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COMPLEXITY AND HUMAN HEALTH: THE CASE FOR A TRANSDISCIPLINARY PARADIGM

ABSTRACT. Transdisciplinary thinking is an emerging philosophy underpinning health social science. We advance a definition of transdisciplinary thinking and link it with complexity theory. Complexity theory's concern with non-linear relationships, interactive causality and emergent properties of systems compels researchers to adopt a transdisciplinary perspective. We construct a generic framework for analyzing health processes from diverse disciplines and apply it to coronary heart disease in the Australian Coalfields. Insights from this analysis support our argument that transdisciplinary thinking maximizes understanding of the complexity of human health.

INTRODUCTION

Social science and health researchers have begun to consider transdisciplinary thinking as a unifying approach to understanding and resolving problems of human health (e.g., Kengeya-Kayondo 1994; Rosenfield 1992) and as a viable perspective to guide the training of health social scientists (Higginbotham 1994). In this article, we extend initial definitions of transdisciplinary research, situate the concept historically and philosophically, and contrast it with other forms of disciplinary research. A generic transdisciplinary framework is developed enabling researchers to pursue the interplay across disciplines and theories in constructing multi-level explanations of health problems. At the heart of the transdisciplinary framework is the anticipated emergence of a common conceptual framework capable of unifying these multiple explanations. We advance complexity theory as a potentially powerful unifying construct for understanding the nature of complex, dynamic systems, such as those in which health problems are invariably embedded. After defining complexity theory and its relevance to health, we examine how it can be used to analyze an 'epidemic' of heart disease among people in a coalmining community in New South Wales, Australia. We hope the example may stimulate other researchers to extend transdisciplinary thinking to other complex health problems where the dynamic systems initiating or exacerbating evolving disease patterns remain to be illuminated.

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EARLY EXPRESSIONS OF TRANSDISCIPLINARY THINKING

During the twentieth century it has become clear to scientists and philosophers alike that the world humans inhabit has a much more complex structure than was thought previously. Mechanistic models of how the world is structured have been challenged by dynamic, process-orientated models. The new models have enabled better understanding of physical and biological systems. They reveal that even seemingly simple dynamic systems produce unexpected outcomes while complex systems behave in ways that are often unpredictable.

Although scientists and philosophers have attempted to provide insight into complex, dynamic systems for much of this century, it was not until the 1970s that 'Complexity Theory' began to systematically challenge the linear and traditional disciplinary approach to human knowledge. Complex systems, philosopher Erich Jantsch argued, require a *transdisciplinary* way of thinking to interpret and understand dynamism and interaction (1972: 215–241). Jantsch envisioned a Transdisciplinary University to house the multi-level coordination of research, education and innovation associated with the increasing complexity in all fields of human activity. He observed that "the essential characteristic of a trans-disciplinary approach is the coordination of activities at *all* levels of the education/innovation system" (1972: 234). While Jantsch's ideas have appealed to academics prepared to work beyond the constraints of a traditional university, transdisciplinary research and publications have been scarce.

Transdisciplinary thinking and health social science

Early foundations of transdisciplinary thinking were laid by theorists such as George Engel (1977, 1980) and Mosley and Chen (1984). Engel's Biopsychosocial Model (1980) was an early attempt to come to terms with the complexity of causal factors affecting health. Engel outlined a "hierarchy of natural systems" ranging from subatomic particles to global systems, including societies, which provided insight into the varying relevancies of aspects of the physical, biological and social sciences in explaining a particular health problem. Mosley and Chen's Proximate Determinants Framework (1984) highlighted the complexity of causal factors determining health, distinguishing between proximate determinates (immediate influences) and distant socioeconomic causes.[1]

Transdisciplinary health social science has gained prominence recently as a unifying approach in the emergence of the International Forum for Social Sciences and Health. Pat Rosenfield (1992) published the first definition of transdisciplinary (TD) health research while Glenn Albrecht (1990) outlined a philosophy of TD thinking applied to human health. Albrecht argued that health problems emerge as expressions of parts of extremely complex interacting systems. They are the culmination of multiple variables, ranging from the genetic and physiological to the social, ecological and political acting over time and space. The World Health Organization definition that health is “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity” (WHO 1946) gives a static image of what we view as a complex process. However, recent environmental concerns have generated ecologically-minded public health policy within some sections of WHO (see Chu and Simpson 1994).

An ecologically informed or process view of optimal health implies the self-regulation and maintenance of all relevant systems promoting ongoing physical, psychological and social well-being. This latter definition gives us a sharper understanding of what ill health is. Namely, loss, for an individual or a community, of the ability to self-regulate and the disintegration of support systems leading to the necessity for intervention. In a process view, intervention is directed towards restoration of all relevant support systems in order for health again to be self-generated and self-regulated. Maintenance of health requires balance in the support systems; health recovery requires detailed knowledge of the dynamics leading to loss of self-regulation so as to intervene in a way that fosters a return to balance.

We argue, along with Rosenfield, that it is a transdisciplinary approach which is most capable of coming to terms with health problems that are embedded in complex causal connections. By exploring these complex connections we will be better equipped to design more effective, culturally sensitive interventions. Transdisciplinary thinking operates through an intellectual milieu comprising diverse theories of knowledge which span traditions of positivism to postmodernism. A sharply contested argument is whether such paradigms can (or should) be integrated.[2] While recognising the tensions between paradigms, we concur with Greene (1994: 537) that it is possible to achieve “dialectically enhanced inquiry benefits through a pluralistic acceptance of multiple ways of knowing.” Our explanation of transdisciplinary thinking proceeds from the assumption that reality is complex and convoluted and that truths about it will be revealed by a multiplicity of perspectives, of which traditional science is but one. Our aim as transdisciplinary thinkers is to create a meta-theory which weaves this multiplicity of perspectives into a coherent whole whereby the differences in approach are complementary rather than contradictory.

