THE KNOWLEDGE DIMENSION OF THE SUSTAINABILITY CHALLENGE

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Abstract

With the increasing awareness of the global environmental challenges, society expects a concerted intellectual leadership from the scientific community in terms of knowledge acquisition and solution generation. This is not a task to be left for few specialized sciences. It requires the mobilization and utilization of human ingenuity within each and every discipline. This leads to the following questions: Is science, as we know it today, capable of fulfilling this expectation? If not, what kinds of epistemological re-orientation do we need to make? Are there any historical parallels in the development of science, which could be used as the basis for a change? This paper takes the position that: yes, science has the capacity to respond to the environmental challenge, however, both the mono-disciplinary sciences and the interdisciplinary environmental sciences have their own limitations which can only be overcome through the development of a transdisciplinary paradigm.

Introduction

The term sustainable development 'rose to the prominence of mantra-or a shibboleth-'(Daly 1996) following the 1987 publication of the report of the UN-sponsored World Commission on Environment and Development (WCED). WCED defined sustainable development as 'development that meets the needs of the present generation without compromising the needs of future generation' (WCED 1987). In the following decade, numerous efforts of defining and redefining have been made. A comparative analysis of most of the definitions shows that they all share an inherent vagueness in terms of the core concept. But they differ in their identification of the solution epicenter, the solution platform, and the leadership center (Mebratu 1998). Some argue that the vagueness surrounding the concept of

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sustainable development is dictated by practical necessity. This point had a strong validity in the eighties. In the mid-eighties, a consensus on a vague concept was better than disagreement over a sharply defined one. Hence, despite its vagueness and ambiguity, the WCED definition on sustainable development has been highly instrumental in developing a global consensus on our planet's future. By 1995, however, 'this initial vagueness was no longer a basis for consensus, but a breeding ground for disagreement' (Daly 1996). Acceptance of a largely undefined term has set the stage for a situation where whoever can pin his or her definition to the term will automatically win a large political battle for influence over our future.

Others say that it is practically impossible to apply our scientific knowledge and develop a concrete body of theory on sustainability and sustainable development. This is, also, true if we attempt to define sustainability within the entrenched disciplinary context. Our current structure of scientific thinking, which is locked to the reductionist epistemological foundation, has a limitation of applicability in dealing with regions of organized complexity such as the environment. Thus, re-engineering our scientific thinking is a fundamental prerequisite for enhancing our understanding about the environmental crisis and developing a conceptual framework for sustainability and sustainable development.

The development of science and technology has been the major catalyst for the unprecedented speed and magnitude of change since the industrial revolution. Although nobody can deny the positive effect of these changes, it is equally true that 'science and engineering have been unable to keep pace with the second-order effects produced by their first order victories' (Weinberg 1975). As a result, we are faced with global environmental challenges that include global warming, desertification and loss bio-diversity. The disciplinary and interdisciplinary responses of the scientific community to the environmental challenge have demonstrated that science is an important tool in our effort to overcome the environmental challenge. However, the full-scale utilization of science for sustainability will require addressing the limitations that have become evident during these disciplinary and interdisciplinary stages.

According to the dominant scientific thinking, science is the study of those things that can be reduced to the study of other things.

Science, in other words, is essentially reductionist. However, it should be noted that the reductionists have not yet succeeded in reducing all phenomena to physical and chemical primitives (Weinberg 1975). Environmental issues are one of the complex and dynamic subjects that will always be beyond the reach of the reductionist scientific thinking. Scientific understanding of the environmental challenge will require overcoming the limitations of the reductionist approach that is inherent in our way of thinking. This implies the need for a shift of paradigm. This paper addresses the inherent possibilities and limitations of current scientific thinking with respect to the environmental challenge with which we are faced. The first section looks at the major epistemological elements that have significant bearing on current way of thinking. The second section analyses the possibilities and limitations of current scientific thinking in our efforts to understand sustainability and sustainable development.

1. The epistemological challenge

Scientific thinking constitutes one of the greatest tools of mankind in the transformation of the agricultural society to the industrial society. Today, its influence is so immense that it permeates through most of the day-to-day decisions of an ordinary life, through the dominant mental models it has created. Scientific thinking has passed through different stages of refinement before assuming its current status. Hence, any discussion on scientific thinking must be conducted within the historical context of its development. Although there could be a number of epistemological issues that constitute the nature of the scientific thinking, the discussion in this section is limited to the following three topics which are of primary relevance to the objective of the paper.

