nicolescu's transdisciplinarity seems applicable to the integration of the humanities, including spiritual subjects such as religion, and philosophies of knowledge and education with physical science subjects such as those extant in laboratories and space observatories. As Sue McGregor explains, Nicolescu concerns himself with the meaning of going *beyond* disciplines and asserts that "transdisciplinarity identifies with a new knowledge about *what is between, across, and beyond disciplines* (the meaning of *trans*)" (McGregor, 2015b, "Nicolescuian Approach to Transdisciplinarity"). He also urges scholars to go beyond the dichotomous, *either/or* mentality that, in his view, produced many of the problems that now plague humanity.

Exactly the same year as the First World Congress on Transdisciplinarity took place, another project appeared presenting a somewhat different approach to transdisciplinarity. The book, *The New Production of Knowledge* (Gibbons et al., 1994), made at least as much of an impact as did Nicolescu's abstruse theoretical framework, but it presented a different vision of and program for transdisciplinarity. The authors, Michael Gibbons, Camille Limoges, Helga Nowotny, Simon Schwartzman, Peter Scott, and Martin Trow, had professional backgrounds in the social and policy sciences as they pertained to science, technology, and education, rather than in the hard sciences or philosophy. Thus, their work was seen as more immediately practical than Nicolescu's programmatic and oracular work, even though it lacked his bold visionary insights. The fact that their work was collaborative is itself significant, since part of their message concerned the collaboration of experts from diverse fields on specific projects that transcended the boundaries of specific disciplines. Their innovation was the concept of Mode 2 knowledge production, involving knowledge developed for a particular application and involving the work of experts drawn from academia, government, and industry. They stress that such knowledge production and problem solving are not merely applied research and development, nor are they limited to the sciences, technology, or medicine, but extend as well to the humanities, as in museums, architecture, and modes of research that rely on information technology.

Mode 2 knowledge production, which the authors link to transdisciplinarity, came about with increased globalization as the Cold War ended. Rather than offering a philosophy of transdisciplinarity, as Nicolescu did, Gibbons et al.'s study was descriptive and analytic. It has helped subsequent readers understand transdisciplinarity and has been influential in paving the way for research on the sociology of science, technology, and higher education, as well as policy in those fields. Their text (Gibbons et al., 1994) and its follow-up by Nowotny, Scott, and Gibbons (2001), have been important in updating the definition and scope of transdisciplinarity since the time of Jantsch and Piaget, and particularly in developing the important new concept of Mode 2 knowledge production (see also Etzkowitz & Leydesdorff, 2000). Even if one does not fully accept Gibbons et al.'s postulation of Mode 2 knowledge production, the interconnections between the academy, industry, governments, and non-governmental organizations are clearly fundamental to an understanding of knowledge production in today's world. This new social, economic, political, and bureaucratic organization is crucial in the works of some transdisciplinarians.

To some extent, Nicolescu and Gibbons et al. can be said to have spawned separate streams of transdisciplinary work. Scholars who have recently reviewed the literature (Segalàs & Tejedor, 2013, Augsburg, 2014, McGregor, 2015b) discern two main schools of thought pertaining to transdisciplinarity: the Nicolescuian school and the Zurich school, named after the International Congress held in that city in 2000 (see Thompson Klein et al., 2001). Nicolescu's writing led to a new way of thinking about knowledge and inquiry that has included writing from ethical, metaphysical, and even mystical perspectives (see Nicolescu, 2008, de Mello, 2008, Voss, 2008), while the Zurich school has led to work aimed at designing and implementing tangible solutions to "real world" problems (Segalàs & Tejedor, 2013). While Nicolescuian transdisciplinarity emphasizes a concept of the human life world and lived meanings (following the philosophical traditions exemplified by Edmund Husserl, Martin Heidegger, and Ernst Cassirer), the Zurich tradition prioritizes the interface between science, society, and technology in the contemporary world, according to McGregor (2015b, see also Augsburg, 2014). Nicolescu himself (2008, pp. 12-13), observing the multiple approaches to transdisciplinarity, has opined that his own work represents theoretical transdisciplinarity while Gibbons and Nowotny represent phenomenological transdisciplinarity, meaning that it builds "models connecting the theoretical principles with the already observed experimental data, in order to predict further results" (Nicolescu, 2008, p. 12).