Politically, transdisciplinary thinking leads away from any form of authoritarianism, towards a politics of inclusion and an awareness that academics do not have a monopoly on wisdom. It is open *a priori* to all theories of knowledge, including those underlying indigenous beliefs. Grounded in traditions that are sensitive to the role of the researcher in the research process, transdisciplinary thinking evolves reflexively as it assembles the meta-theory.

Barriers to transdisciplinary thinking in health

Given that a large number of disciplines must be engaged in order to explain what is a complex and dynamic interaction of causal factors, why isn't such an engagement the norm? A number of barriers work against complete or 'holistic' explanations. These include 'reductionism,' the attempt to reduce a problem to its most basic parts. For example, cardiologists reduce heart disease to the workings of arteries and valves or even further to changes at the cellular level in the walls of these arteries. A second barrier is 'strict holism' which is the examination of a problem exclusively in terms of its broadest possible context. Researchers following strict holism would interpret a health problem like heart disease using global concepts only, such as the person's cultural beliefs or social class position. A third barrier is discipline rigidity and super-specialization. By controlling knowledge, and developing professional bodies that accredit the practice and use of such knowledge, disciplines acquire power within institutions and societies. The quest for discipline autonomy promotes greater specialization of individual workers within disciplinary boundaries at the expense of a fuller understanding of the problem. The fourth barrier is the complex and unpredictable nature of health outcomes. Because of such complexity, health problems[3] can emerge that could not be predicted, or readily understood, using causal models suggested by reductionism or strict holism.

In this paper we attempt to overcome the barriers outlined above through 'trandisciplinary thinking.' Table 1 illuminates the character of transdisciplinary research in contrast to the single, multiple and interdisciplinary approaches.

Transdisciplinary insight

The transdisciplinary approach examines and explains health issues by "drawing together disciplinary-specific theories, concepts and approaches" (Rosenfield 1992: 1351). There are two ways of going about transdisciplinary thinking: through an individual synthesizing findings from a multitude of disciplines to provide a comprehensive explanation of a complex health

Table 1. The character of transdisciplinary research

	Health problem/ problem boundary	**Teamwork/ collaboration**	**Role of conceptual framework**	**How knowledge is applied**
Single disciplinary	The health problem is what a single discipline thinks it to be.	None.	Arises from a single discipline.	Production of `specialised' knowledge and reductionistic accounts of problem or intervention.
Multidisciplinary	The health problem is what several disciplines working independently think it to be; hard disciplinary boundaries are placed around the problem facets.	None or limited; disciplines work independently on distinct facets of a broadly conceptualised problem.	Mutually exclusive conceptualisations juxtaposed and broadly cumulative.	Interventions suggested by isolated, discipline-specific problem explanations.
Interdisciplinary	The health problem is what several disciplines working together agree it may be. Aspects of the problem from disciplines not included may be ignored. The health problem is defined by the totality of `soft' boundaries between the various disciplines working together.	Collaboration using limited knowledge-bases. Different disciplines address inter-connected aspects of specifically defined health problem, mainly bringing to bear their own theories and conceptual frameworks.	Isolated explanations of a problem from a limited number of disciplines are assembled and connections among them are sought.	Interventions sensitive to an explanation of the health problem informed by understanding the connections among participating disciplines.
Transdisciplinary	Problem is defined as part of an open, dynamic system operating at multiple levels. Problem broadly expands to include all relevant disciplinary insights.	Open ended collaboration. All disciplinary insights required to define the problem are assembled.	Common conceptual framework is sought which will be useable by any discipline, achieving a new insight about the problem.	Interventions with the greatest possibility of success follow from a synthesis of knowledge from disciplinary collaboration.

issue; or via a transdisciplinary team bringing combined resources to focus on solving a puzzle.

The first approach involves an individual researcher examining findings from a multitude of disciplines. Using findings from single and interdisciplinary collaborations as a point of departure, the researcher transcends disciplinary boundaries by linking the disparate analyses together into a coherent framework. In some cases this involves thinking "associationally" (Stephen Kunitz, personal communication) rather than in a narrow and reductionistic fashion.

The second approach involves the collaboration of team members with backgrounds in different disciplines. Disciplinary boundaries are blurred as researchers work co-operatively to bring together into some unified framework the diverse elements of a total explanation, including the objective and subjective, the reductionistic and holistic and so on. Under some circumstances, the effect of team members focusing on a particular problem is the creation of a common conceptual framework out of what were formally disparate analyses. Under a shared conceptual framework, discipline boundaries disappear altogether or are 'transcended' and a new or 'transdisciplinary' way of explaining a problem is created.