1.1 The logic of truth

The ultimate objective of science is enshrined as the search for facts or truth. But what is truth? This question seems to be the supreme question underlying the philosophy of science and the pursuit of knowledge. The search for truth is also where the logic of bivalent and multivalent truth begins. Looking back at the ancient history surrounding the logic of truth, one stumbles upon the history of logic of the West and the East. For the West, Aristotle offered a binary logic chop which always draws the line between opposites, between the thing and the not-thing, between A and not-A, between black and white. According to Aristotelian methodology, 'the better you drew those lines, the more logical your mind and the more exact is your science' (Kosko 1994). In contrast, the great cultural leaders of the East were "mystics." They tolerated vagueness and even promoted it. Buddha rejected the black-and-white world of words on his path to spiritual or psychic enlightenment, while Lao-tze gave humanity the Tao and its yin-yang emblem of opposites, both thing and not-thing.

Aristotle's logic and scientific bent have shaped much of the modern Western mind and defined its range of parameters, its boundaries, its listing of correct and incorrect. Each generation has refined Aristotle's model of the mind and the universe. To a large degree Aristotle is till the accepted authority on what is philosophically correct in logic and reasoning. Science has been less critical of Aristotle's model of the mind until the beginning of the twentieth century when the challenge to Aristotelian truth started to emerge with the evolution of new theories such as the quantum theory.

Table 1:
Analysis of the Logic of Truth

Factors	**Bivalent truth**	**Multivalent truth**
Philosophical origin	Aristotelian	'mystics' of the East
Logic	binary logic	fuzzy logic
Truth	black or white	gray
Stance	denial	recognition

At the root of the difference between bivalent and multivalent truth lies the mismatch problem. The mismatch problem - gray worlds but black-white scientific description- reduces to a truth problem, the problem of gray truth. In terms of truth, the mismatch problem recounts the antagonism between bivalence and multivalence, between the black-or-white and the gray. Multivalent (Fuzzy) logic says all scientific truths are gray. Bivalent science says none are gray, but are tentative and may pass from all true to all false in the light of confounding data. Multivalent logic agrees that scientific truths are tentative but holds firm to the concept of grayness. That is the conflict. Whether truth is gray or not and to what degree (Kosko 1994). Multivalent logic views truth as accuracy.

And accuracy is clearly a matter of degree. Scientific truth with 100% accuracy brings us back to the mismatch problem of gray world with black-white description. As was stated by Kosko (1994), the bivalence of modern science ignores or denies or whitewashes and blackwashes gray truth. The multivalent view says that almost all truth is gray truth, partial truth. It allows mathematical truths to remain black or white as extreme cases of gray.

The rivalry between the bivalent and multivalent interpretations of truth has been a long-standing one in the philosophy of science characterized by the dominance of the bivalent truth. However, in the early twentieth century, this rivalry has taken on a new dimension giving an increasing recognition to the multivalent view. This has been further strengthened by the evolution of such theories as quantum theory, systems theory, and cybernetics. The recognition of the fact that our scientific knowledge is based on the establishment of partial and gray truths is a key element in understanding complex systems. This, also, has a significant bearing on our efforts to understand the environmental crises.

1.2 The cosmic view

The image of nature as an organism, ensouled and purposeful, created by God and replete with signs of His creative and loving providence, reached its culmination in the West during the Renaissance period (Clark 1993). In the course of the sixteenth century, however, a new and dramatically different model of the universe began to emerge. Copernicus replaced the old Ptolemaic geocentric universe with a heliocentric model, thereby destroying the image of a cosmos which, since Plato, had come to symbolically reflect the centralized position of humanity within the great chain of being. But, the main task of building a new model fell on Kepler, Galileo, and Newton, who reordered the concept of the solar system so that it no longer resembled an organism but rather a 'magnificent piece of clockwork'(Clark 1993). They showed that the processes of the natural world, whether in the heavens or on earth, could be understood without reference to soul or purpose. It could simply be understood in terms of material particles moving in infinite space in accordance with strict, mathematically precise, universal laws.