2. Current Issues in Transdisciplinary Research

The appearance of two nearly simultaneous major statements on transdisciplinarity created something of a buzz and caused many researchers and educators to take notice. Through a range of disparate efforts, something approaching a consensus on what transdisciplinarity should be is emerging among researchers who are informed both by the Nicolescuians and the Zurichers. First, transdisciplinarity involves work that creatively re-imagines the disciplines and the possibilities for combining them (Castán Broto et al., 2002; Lawrence & Després, 2004). While the distinction between transdisciplinarity vis-à-vis multidisciplinary (collected inputs from different disciplines without synthesis), and interdisciplinarity (collaboration between researchers from different disciplines aimed at a synthesis and integration of knowledge) need not be sharp or absolute, transdisciplinarity generally rejects the separation and distribution of topics and scholarly approaches into disciplinary "silos" (see Choi & Pak, 2006 for an explication and discussion of these terms). Transdisciplinary work challenges the entire framework of disciplinary thinking and seeks to assemble new approaches from scratch, using materials from existing scholarly disciplines for new purposes.

Nicolescu wrote frequently about levels of reality—subjectivity, objectivity, and what he called "the hidden third between the subject and the object" (Nicolescu, 2012). Nicolescu aimed his discussions about the subject and the object at the study of physical, chemical, and biological reality, but he also asserted that his concept of levels of reality (which he identified as the key concept of transdisciplinarity) is applicable to social inquiry. Some interpretive social scientists, perhaps following the provocations of Jürgen Habermas, Hans-Georg Gadamer, and Charles Taylor more than those of Nicolescu (see Rabinow & Sullivan, 1987, Richardson & Fowers, 1998), have pondered the relations between the supposedly detached and objective researcher and the individuals or populations under

investigation. These considerations require researchers not only to admit to their own subjectivity but to foreground questions about the ethics of studying populations where a power differential exists between the investigator and the subject of research. This has resulted in research that transcends standard interpretive social science and becomes transdisciplinary in that it brings in the subjects of research participating in the research on an equal footing with the investigators. Such an approach is exemplified in an ethnographic and ethnohistorical project of Alaskan natives that resulted in a book and a community-based museum exhibition that simultaneously examine and reflect the values of the Alutiiq people who were not studied as objects of research by experts but shared in the creation of the work (Crowell et al., 2001). Such a work creates a dialogue between minority and majority cultures, includes participants from outside the academic community, and strives to transcend the traditional dichotomy between objective and subjective viewpoints. Like another book from the same time period, *Exotic No More* (MacClancey, 2002), it shows the possibility of anthropology, an established social science, to engage at least implicitly with emerging transdisciplinary research paradigms and contributes to the corpus of transdisciplinary research literature. The ethnographic method of participant observation, which was originally developed in cultural anthropology, has more recently been picked up and adapted by other disciplines wanting to gain insights into the thoughts and practices of people being studied. Related to the use of ethnographic methods is the involvement and participation of stakeholders in transdisciplinary projects (Bergmann et al., 2012, p. 124).

Other research that can be described as transdisciplinary is also aimed at creating engaged, socially responsible science. As we have already seen, a concern with global climate change has been a focal point in coalescing a movement for transdisciplinary research. Many have sought to create a science of sustainability, and such research is closely identified with the transdisciplinary movement (Brandt et al., 2013, Hirsch Hadorn et al., 2006). Moreover, the research and educational aims of this work are intertwined (Evans, 2015). The notion of sustainability has evolved from a concept to a movement involving not only science, government, and industry but citizen participation, including input from religious leaders, consumer awareness, boycotts and protests, and much more (Cardonna, 2014). With concerns voiced about a possibly dying planet, the need to prevent catastrophe lends a sense of urgency and running against the clock to this work, with a requirement not only to raise awareness but change behavior. Tina Lynn Evans (2015, p. 72) has written of a sustainability crisis and thinks educators need to situate their discussions of sustainability in terms that are not only scientific but ethical, involving “intergenerational fairness extending over long time frames and on the health and integrity of human societies and the natural world.” She cites Michael Crow in identifying hunger, poverty, global climate change, the extinction of species, the exhaustion of natural resources, and the destruction of ecosystems as topics requiring a response from educators.

Such problems are extremely complex and can rightly be described as “wicked” (Brown, Harris, & Russell, 2010), meaning that beyond being intractable they defy complete definition and cannot be solved using existing modes of inquiry and decision making. Moreover, no final solutions for such problems are possible since any resolution generates further issues (Brown, Dean, Harris, & Russell, 2010, pp. 1-2). The concept of

the wicked problem, first identified and defined by the design theorists Horst W. J. Rittel and Melvin M. Webber (1973), has grown from being a discussion point in the policy sciences to a focal concern in recent transdisciplinary literature (cf. McGregor, 2015a, who also uses another commonly found expression, “wicked messes”). Wicked problems, including conflict and sustainability, that transcend the resources for any single disciplinary or even traditional interdisciplinary approach for solution have become primary sources of material for contemporary transdisciplinary work. These are pressing problems, even crises, reaching in multiple domains or dimensions and involving not just academic disciplines and the interplay among them but also practitioners seeking solutions in the real world outside the academy.