Transdisciplinary analysis of disease and the destruction of indigenous populations

The individual researcher approach to transdisciplinary thinking is illustrated through Stephen Kunitz's analysis of disease and destruction of indigenous populations in the New World (1994: 1–34). Our main focus is the process underlying individual TD research rather than the substantive findings. Between 1492 and the 1960s the indigenous population of South America dropped from an estimated 20 million to 10 million. In the Amazon region alone, the Indian population declined from approximately one million in 1500 to about 39,000–57,000 in the 1970s. What forces and processes combined to bring about these significant declines? Stephen Kunitz, a medical doctor and anthropologist, examined the multiple elements interacting to bring about depopulation in the New World following European colonization. The primary cause of depopulation appears to have been the spread of epidemics of acute infectious diseases such as measles and smallpox at initial contact. This generalization marks the point of departure for Kunitz's broad synthesis of elements from single, multidisciplinary and interdisciplinary studies that formed his transdisciplinary analysis.

First, Kunitz examined single disciplinary epidemiological findings revealing that the introduction of acute infectious diseases had catastrophic effects for all indigenous groups. However, in the Amazon region, rates of survival of the agricultural empires of the highlands were higher than survival rates for the hunter-gatherer-cultivators of the forest lowland coastal areas of Brazil. Why such a difference? Clearly, the differential impact of colonization on indigenous people in the Amazon is too complex to be explained by a single discipline approach. In drawing together the insights from single disciplinary epidemiological and demographic studies, Kunitz was inspired to seek out knowledge from diverse areas to understand dynamic processes operating both within and across systems.

Second, Kunitz drew on various multidisciplinary insights relating to a broadly-defined issue: the resistance of different indigenous groups in Amazonia to infectious disease. Kunitz synthesized findings from history, geography, ecology, demography, nutrition, political economy and anthropology to argue that isolation and mobility were crucial factors affecting the ability of tribal groups living in different locations to adapt to the changes brought about by colonization.

Third, Kunitz drew upon interdisciplinary findings to examine a specific problem: the effect of acute infectious diseases on populations not previously exposed (i.e., 'virgin soil populations'). Immunological and psycho-social research into 'virgin soil' populations discusses whether high mortality rates of indigenous people after European colonization were the result of "hereditary susceptibility" or "social collapse." Immunologists argue that in previously unexposed populations newly introduced diseases such as measles and tuberculosis are especially virulent because the victims have not been selected for resistance by epidemics that affected their ancestors. Other authors argue that dislocation, demoralization and social collapse accompanying colonization exacerbate the effects of epidemics leading to high case-fatality rates.

Interdisciplinary insights gained from combining immunology and social psychology cast light on the issue of 'virgin soil populations.' However, other disciplines not yet included in this debate may add to our grasp of the problem. An anthropological study might reveal, for example, that the ability of particular groups to survive acute epidemics is related to the degree of social control imposed by leaders, or the strength of religious beliefs. Nevertheless, interdisciplinary approaches do make possible a limited system-wide perspective of problems.

Finally, Kunitz employs a political-economy approach to tie together disparate elements contributing to a transdisciplinary analysis of the destruction of indigenous people following colonization. The Spanish conquerors came to plunder the wealth of the New World and treated the indigenous population as a servile labor force to be exploited. Relegation of Indians to the lowest social and political levels, combined with the generally low level of economic development in most Latin American countries, has contributed to a pattern of high infant mortality and deaths from endemic infectious diseases. Even today, activities such as exploration and mining, road building and ranching encouraged by the Brazilian government, multinational corporations and the World Bank result in increased exposure to exotic diseases, violent clashes between indigenous people and intruders, shrinking of the Indians' land holdings, destruction of the rainforest and continuing population losses.

Kunitz' analysis is truly transdisciplinary; he has sought to fully explore all facets of the problem by transcending traditional disciplinary boundaries and allowing "the problem to define the field" (Kunitz, personal communication). His analysis works within two common conceptual frameworks, 'domination' and 'adaptation,' operating as a dialectical process. Kunitz observes that socio-political domination accompanied the introduction of epidemic diseases and facilitated cultural domination in the form of destruction of traditional customs and institutions and also exacerbated psychological collapse from stress and demoralization arising out of the colonization process. 'Domination' is the structural process colonial governments imposed, while 'adaptation' explains the dynamic processes occurring at the local level in response to continual change. In analyzing the economic, socio-political, cultural, physiological, psychological, genetic and ecological adaptation of various groups to the colonizing experience, Kunitz reveals how a web of causal factors has resulted in such a diversity of outcomes that attempts by any one discipline to explain the connections seem doomed to failure.

Transdisciplinary teamwork examining the colonization of the Amazon and malaria

Pat Rosenfield's (1992) pioneering article illustrates the team approach to trandisciplinary thinking. Malaria and tuberculosis continue to contribute to the decline of populations in Amazonia. Pat Rosenfield (1992: 1343–1357) details a research project inquiring into this issue which over time led to a "convergence of concepts and approaches necessary to transcend disciplinary biases." The project was carried out in Brazil by a team working on Social Economic Research for the United Nations Development Program/World Bank/WHO Special Program for Research and Training in Tropical Disease (TDR/SER).

From 1979, a team of malariologists, vector biologists, immunologists, epidemiologists, sociologists, economists, anthropologists, regional planners and demographers attempted to identify the impact of colonization of the Amazon on the spread of malaria. A comprehensive assessment of the problem, taking into account the "perspectives of the migrant, the mosquito, the malaria parasite and the ministry of health," was related to the "social and economic forces that bind these elements together" (Rosenfield 1992: 1351). A major finding was that, even when migrants had suffered multiple attacks and the death of family members from malaria, the perceived economic benefits offered by life in the new environment were a more important consideration.