The culminating synthesis was laid out in Isaac Newton's *Principia Mathematica*, a work that became a model for all future scientific endeavour. However, it was René Descartes who gave the first clear articulation to the idea that all the workings of nature could be understood by analogy with the workings of a clockwork machine. The reductionist idea that is based on the notion that nature is not a great organism but rather a great machine has become the central inspiration of the scientific revolution, and as a potent metaphor it runs through the whole of modern thought and culture. Since the late 19th and early 20th centuries, 'a subversive sub-culture has sought to keep alive and even amplify a more traditional and more metaphysical conception of nature' (Clark 1993). The French philosopher, Bergson, and the Anglo-American philosopher, Whitehead, are representative of such an alternative view of nature. This view emphasizes creativity rather than a deterministic mechanism, process rather than substance, the whole rather than the parts. It links together the human and natural realms, and pictures the world as an ever-interacting flow of energy, thereby laying down the basis for what is called 'holistic view'.

This term has come to be widely used in the second half of the 20th century to represent a new (but traditionally based) view of nature. One that has arisen in part from developments within science itself, and which is vaunted by its supporters to overcome the limiting and dispiriting aspects of positivistic and mechanistic philosophies of nature. The word 'holism' is a term that has played a central role in much subsequent discussion on environmental and ecological questions; and according to Clark (1993), it was first coined by the South African philosopher, Jan Smuts (1870-1950).

Table 2:
Comparative Analysis of Cosmic View

Factors	**Reductionist**	**Holistic**
Nature	as a machine (Clock)	as an organism
Focus	the parts	the whole
Mechanism	deterministic	creativity
The 'whole' as	mechanistic sum of the parts	dynamic interaction of the parts

According to holistic thinking, both matter and life consist of unit structures whose ordered grouping produces natural wholes, which we call bodies or organisms (Smuts 1993). This character of 'wholeness' meets us everywhere and points to something fundamental in the universe. Holism is the term that stands for this fundamental factor operative towards the creation of the universe. Its character is both general and specific or concrete, and it satisfies our dual requirement for a natural evolutionary starting point.

Jan Smuts (1993) states that the wholes are not mere artificial constructions of thought; they point to something real in the universe. Taking a plant or animal as a type of a whole, we notice the fundamental holistic characters as a unity of parts, which is so close and intense as to be more than the sum of its parts. This does not only gives a particular conformation or structure to the parts, but so relates and determines them in their synthesis that their functions are altered. The synthesis affects and determines the parts, so that they function towards the 'whole'. The whole and the parts therefore reciprocally influence and determine each other, and appear more or less to merge their individual characters. The whole is in the parts and the parts in the whole, and this synthesis of whole and parts is reflected in the holistic character of the functions of the parts, as well as of the whole.

Furthermore, the holistic view asserts that natural wholes are always composed of parts; in fact the whole is not something additional to the parts, but is just the parts in their synthesis, which may be physico-chemical or organic or physical or personal. As holism is a process of creative synthesis, the resulting wholes are not static but dynamic, evolutionary, and creative. This is a universe of whole making. Consequently the explanation of nature can not be purely mechanical like the machine clock; and the mechanistic concept of nature has its place and justification only in the wider setting of holism.

A natural whole has its 'field', and the concept of field will be found to be most important in this connection also. An organism can only be explained by reference to its past and its future, as well as its present. The central structure is not sufficient and literally has not enough in it to go around in the way of explanation; the conception of the field becomes necessary and will be found fruitful in biology and psychology, no less than in physics (Clark 1993).

Competitive existence of these two views may be observed in the fields of social science. In this regard, Redclift & Benton (1994) presented the two views as 'individualist' and 'social realist'. Individualists within the social science domain generally claim that 'society' is nothing over and above the individual people of which it is composed and tend to focus on individual demands, desires, or decisions. On the other hand the holist, or 'social realist', approaches within the same domain tends to emphasize ways in which individual behavior is shaped by the wider collectiveness or normative frameworks within which individuals are situated. Fundamentally, the holistic view recognizes the validity of the reductionist way of thinking within the broader domain of the holistic view. In this context, disciplinary sciences, as reductionist as they are, will remain to be the best source of gaining in-depth knowledge about the parts. But, when it comes to complex systems, the limitation of the reductionist view needs to be rectified through the application of the holistic view. Recognizing the relationship between the holistic and reductionist view is one of the major challenges that must be addressed by the scientific community in its efforts of dealing with environmental issues.