Some projects on wicked problems involve using multiple prongs of research to solve ever-present yet multifaceted social justice problems including crime or poverty, and focusing on issues such as education, health, sanitation, and housing (Lawrence, 2010). Transdisciplinary work is often dedicated to studying and helping to solve such problems, as shown in examples of projects combining research and action on sustainable housing renovation, sustainability and urban design, and the forecast of water demand (Bergmann et al., 2012). An entire branch of transdisciplinary work, involving experts from multiple fields along with stakeholders, focuses on community problem solving to facilitate change (Stokols, 2006). Such projects generally require a division of labor in a team with meetings to discuss findings and brainstorm solutions. While some commentators give the impression that teamwork is a defining characteristic of transdisciplinary research, the team approach is only used in some cases and is not essential to transdisciplinary inquiry. What is important for the solo transdisciplinary researcher not working in a team is an ability “to fuse knowledge from a number of different disciplines and engage with stakeholders in the process of generating knowledge” (Wickson, Carew, & Russell, 2006, p. 1052). The wickedness of other problems derives from the subtle considerations that need to be weighed in innovating scientific and technological solutions in genomics, biomechanics, nanotechnology, and mechatronics (the confluence between mechanics and electronics).

Nanotechnology is a field that has become a focal point in the theory and practice of transdisciplinarity (Mittelstrass, 2011). It involves the use of particles measuring in the range of billionths of a meter in size, practically at the atomic scale. At such a small scale, objects have qualities that can make them significant in many domains, pushing to the limits our understanding of the nature of life in relation to matter, energy, and information. The advent of nanotechnology is thought to have a unifying effect on the political economy of scientific research signifying a swing of the pendulum away from hyperspecialization toward applications and approaches shared by many disciplines (Collins, 2008, p. 364). These applications concern industry, biomedicine, and the environment. While current uses are sundry and involve cosmetics, scratch-resistant coatings and self-cleaning windows, nanotechnology as it is developing could in the near future be responsible for producing combat suits that morph camouflage and absorb bullets, applications to quickly and efficiently clean up toxic waste and pollution, devices that can diagnose and treat inoperable cancers, and “self-replicating nanobots” (Collins, 2008, p. 364). The potential of nanotechnology for beneficial (in computing and medicine) or for destructive purposes (in germ warfare), for surveillance (which can be good or bad for society), and for many other purposes makes it important for policies

about the uses of nanotechnology to take into account the concerns and interests of all people, not just those of the scientists, technologists, enterprises, industries or other entities underwriting the research. There are consequences for social justice and the common good (Fisher, 2007). As with climate change, the risks to health and safety in nanotechnology are so high that global policies beyond the interests of any one group need to be heard and accounted for (Hook, 2004). Scientists are aware that risk, ethical, and social justice factors need to be worked out in advance of the development of nanotechnology rather than afterwards, following irreversible damage.

The issues involved in understanding, developing, and planning policies for nanotechnology capture the sense of complexity and intricacy of problems in contemporary science. Transdisciplinarity is sometimes described in part as a response to the increased complexity of contemporary problems in science and technology. Indeed, complexity itself could be a problem area for transdisciplinary studies (Cilliers, 1998; cf. Waldrop, 1992 for an introductory biographical history of the science of complexity). Complexity is not exactly synonymous with complicatedness, since a complicated system may be understandable in terms of its components, while in a complex system the individual components interact with each other and with their environment in such a way that the system as a whole cannot be explained in terms of its parts.

A key property of complex systems is emergence, meaning that the whole is greater than the sum of all the parts. The wetness of water provides an easily understandable explanation of emergence. In the words of John Holland (2014, p. 49), “the characteristic of ‘wetness’ cannot reasonably be assigned to individual molecules, so we see that the wetness of water is not obtained by summing up the wetness of the constituent H₂O molecules—wetness emerges from the interactions between the molecules.” Indeed, this concept of emergence might be useful in explaining transdisciplinarity itself, since “information, data, theories, and methodologies from multiple disciplinary viewpoints are brought into the [transdisciplinary research] process and are . . . combined in order to create something new that is irreducible to the disciplinary components that were initially brought to bear” (Leavy, 2011, p. 31). Leavy indeed explicitly relates transdisciplinarity to emergence, stating that “The idea of emergence speaks to the part of research practice that is unplanned, when unexpected pathways come into view, and when new insights are unearthed” (2011, p. 32).