Rosenfield sees the transdisciplinary team as opening the way for new and exciting possibilities to be explored. In the TDR/SER project in Brazil, sociologists dealt with the issue of prevalence detection strategies, entomologists examined changing patterns of behavior, and anthropologists confronted changed "vectorial behaviors." After working together to define the problem and discuss concepts, methods and results, the team arrived at a common understanding of the problem of migrants coping with a new disease. New approaches to disease control based on new social and medical science concepts emerged, including a redefinition of the concept and meaning of malaria in a mobile population. More practical ways of assessing and controlling malaria in a specific context were also developed and eventually the team was able to analyze the problem "from all systems levels at the same time" (Rosenfield 1992: 1351).

In summary, we see transdisciplinary teamwork as a process which helps conceptualize health problems as the lived experience of morbidity and mortality in populations and individuals. These problems are then more accurately defined by the application of the highest skills and knowledge in single disciplines (e.g., epidemiology, anthropology, pathology). As single disciplines work to analyze the cause of the problem, they intersect with other disciplines at the limit of their own powers of explanation or expertise.

Co-operative teamwork enables the creative exploration of these intersections with the use of flow diagrams, matrices of interconnections and/or models. A picture of the 'elements of influence' surrounding a health problem begins to emerge. Conceptualizing the elements of influence as a complex, dynamic system involves looking for regularities and patterns that occur in the system. Regularities and patterns can then be conceptualized as a dynamic principle or 'common conceptual framework.' Finally, researchers are able to identify the point(s) at which the most realistic and effective forms of intervention can be used to break the process that leads to the disease outcome.

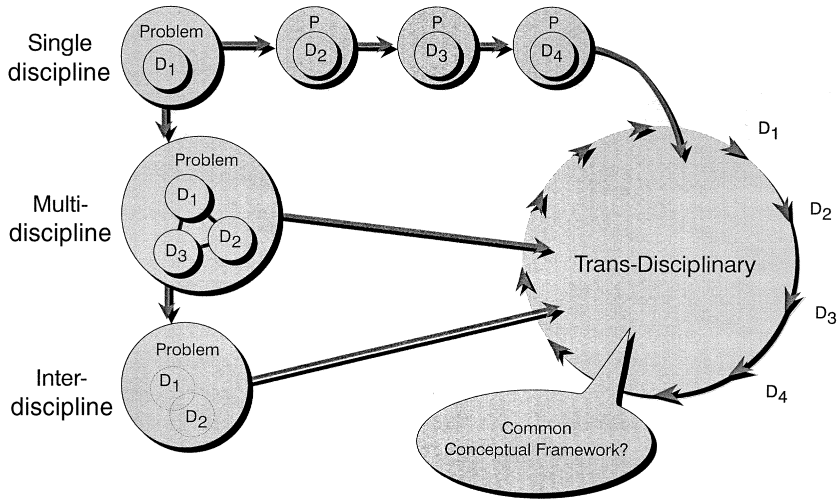

Figure 1 The transdisciplinary dynamic.

The transdisciplinary model

The transdisciplinary model in Figure 1 illustrates how single, multi and interdisciplinary insights are worked through to construct a transdisciplinary model of a health problem. The diagram shows how it is possible to move from a series of single discipline analyses to a transdisciplinary solution, or to progress from single, multiple and interdisciplinary perspectives to a transdisciplinary insight. Finally, we note that attainment of a common conceptual framework that links together the sequence of causal connections may or may not be possible for a specific problem.

CONSTRUCTING A GENERIC TRANSDISCIPLINARY FRAMEWORK

The complexity of the dynamic processes and interacting elements of influence that govern health status requires that scientists use a perspective capable of providing comprehensive explanations of the system within which health issues are situated. In essence, we require a 'generic' transdisciplinary framework; a framework that can give multi-level explanations which encompass 'emic' (subject generated) and 'etic' (researcher-imposed) perspectives and qualitative and quantitative assumptions and methodologies. Such a framework would allow for interventions that are either researcher-initiated or the result of local action (e.g., participatory action research).

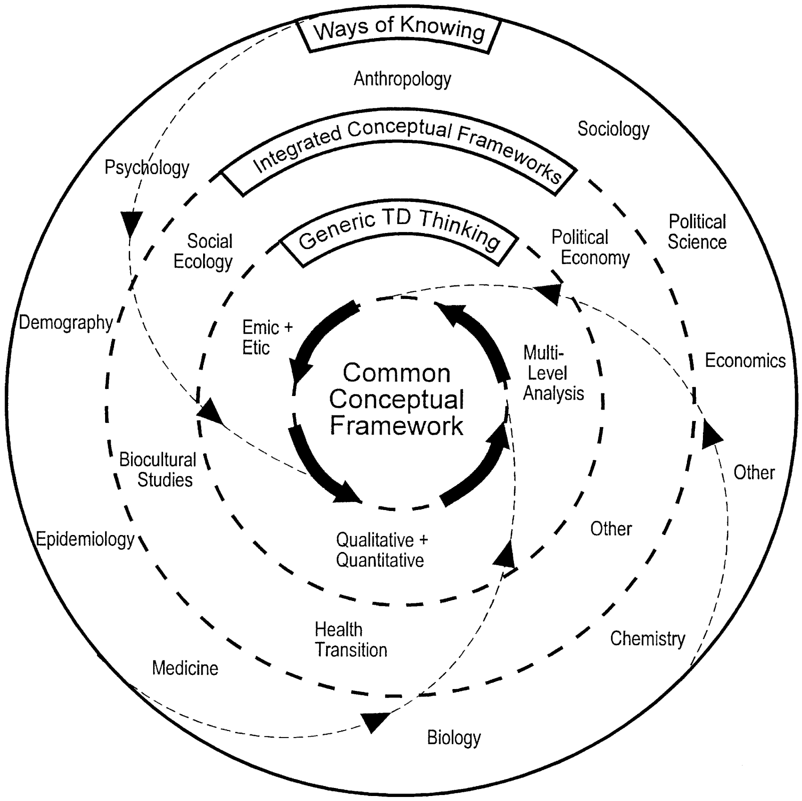

Figure 2 The dynamic process of transdisciplinary thinking.