1.3 Framework of thinking

According to Clark (1993), the nineteenth century was a period of spiritual and moral crisis, concluding with Nietzsche's prophetic warning concerning 'nihilism' (belief in nothing) and his famous cry 'God is dead'. The trends and conflicts of the nineteenth century continue unresolved into the twentieth century. Positivism, as a philosophy that celebrates most powerfully the sense of the domination of nature through the power of the human mind, is philosophically, perhaps, most typical of the first half of this century. According to this way of thinking, any attitude towards nature other than the strictly scientific is consigned to the subjective realms of emotion and poetry (Clark 1993). The positivistic thinking is the traditionally dominating approach and is used widely in natural sciences research. One basic assumption is that there is an objective reality that is independent of individual human beings, such as the scientists (Nilsson 1995). The gaining of scientific knowledge thus follows formal logical procedures. Furthermore, consolidating the reductionist stance, positivistic thinking advocates that scientific knowledge is of an additive character. This means that the whole can be explained by the sum of the parts, and the objective of science is to reconstruct reality from the parts and establish casual connection between entities, often to explain and guide or forecast.

The interpretive framework of thinking is based on the assumption that reality is socially constructed and is always dependent on the actors. According to this way of thinking, reality consists of several different images, picturing the meaning and content particular actors put into their actions and surrounding environment (Nilsson 1995). Furthermore, it asserts that knowledge is a subjective property and reality does not exist in an objective sense. The reality of several individuals can have common components that constitute an objectified reality for this group of individual scientists, organizations or the society. According to this thinking, this objectivity is not universal, but created by man and can therefore be questioned and changed.

On the other hand, we have the systems thinking that emerged in the 1950's as a reaction to the additive picture of reality of the positivistic thinking. Systems thinking is based on the premises that any system consists of a group of things or parts working together in a regular relationship. According to this thinking, the system as a whole has properties that are not founded in any one of the parts (Weinberg 1975). The positivistic thinking focuses more on linear cause-effect relations, which in complex reality is often replaced with circular causalities. In contrast to the linear cause-effect relationship, systems thinking recognizes that the relationship between parts or entities can add positive or negative effects to the system (Senge 1990). It further recognizes that a cause can lead to more than one effect (multifinality), while a number of causes can also lead to an identical effect (equifinality).

Table 3:
Comparative Analysis of Framework of Thinking

Factors	Positivistic	Systems	Interpretive
Reality	objective	objective & constructed	socially constructed
Knowledge	additive	evolving	subjective
Focus	cause-effect	interrelationship	contexts
Approach	reductionist	holistic	phenomenological

Although systems thinking is gaining acceptance within the scientific domain, most of the conclusions and solutions are still locked within the deeply ingrained linear thinking. In this context, the major challenge may be the challenge of unlearning most of the prevailing mental models, which are largely locked within the linear thinking, and replacing them with system mental models that incorporate the relationship and interaction between parts as an important element of our mental model.

2. Science and the Environmental Challenge

One of the major outcomes of the change in global environmental consciousness witnessed over the past three decades was its effect on the various disciplines of science, which resulted in an academic process that might lead to the 'ultimate breakdown of the entrenched systems of scientific disciplines' (Benton 1994). This process has been a two-way process helping the environmental debate to benefit greatly from the insights of sciences, and equally enabling the scientific communities to learn from their attempts to rise to these challenges. On the one hand, as science and technology progress, our ability to recognize the complex cosmic interaction has developed, leading to a higher forecasting ability of long-term effects of today's activities. On the other hand, as the reality of the potential immediate and long-term implications of current development activities has sunk down, the scientific community has started to work on generating remedial measures and solutions for the problem.

New ways of scientific thinking are related to the development of new paradigms. The concept of scientific paradigm was first systematically introduced by Thomas Kuhn in 1962. But precursors to the concept date back at least to Max Wertheimer in 1912 (McCaine & Segal 1988). Thomas Kuhn (1962) defines paradigm as 'the sets of assumptions, stipulations, or normative propositions can collectively be called a research paradigm'. McCain and Segal (1988) states that it is difficult to give a simple definition to the concept of scientific paradigm. But, they further elaborate that, '…it refers to the total complex of science. It includes the language, conceptual framework, theories, methods, and limits of the science. It determines which aspects of the world scientists study and the kinds of explanations they consider. Most importantly, it includes the way scientists see the data, laws, and theories of their science. All scientific paradigms contain these multiple elements'.