A final characteristic of transdisciplinarity, alluded to above, is the tendency to think laterally, imaginatively, and creatively not only about solutions to problems but to the combination of factors that need to be considered. Inputs from the arts and humanities can transform research and education in sustainability or other topics traditionally viewed as scientific into an entirely new kind of product (Clark & Button, 2011). The impulse to recombine the given disciplinary elements in a creative way is implicit in what Julie Thompson Klein (2015) calls the “discourse of transgression” that underlies much recent research in the humanities and social sciences. Indeed, transdisciplinary researchers frequently encounter paradoxes that cannot be resolved, according to Wickson, Carew, and Russell (2006, p. 1054). As identified by Tanya Augsberg (2014, p. 240), some of the characteristics desirable in one who wishes to undertake transdisciplinary work include abilities to think in a complex, interlinked manner, and acknowledge the pain inherent in

abandoning one's intellectual comfort zone by working outside one's home discipline and engaging in new modes of thinking and taking action. Of course, being transgressive alone does not qualify academic research as transdisciplinary. But in foregrounding wicked problems transdisciplinarity combines the discourse of transgression with problem solving, "breaking free of reductionist assumptions about the way things are related, how systems operate, and the expectation that science delivers a single 'best' solution or final answers" (Klein, 2015, p. 14). From the above descriptions of the nature of the transdisciplinary research enterprise we can see the potential for frustration and pain as well as for the exhilaration that comes from seeing things in a new way.

3. Transdisciplinarity and Integration of Knowledge

The need for transdisciplinary research to integrate knowledge has frequently been mentioned as a goal by those developing theory in the area. For example, Burger and Kamber (2003) write of the integration of knowledge at the problem level, the research level, and the solution level. Given the highly abstract level of these discussions, it is hard to know how such integration of knowledge would work in practice. Therefore, a few examples would help explain the possibilities for transdisciplinary knowledge integration.

A subject such as water falls between the various disciplines and is easily ignored or taken for granted by scholars since it seems on the surface to be neutral—a feature of the landscape, something used by animals and plants or that gets combined with other substances, something that makes everything else work, but that seems rather lacking in character in its own right, even though life itself could not exist without it. It has a chemical basis and can be studied from a chemical or physical perspective (hydraulics and hydrology); it is also important in technology, engineering, manufacturing, and equally important, the culinary arts—there could be no food or drink without water. It is a component of nutrition, digestion, physiology, and health; there are sanitation and purity considerations in using water and having it in our environment. There are cultural and religious aspects of water and it is a theme in all the arts. Water as a resource would be studied by geographers, geologists, economists, and agricultural scientists. Obviously, the sustainability of water as a resource is an issue, as in the problem of waste caused by packaging in disposable water bottles (Royte, 2008). There are even political aspects to an important resource such as water, shortages of which can lead to famine, war, revolution, or other vast sociopolitical changes. One could continue *ad infinitum* about the innumerable facets of water that need to be studied. Questions about water bring together the social sciences, humanities, physical sciences, biological sciences, and practical arts and sciences in ways that can be enlightening for educational purposes on the interaction between disciplines.

But even more subtle and surprising connections can be found through transdisciplinary work, as practiced by Johann Tempelhoff, a South African historian who focuses on the study of water. In studying community responses to the contamination of a local municipal water supply, he and his research team found it particularly enlightening to reflect on the complex environmental and social issues involved with the project while listening to music—not just any music, but specifically the Simon and Garfunkel song, *The Sounds of Silence*, as rendered on a 42-string guitar by the American jazz

virtuoso Pat Metheny (Tempelhoff, 2013). Tempelhoff's juxtaposition of music (including phenomenological and therapeutic aspects), environmental and resource issues, citizen participation, and science and technology studies as applied to problems in water resources brings to bear an entirely novel, transdisciplinary way of thinking about the situation. He writes that the music enabled the researchers to comprehend the "profoundly silent but marked effect" the aquatic system had not only on the people who relied on the resource but also on "the non-human network" of equipment. This gave them insight into the resilience of the human spirit under circumstances of hardship and suffering (Tempelhoff, 2013, p. 372).

Tempelhoff's essay represents a characteristic trend in transdisciplinary research of locating and analyzing unsuspected connections between several levels of reality and modes of analysis. It contains social science, environmental and earth science, public health, humanistic psychology, and musicological dimensions. Though highly specific and idiosyncratic, such a study can usefully serve educators as a model of the innovative kind of work that is possible in tracing connections that may be hidden in standard disciplinary work.