Researchers seeking a generic perspective of health complexity can draw on existing integrating conceptual frameworks such as biocultural studies (Inhorn and Brown 1990; McElroy 1990a), social ecology (Stokols 1992; Townsend and McElroy 1992), political economy (Chrisman and Johnson 1990; Morsy 1990) and health transition (Caldwell and Caldwell 1991; Cleland and Hill 1991; Frenk et al. 1991). Although incapable of illuminating all aspects of the interactions and processes surrounding a health problem, these frameworks provide multi-level analyses of the context in which health problems are situated.

Figure 2 offers a generic framework for situating diverse ways of knowing and integrating conceptual frameworks across disciplines. The diagram illustrates dynamic processes leading to the heart of the model and a common conceptual framework that draws together the major connections affecting health. Figure 2 is a conceptual tool sharing similarities with the new field of complexity theory.

THE ESSENTIALS OF COMPLEXITY THEORY

Once it is understood that human health is the outcome of complex processes that operate within and across physical, psychological, social and ecological systems, our way of thinking about health problems will need to reflect this complex interrelatedness. Detailed knowledge of complex, dynamic systems cannot come from within the narrow focus of traditional disciplines. In order to understand complexity, we need the "nondiscipline" of being able to work across disciplines (Nelson, quoted in Chu and Simpson 1994: 21).

The transdisciplinary perspective assumes that health problems exist in what we might call 'transdisciplinary space.' Within this space are interactions between humans and their environment that range from deeply subjective and intersubjective to the impact of global climate change. The new developments that have taken place in complexity theory over the last decade have attempted to produce a theoretical framework that can explain such diversity. We now describe these theoretical developments in order to examine the relationship between formal complexity and human health.[4]

The most recent form of complexity theory, unlike closed systems theory, suggests that complex, open systems have distinctive properties that cannot be reduced to constituent parts. Davies explains:

> In the traditional approach one regards complex systems as complicated collections of simple systems. That is, complex or irregular systems are in principle *analysable* into their simple constituents, and the behavior of the whole is believed to be reducible to the behavior of the constituent parts. The new approach treats complex or irregular systems as primary in their own right. They simply cannot be 'chopped up' into lots of simple bits and still retain their distinctive qualities (Davies 1989: 22).

Complexity theory has elements which run directly counter to all forms of determinism. One strand of complexity, chaos theory, suggests that small, random changes to the parts of a system can give rise to large-scale or global changes to that system. Another strand of thinking gives emphasis to the spontaneous generation of order in complex systems.

Despite the problems encountered in understanding complex, dynamic systems, considerable progress has been made in finding regularity and pattern in what initially appears to be disordered chaos. Indeed, disorder appears to be a vital factor in the creation of order in all kinds of open, complex systems. Kauffman (1993) argues that there are deep and fundamental principles within complex living systems that help create an emergent order in them long before evolution and genetic mechanisms exert their influence. Complexity theory is being applied across a great variety of disciplines to biophysical and human social systems in an attempt to provide greater insight into both the nature of disorder and the emergence of new forms of order (e.g., Goerner 1994; Guastello 1995).

Self-organization

A constant theme that emerges in the literature on dynamic, open systems is that complexity is achieved through spontaneous self-organization. After developing this theme we describe the general characteristics of complexity in dynamic systems.

A central claim of complexity theory is that spontaneous order and organization can come from flux and disorder in natural systems. The claim that physical and biological systems can self-organize to produce greater structural complexity is not new. The German philosopher G.W.F. Hegel created an organicist, process-oriented philosophy in the early nineteenth century. Hegel used the term 'dialectic' to describe the idea that all things must be seen as phases or moments in a state of transformation in a wider process within which they are located. He also saw this wider process as moving in a dynamic, self-determined way from a state of simplicity to one of complexity:

> . . . this dialectic is not an activity of subjective thinking applied to some matter externally, but is rather the matter's very soul putting forth its branches and fruit organically (Hegel 1976: 34–35).

What is new is the claim that all the sciences, ranging from mathematics to biology and the social sciences, can now support our intuitions about the evolution in life from the simple to the complex. The dialectical and evolutionary view of the world is supported by claims in complexity theory that open systems have the potential to evolve of their own accord toward greater complexity. The method by which this complexity evolves is substantially explained through the idea of a 'dissipative structure.' To define dissipative structures, though, we need to briefly review the state of thinking about complex systems prior to complexity theory.

The image of the world Newton and his followers described was essentially mechanistic and deterministic. In a Newtonian world, a finite number of rules or laws govern the motion of material bodies and these laws are universal. All other aspects of the world-machine could similarly be determined and a complete account of the workings of parts of the machine was possible. Thus, in mechanistic structures it is entirely valid to break down the structure of large things into smaller things in order to study them (reductionism), because a complete account of the parts will constitute an account of the whole. An important outcome of this perspective, quite apart from its success in producing technologies from cannons to jet aircraft, was the idea that ultimately all things can be explained through mechanistic and deterministic laws. Finally, the use of the machine metaphor implies that regularity and linear order is the norm for complex systems and that instability or non-linear change is the exception.