The response of the scientific community to the environmental challenge can be mainly classified into three stages. The first stage was the period of disciplinary response during which each scientific discipline made an attempt to understand the causes of the environmental crisis from their own disciplinary domain. This was followed by the multi- (or inter-) disciplinary response, which is the current dominant approach to environmental issues. The transdisciplinary response that is emerging as a third stage of scientific response for managing complexities at the science and society interface.

2.1 The disciplinary response

Science as we know it today 'was created in the seventeenth century by Galileo, Newton, and others who, following Descartes' inspiration, forged this view of nature as a great machine' (Clark 1994). Since then, it has passed through the rugged terrain of conceptual ups and downs but has consolidated the reductionist simplification as its epistemological foundation. The initial response to the increasing level of the environmental crisis has, naturally, originated within the entrenched domain of the different disciplines (Mebratu 1998). The initial effort of responding to the environmental challenge within the domain of the discipline led to the creation of a specialized area of research and education within the mainstream disciplines. Specialized disciplines such as environmental economics, environmental engineering, environmental science, and environmental law are an outcome of the effort of the scientific community responding to the global environmental challenge. The subsequent transformation of these specialized disciplines from the level of frontier sciences to textbook sciences[1] took a relatively very short time. Thus, specialized environmental disciplines currently constitute the core elements of environmental education and research of major universities.

Table 4:
Comparative Analysis of the Disciplinary Versions' of Sustainability

Disciplin-ary Version	Epistemological orientation	Source of Environmental Crisis	Solutions Epi-center	Mechanism of Solutions
Economics	Neo-classical reductionism	Market imperfections	Internalization of externalities	Market instrument
Deep Ecology	Ecological reductionism	Human domination over nature	Reverence and respect for nature	Bio-centric egalitarianism
Social Ecology	Reductionist-holistic	Domination of people and nature	Coevolution of nature and humanity	Re-thinking of the social hierarchy
Engineering	Deterministic	Inefficient production	Efficiency improvement	Technological progress

(Source: Mebratu, D., (1998), Sustainability and Sustainable Development: Conceptual review, In EIA Review. Elsevier Science Publication)

The disciplinary responses are to a large extent based on an extension of the basic principles and theories of the disciplinary domain toward the field of environment, which is inherently an area of dynamic complexity. This has led to two major constraints. Primarily, the effort of understanding the root causes of the environmental crisis within the reductionist way of thinking has led to either a factual error in their premises, or to a logical error in their analyses, or both (Mebratu 1998). This has led to the generation of completely different and sometimes conflicting views about the scope and nature of the environmental crisis.

As can be seen from the Table 4, all of the disciplinary versions for which a comparative analysis was conducted present part of the source of the environmental crisis. But none of them on their own present the complete picture. It is like describing a building based on a view obtained from one perspective. The second constraint, which is a natural outcome of the first, is that the independent solutions generated and proposed within the disciplinary domain have a limited scope of application and influence in dealing with the complexity of the environmental crisis.

Despite its limitation, this exercise has been very important for three reasons. Primarily, it has significantly expanded the knowledge base about the different aspects of the environmental crisis. Secondly, most of the serious attempts of coming to terms with the issues posed by the environmental crisis have exposed some of the basic 'settled' assumptions of the 'mainstream' traditions of the sciences to critical examination. Calling into question these settled assumptions has opened up a research agenda for the sciences that extends well beyond the traditional environmental issues. And thirdly, as the impossibility of fully understanding, let alone resolving, any of the environmental issues has sunk down within the scientific community, it has opened the door for interdisciplinary dialogue that has led to the creation of new interdisciplinary fields of research and education.

2.2 The interdisciplinary response

During the late seventies and early eighties, a number of organizations and institutions dealing with environmental issues came to realize that the disciplinary approach has a serious limitation when it comes to dealing with environmental issues (Mebratu 2000). Thus, the multidisciplinary approach began to emerge as a matter of necessity as the environmental challenge became too complex to be treated within the narrow scope of the different disciplines. The multidisciplinary approach, which emerged out of operational necessity, led to the shift towards interdisciplinary approach in environmental education and research.