Indeed, the problem of knowledge itself as the foundation of civilization and the basis of communication both inside and out of the academy could provide a starting point for a transdisciplinary viewpoint that would unite the humanities, social sciences, physical sciences, biological and psychological sciences, and more in creating a fresh and integrative approach to knowledge, as advocated recently by Søren Brier (2009; see also Bernstein, 2014). Education itself, as a field that brings together all other subjects in the context of organized teaching and learning, must also come into play in such a project. Recent approaches to the teaching and practice of business administration and management also prioritize knowledge management and organizational learning (O'Dell & Hubert, 2011). Such a focus on reconceptualizing knowledge for the age of global markets, especially in terms of how it is produced, hearkens back to early statements on transdisciplinarity, including that of Gibbons et al. (1994), and is strengthened by recent statements that a new post-epistemological conceptual framework is needed to understand knowledge since the conditions taken for granted by traditional epistemologists no longer apply to today's networked, globalized, postmodern, neoliberal environment (Allen, 2004, Harris, 2009, Weinberger, 2011). Post-epistemology and transdisciplinarity share several characteristics, according to López-Huertas:

- a) sensitivity to social demands and social welfare; b) the resurrection of the subject as a reaction to . . . classical ideas about it and about knowledge (a reification of the subject and knowledge); and c) the criticism of . . . how nature and reality are conceptualized. (López-Huertas, 2013, p. 403)

In his book, *The Knowledge Landscapes of Cyberspace*, David Hakken (2003) pioneered the study of knowledge practices in virtual worlds, using a transdisciplinary approach, even if he did not label it as such (Bernstein, 2014). A more recent transdisciplinary approach to knowledge practices can be seen in Barbara E. Truman's (2013) study of collaborative, simulated, virtual environments used in the online virtual world Second Life and role-playing games such as Minecraft, Eve Online, and World of Warcraft. Such a research

project involves innovative ethnographic research techniques in virtual communities and probes into questions about knowledge practices related to business management, leadership, organizational studies, leisure studies, sociology, social psychology, operations research, educational psychology, media studies, science and technology studies, and philosophy. Such work responds to a need to understand the construction and use of hybrid identities as mediated through avatars under the conditions of post-epistemology.

4. Conclusion

Transdisciplinarity emerged in the latter part of the twentieth century in response to a host of concerns about the pitfalls of specialization and the compartmentalization of knowledge, a globalized economy, shifts in the center of gravity in knowledge production, the ethics of research, and environmental crisis. It has grown into more than a critique of disciplinarity and has gained recognition as a mode of research applied to real world problems that need not only to be understood in new ways but also demand practical solutions. For transdisciplinarians concerned with justice, sustainability, and ending poverty, war, genocide, hunger, or other such wicked problems, theoretical solutions do not suffice, even though they realize that wicked problems by definition may be impossible to solve. Yet transdisciplinarity is not necessarily applied or practical. Those who focus on the educational benefits of transdisciplinarity, such as Roderick Macdonald (2000, p. 244), insist that “transdisciplinarity is as much about the liberal arts, and about cultural symbolisms, as it is about the so-called social and natural sciences, or professions like medicine, engineering, or law.” What sets transdisciplinarity apart from other approaches and what assures its role in twentyfirst-century education is its acceptance of, and its focus on, the inherent complexity of reality that is seen when one examines a problem or phenomenon from multiple angles and dimensions with a view toward “discovering hidden connections between different disciplines” (Madni, 2007, p. 3).

Tempelhoff’s (2013) example of making sense of hardship and crisis by reflecting on a classic rock song re-interpreted on a 42-string guitar is emblematic of the transdisciplinary paradigm in that unlike a standard six-string guitar, which has one set of strings and one fingerboard, the 42-string guitar has three fingerboards and four sets of strings (the strings not strung on a fingerboard are plucked or strummed as on a harp or lyre). Unlike the experience of hearing music played on a conventional guitar, experiencing a performance on such an instrument on both a visual and auditory level can evoke a sense of multiple dimensions that is analogous to an awareness of the multiple levels of reality described by Nicolescu (2012). The song must echo through the original composition, and Tempelhoff’s analysis of it must consider not only his own subjective experience of hearing the song but, at the very least, the experiences and feelings of the members of the research team and community, and then must tie everything back to the municipal project and the water resource on which the community relies. It is in using this multidimensional complexity to analyze problems and communicate and teach lessons about them that the novel contribution of transdisciplinarity lies.

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