Newton's laws of motion worked well at one level of human experience, but at other levels were counter-intuitive. In a Newtonian universe, if we had absolute knowledge of all laws and rules governing matter, then we could with equal plausibility reconstruct the past or predict the future. Within linear systems parts are related to each other in ways that do not change the nature of the whole and temporal sequences are in principle reversible.

Time's reversibility was put to rest by nineteenth century physicists such as Clausius and Boltzmann when they developed the idea that the universe is tending toward thermodynamic equilibrium. The first and second laws of thermodynamics suggested (1) that the energy of the universe is constant, and (2) "that any system left to itself, in an isolated system, will tend spontaneously to a state of maximum possible disorder, that is the state of thermal equilibrium" (Pais 1991: 81). Entropy is a measure of "the degree of disorder" of a system (Pais 1991: 81). The idea that entropy increases in a closed system suggests an "inevitable element of irreversibility in mechanical systems in the course of time" (Pais 1991: 82). The implications of this view, however, were even more alarming than the theoretical Newtonian reversal of temporal order. Von Helmholtz pointed out that if entropy always increases, then the universe is moving toward its own destruction. Davies gives a graphic summary of this gradual running-down of the universe:

> The remorseless rise in entropy that accompanies any natural process could only lead in the end, said Helmholtz, to the cessation of all interesting activity throughout the universe, as the entire cosmos slides irreversibly into a state of thermodynamic equilibrium. Every day the universe depletes its stock of available potent energy, dissipating it into useless waste heat. This inexorable squandering of a finite resource implies that the universe is slowly but surely dying, choking in its own entropy (Davies 1989: 19).

This depressing view of our planet's fate was not seriously countered until the idea of a dissipative structure, based on nonequilibrium thermodynamics, emerged in complexity theory in the 1970s. Complexity theory changed the nineteenth century view of entropy as a destructive force to one involved in the creation of order. Kauffman argues:

> . . . contrary to our deepest intuitions, massively disordered systems can spontaneously 'crystallize' a very high degree of order. Much of the order we see in organisms may be the direct result not of natural selection but of the natural order selection was privileged to act on (Kauffman 1993: 173).

The way physicists and others have come to this view is through the observation that in certain circumstances (described as 'far-from-equilibrium') matter displays a tendency to self-organize in new and often unpredictable ways. Prigogine and Stengers describe this fundamental shift in thinking:

We now know that far from equilibrium, new types of structures may originate spontaneously. In far-from-equilibrium conditions we may have transformation from disorder, from thermal chaos, into order. New dynamic states of matter may originate, states that reflect the interaction of a given system with its surroundings. We have called these new structures *dissipative structures* to emphasise the constructive role of dissipative processes in their formation (Prigogine and Stengers 1984: 12).

The most important discovery associated with dissipative structures is that the second law of thermodynamics, while still having universal relevance, can be negated at a more local level. By "exporting entropy into its environment" (Davies 1989: 85), a dissipative structure can maintain its structural integrity and evade an increase in entropy. In order to maintain or increase coherence and complexity, a dissipative structure must exist in relationship with an open system where exchange of energy can take place. A dissipative structure creates an internal order that "is far more efficient in utilizing energy for organization and maintenance than the background system within which the primary flux occurs" (Dyke 1988: 360).

Dissipative processes have been studied in many types of physical and biological systems and they are now being identified in human social systems. In physical systems, a now well-known illustration of a dissipative process is the Belousov-Zhabatinski (BZ) chemical reaction. The experiment involves a number of chemical reagents that react with each other in a system kept open with pumps. When chemical throughput is slow there appears to be an even distribution of chemicals as indicated by a lack of dominance of any one color from dyes that are injected to indicate excess ions of a particular chemical. The system could be described as 'close to equilibrium.' However, when the flow rate increases and the system moves far-from-equilibrium, the reaction changes such that it manifests a blue color, indicating that a particular ion has increased its concentration. It stays blue for a short time then changes to red, indicating that another ion has come to predominate. The system then oscillates from blue to red with a regularity so precise that Prigogine calls the reaction a 'chemical clock.' Barton explains that this regularity

. . . occurs because the chemical processes that result in the red state coming into existence become linked to the processes resulting in the blue state. When this happens, the two states codetermine one another in a cyclical, nonlinear fashion (Barton 1994: 7).

Remarkably, the BZ reaction reveals in a simplistic way forms of self-organization in matter previously thought only to operate at more complex levels in living systems. Complexity theory has developed to the point where we can begin to see common dynamic processes operating across all types of natural systems. This change in thinking that complexity theory requires of us is illustrated in biology where equilibrium models of living systems are being re-evaluated in the light of work on the nonequilibrium determinants of biological structure. The old view assumes that ecosystems move toward a steady state which represents the maximum diversity that is possible. Rainforests and coral reefs were held up as examples of such 'climax' communities. The new view suggests that it is random (stochastic) disturbance that is the ultimate determinant of the order present in complex and diverse ecosystems. As Reice (1994: 427) argues, "the nonequilibrium determinants of community structure" are more important in the evolution of ecosystems than has previously been considered.