In recent years, this interdisciplinary approach has been embraced by an increasing number of academic institutions. This has led to the establishment of a number of interdisciplinary environmental research centers and academic programs at different universities. This new breed of interdisciplinary approach within the academic community is based on the combined application of the specialized knowledge and principles from the different disciplinary domains. Although this approach represents a step forward in terms of reducing the barriers between the different disciplinary domains, it has also led to the following constraints with respect to effectively addressing the environmental challenges.

- First, in the absence of a concrete body of theory that serves as the thread of synthesis between the different parts, the interdisciplinary approach is, to a large extent, characterized by the mechanistic combination of concepts and tools that are generated under the different disciplinary domains. Thus, the fundamental epistemological shortcomings that are observed within the independent disciplines are transferred to the interdisciplinary packages.
- Second, the effort of developing interdisciplinary tools and techniques for moving towards global sustainability is highly characterized by the fervent desire to impose disciplinary concepts and principles on the decision-making process. This, combined with the mechanistic approach, has led to considerable confusion and at times frustration at the practitioner level.
- Third, the passive integration of the various conceptual principles and conclusions through the multidisciplinary approach has led us into an era of detailed complexity under which the underlying root causes of the environmental crisis are overshadowed by a long list of symptomatic solutions.

Besides these major limitations, the growing institutional recognition of the interdisciplinary approach within the academic institution is accompanied with a subtle sidelining of environmental issues from the disciplinary domain and vice versa. This trend is being propagated by both the interdisciplinary institutions which underrate the contribution of other disciplinary sciences to the development of the environmental knowledge base and by the so-called 'hard-core' disciplinarians who generally tend to brand the interdisciplinary approach as being unscientific. Neither of these trends are beneficial to the overall effort of moving towards a sustainable society.

The interdisciplinary paradigms, which have become the dominant paradigms of the environmental discourse in recent years, are fundamentally aimed at overcoming the limitation of compartmentalized nature of the disciplinary paradigms. According to Leroy (1997), 'the distances and differences between the disciplines involved- in terms of epistemologies, concepts, theories and methods, and in terms of priority and relevance to environmental problems - complicated the development of interdisciplinarity more than some had expected'. Similarly, Ziegler (1997) said that, 'the inside barrier to environmental interdisciplinarity is the split between ecological, social and economical lines of thought with the tendency of the ecological to follow the others in grouping separately, erecting a discipline above the other disciplines. Even if the intention is multidisciplinarity, often the organizational behavior is different'. In terms of solution, the dominant mechanistic nature of the inclusion process results in solutions of detailed complexity, which diverts attention away from systemic causes by focusing on symptoms.

Leroy (1997) further noted that, despite the huge efforts over the last 20 years on the development of new concepts, models and methods, it is still uncertain whether the environmental sciences do have or will ever have a common and interdisciplinary *body of knowledge* or any other robust scientific foundation. Although the interdisciplinary debate gave rise to some scientific metaphors and modeling on the man-environment interaction - varying from the 'pressure-state/impact-response' model to the 'metabolism' metaphor -, interdisciplinarity so far seems primarily a question of the transfer and integration of methods, rather than the forging of substantive theories. This situation can be referred to the youthfulness of environmental sciences, and to the social commitment of most environmental scientists, more concerned about problems and their solution than about scientific theory. Nevertheless, interdisciplinarity complicates (Leroy 1997) the search for scientific foundation whereas mono-disciplinary often enjoys a more robust scientific underpinning.

While fully recognizing the importance of interdisciplinarity, Leroy (1997) argues for a close link from environmental sciences to the classical basic disciplines. He further asserts that, without such a link interdisciplinarity may lead to some superficial eclecticism or run into some formal modeling. It is this notion that is giving rise to the evolution of transdisciplinary paradigms.