The problem for students of complexity, despite the idea that all complex systems might be subject to common physical laws, is that such systems can change in ways that are unpredictable when in a far from equilibrium state. There is potential for either greater complexity or greater disorder; unless one had complete knowledge of all the initial and boundary conditions, uncertainty will predominate. In simple systems where boundary conditions can be accurately specified, we know that dissipative structures will become more complex as they adapt and change over time. This insight offers some hope that complexity can be explicated as does the view that we can develop "idealised complex or irregular systems" (Davies 1989: 23) that will assist in approximating the features of real systems. The concept of an 'attractor' within complex systems provides further opportunity to offer detailed explanation of the order that arises out of dynamically changing systems.

'Attractors' are patterns or "states to which the system eventually settles" (Lewin 1993: 20). At least four mathematically defined types of attractors are used to explain pattern emergence in dynamic physical systems (Barton 1994: 7). Goodwin (1995: 169–173) and Kauffman (1993) apply the concept of 'dynamical attractors' to explain pattern emergence in natural systems (i.e., organs, organisms, species and ecosystems). We believe that the idea of an attractor generating order applies to the complex dynamic system that is human society.[5] 'Social attractors' act as catalysts in the production of regularities or patterns that can be discovered and studied in society. Rather than a situation of 'anything goes,' it is possible that the number of states to which [any] dynamic system settles will be determined by a finite number of attractors.

Characteristics of complex non-linear dynamic systems

From this brief summary of self-organization, we can distill a number of interrelated characteristics of complex, non-linear dynamic systems.

- There is order in what appears to be chaotic; order arises from fluctuations within a system.
- The sensitive interaction of local and global levels of complex systems determines their properties.
- Local interaction can produce global order and global order can affect local behavior.
- Interactive causal relationships exist within and between entities.
- Complex systems can form patterns around attractors and follow predictable paths of development.
- The whole is greater than the sum of its parts.

Complexity and human health

Most health problems exist within the full spectrum of levels of complexity from the sub-molecular to the global. Integrating common conceptual frameworks will be useful in gaining some leverage over these domains. However, with interactive or co-determinate causality, as when major changes to systems precipitate from small perturbations and global order affects local behavior, even detailed knowledge of elements of the system may "not lead to useful knowledge about the behavior of the system as a whole" (Barton 1994: 7).

Transdisciplinary thinking in the health context, informed through complexity theory, approaches the task of setting health and disease in its broadest possible context. The pursuit of knowledge about the nature of the system as a whole inexorably demands a transdisciplinary mode of thinking. The transdisciplinary approach represents a realistic response to understanding and then assisting in the task of alleviating major health problems the world currently faces. It could also lead to interventions that use health resources more efficiently because they are allocated on the basis of a fuller knowledge of the sources of the problem and the most effective points of leverage for problem alleviation. At a minimum, transdisciplinary understanding would suggest intervention avenues that would not make the problem worse, something that has occurred when culturally inappropriate or iatrogenic 'solutions' to health problems have been used (e.g., misuse of antibiotics) (Levy 1991).

Discoveries about the complexity of health issues come as no surprise to those prepared to think through the total picture in a systematic (TD) way. For instance, some disturbances that humans are enacting on long-stable cultural and ecological systems are manifested as epidemics of disease. An example of a small change to a system leading to a large effect is provided by Desowitz's case study of 'tractor-induced' Japanese encephalitis in Northern Thailand.

The traditional practice in Northern Thailand was to plough the rice paddies with water buffaloes and to keep pigs for food and market. Since *Culex tritaeniorhynchus* [the mosquito carrying the virus] prefers steak to pork, the water buffaloes acted as a 'blotter,' limiting viral transmission. Then, heeding the call of progress, the farmers of the region replaced their buffaloes with tractors. As the buffaloe [sic] population declined, the mosquito(s) turned their attention to the pig and to man. Many pigs now became infected; the virus multiplied in the pigs; more and more mosquitos became infected; and, in turn, so did more and more humans. Hundreds died, and many of these victims were children (Desowitz 1981: 21–22).

Desowitz's observations illustrate the characteristic in complex systems of interactive causality among people, the mosquito, the virus, domestic animals, and introduced technology. The next example provides further evidence of how perturbations to eco-systems can end up having unexpected health outcomes.

During the Korean War a mysterious disease emerged which affected thousands of United Nations troops, killing many. It was later discovered that the cause of the disease, known as Korean Haemorrhagic Fever, was a virus transmitted to humans via rodent urine and excrement (Hantaan or Seoul virus). The virus had remained dormant perhaps for centuries until heavy machinery and digging by soldiers disturbed the environment and exposed them to the pathogen through contact with soil and dust. Forty years later, the Seoul virus, possibly transmitted by adventurous rats aboard ships, is now endemic in major cities in the USA and is being detected in patients on the East Coast (McAuliffe 1990).

Coincidentally, in 1992–1993 a mystery virus struck at least 18 people living on or near a Navajo reservation on the New Mexico-Arizona border, 14 of whom died (MMWR 1993). The pathogen was discovered to be a member of a previously unknown type of hantavirus, called *sin nombre*, and is a worrying example of what are termed "emerging pathogens" (Le Guenno 1995: 30–31). Yet, what appear to be novel viruses are in fact viruses that may have existed for millions of years but come to light with environmental disturbances.

Le Guenno (1995: 32) asserts that the primary cause of most haemorrhagic fever outbreaks is 'ecological disruption' which brings humans into contact with animal vectors (e.g., the Korean War). However, perturbations to ecosystems also result from natural disturbances. The emergence of *sin nombre* in the USA was the result of unusually heavy rain and snow in 1993 in the mountains and deserts of New Mexico, Nevada and Colorado.