2.3 Transdisciplinary response

The transdisciplinary paradigm is based on identifying and developing the general theories and principles that govern the disciplinary thinking based on the conceptualization experience of the disciplinary and interdisciplinary schools. The main feature of this school is its cross-sectional nature running through all disciplinary domains. The systemic methodology upon which it is based enables it to look at the dynamic interrelationships between systems and generate solutions with maximum synergistic effects. Most importantly, the transdisciplinary paradigm does not dissociate itself from the disciplinary domains. It rather works within each and every domain serving as the synthesizing thread of our action in response to the environmental crisis. This gives us the basis to work with 'competent rebels' that do not emigrate with justified contempt for their discipline/area, but keep positions by changing them from inside. As it was pointed out by Ziegler (1997), 'competent rebels do not emigrate into niches but shoulder the negative task of undermining the self-reliance of their origin parallel with the constructive task'.

The transdisciplinary approach is based on the combined application of systems theory and evolutionary theory. Most scholars interested in evolutionary theory would agree that the term evolutionary 'ought to be reserved for theories about dynamic time paths that aim to explain how things change over time, or to explain why things are what they are in a manner that places weight on how they got there' (Dosi et al. 1993). In other words, the adaptive dynamics of the system becomes the principal focus of the evolutionary approach. The systems evolutionary approach is based on the recognition of the fact that: all systems are in a state of disequilibrium, following an irreversible path of development, and sustaining their systemic function through successive adaptation (Mebratu 2000b).

That is why the study of the adaptive dynamics of complex systems becomes the analytical focus of the evolutionary school of thought. On the surface, the distinctions between the ecological and evolutionary approaches might not be discernible. But, there are some fundamental differences of which the following are the major ones. Primarily, the evolutionary approach is not aimed at generating prescriptive solutions and predictions based on the extension of biological evolutionary principles on socio-economic systems. Rather, it attempts to define the basic principles that maps out the evolutionary path of any kind of system within a given 'possibility domain' (Mebratu 2000b). Secondly, the marginal consideration of social/organizational dimensions is the major shortcoming of the ecological approach in terms of its contribution to sustainable development. Under the evolutionary approach, population dynamics is one of the major phenotypic parameters that determine the specific evolutionary path followed by a given system.

Gibbons and Nowotny (2001) state that a transformation is occurring in the relationship of science and society. A new model of knowledge production is at the heart of this social transformation. Much of the thrust of innovation is coming from new links between traditionally compartmentalized and segmented producers and users of knowledge. It is believed that the contextualization of research around the interests of stakeholders fosters a more socially robust and useful knowledge that transgresses disciplinary and institutional boundaries. The contextualization of knowledge production is not limited to the context of application but it includes also the context of implication. It is in this context that the knowledge base becomes critically important. Thus, when one talks about transdisciplinarity, the link between the modern knowledge system and the traditional (indigenous) knowledge system constitutes the major challenge besides the transgression of disciplinary boundaries. This is particularly important in terms of understanding the nature of the socio-economic and socio-ecological challenges of the developing world (Mebratu 2000a). The scientific community has to recognize that the traditional knowledge base of the developing world may have something to contribute towards the global effort of promoting sustainability.

Conclusion

The response of the scientific community to the global environmental challenge, naturally, started within the disciplinary domains which later evolved towards the interdisciplinary response. The move from the disciplinary to interdisciplinary response is dictated by the inherent limitation of the disciplinary sciences in dealing with systems of organized complexity. Nevertheless, the interdisciplinary response, which is strongly anchored within one or another disciplinary domain, is leading to an era of ‘detailed complexity’ where root causes of systemic dysfunction are increasingly replaced for symptomatic details. The limitations of the interdisciplinary response are yet again dictating the need for transition to transdisciplinary paradigms in dealing with the global environmental challenge. Despite their limitations, the disciplinary and interdisciplinary response to the environmental challenge have made major contribution in terms of expanding our knowledge base and opening doors for questioning some of the settled assumptions of the dominant scientific thinking.

The global environmental crisis is an outcome of a global systemic deficiency that requires societal re-engineering at all levels of our society. We are standing at crossroads where the interface between science and society is being tested yet again. Problems that arise at the science-society interface can only be solved by understanding the actual complexity of the societal transformation process. Understanding sustainable development as a societal transformation process will require us to begin a new form of dialogue on a transdisciplinary basis. The scientific community is faced with the challenge of spelling out more precisely the form of this new dialogue, if we are to overcome feelings of alienation and frustration. In confrontation with the entrenched compartmentalization of specialized disciplines, progress in transdisciplinary paradigm development must prove stronger than the territoriality that keeps theories developed within specialized disciplines apart.

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