The principal host of *sin nombre* in this area is the deer mouse which lives on pine kernels. The high humidity resulted in an abundant crop which created conditions suitable for an explosion in the deer-mouse population which in turn coincided with the epidemic of *sin nombre*.

The emergence of new diseases and unexpected outbreaks of ‘old’ diseases are becoming common in an era of increasing air travel, the development of tropical mega cities, modern factory-farming methods and the encroachment of humans into previously untouched natural environments (McAuliffe 1990). The outbreak of Ebola in Africa has been linked to the emergence of the virus from an as yet unknown reservoir that had previously been left undisturbed by human action (see Le Guenno 1995: 34). A consequence of modern factory-farming, mad-cow disease is thought to be the outcome of the passage of a disease-causing agent from sheep to cows, finally being expressed as a brain disease in humans through the consumption of beef. The interaction of host and parasite, the role of vectors, the host’s state of health, genetic predisposition, standards of hospital infection control, the way humans produce food and a multitude of social factors will all have some influence on disease outcomes. Such complexity of modern health problems has led to the suggestion that:

> In the end, it is likely that the classification of diseases into infectious, environmental, psychosomatic, autoimmune, genetic and degenerative will prove to be applicable only to a sample of cases where one factor overwhelms all others. The more accurate viewpoint will encompass full complexity of this network of factors that leads to recognisable disease (Levins et al. 1994: 55).[6]

What follows is an example of transdisciplinary team research on heart disease prevention in the Hunter Region, Australia, in which we draw out characteristics of complexity theory. We illustrate how the process of combining TD thinking with the principles of complexity theory allowed new insights to emerge from a consideration of disparate elements of influence on heart disease in this region. The illustration highlights the benefits of using complexity theory as a common conceptual framework in future TD health research.

CORONARY HEART DISEASE: A SILENT EPIDEMIC

Common bio-behavioral pathways to coronary heart disease

Cardiovascular disease remains the leading cause of mortality in Australia, accounting for 46% of all fatalities; 57% of these deaths were due to coronary heart disease (ABS 1991). Non-modifiable risk factors for coronary heart disease (CHD) have been identified as advancing age, male sex and genetic heritage (see Berg 1983; Goldberg 1992; Johnson 1977). Primary 'preventable' or 'modifiable' factors are hypercholesterolemia, smoking, hypertension and physical inactivity (see Bijnen et al. 1994; Gotto et al. 1990; Kannel et al. 1983). Secondary 'modifiable' factors include obesity, diabetes, excessive alcohol consumption, the contraceptive pill and psycho-social factors such as socio-economic class and status,[7] education and occupational stress[8] (see Barrett-Connor 1985; Booth-Kewley and Friedman 1987; Commonwealth of Australia 1994; Dressler 1990; Friedman and DiMatteo 1986; Kleinman et al. 1988; Plotnikoff 1994).

Risk factors work 'synergistically': co-existing risk factors interact to produce a compounding effect rather than being additive. For example, results from the United States Pooling Project show that an increase in the rate of CHD associated with a rise of 100 mg/100 ml in blood cholesterol is three times greater in smokers with high blood pressure than in non-smokers with low blood pressure (Hetzel and McMichael 1987: 83–84). These epidemiological findings underpin our examination of CHD in the Hunter's Coalfields area (see Plotnikoff 1994). Elliott (1995) demonstrates that relatively little research has been conducted on the etiology and epidemiology of coronary heart disease in women. This is also true in the Coalfields; our analysis deals predominantly with factors affecting coronary heart disease in males.

HEART DISEASE IN COAL COUNTRY

In the early 1980s, a group at the University of Newcastle became a collaborating center for the World Health Organization's MONICA Project to Monitor the Trends and Determinants of Cardiovascular Disease. The MONICA Project confirmed earlier studies showing that, compared to other parts of Australia, the Hunter Region in the 1980s had consistently high mortality rates from heart attacks. The rate of death from coronary disease was especially high in the Coalfields area, which contains about one tenth of the region's population. Furthermore, rates of non-fatal heart attack were more than 50% higher in the Coalfields in 1993 than in the rest of the Hunter (calculated from data presented in Steele and McElduff 1995). Similarly, the standardized mortality rate for all causes of death is significantly higher in the Coalfields compared to the rest of the Hunter (Page, Lam and Gibberd 1990) and the state of New South Wales (Glover and Woolacott 1992). What are the dynamic processes that underlie the evolution of this problem in the Coalfields community?

In order to answer this question we combine principles derived from complexity theory and previous transdisciplinary research findings. Our aim is to construct a framework that can analyze the interconnections between mutually-affecting influences determining patterns of coronary heart disease in the Coalfields. We examine how the adoption of practices such as smoking, eating a diet high in saturated fat and drinking excess alcohol can be traced to particular ways of understanding the world. In turn, these 'world views' are associated with historical events which have contributed to the formation of ideas relating to both risk factors for CHD and risk imposition from environmental health hazards.[9]

Transdisciplinary analysis of CHD in the Coalfields

The Coalfields is an area of low economic status with a predominance of manual occupations, low educational attainment and high unemployment levels (see Dobson et al. 1991). There is a large percentage of people of Anglo-Celtic background.[10] The socio-political environment has long revolved around coal mining and associated industries. Last century in the coal regions of England and Wales, and from early this century in Australia, coal miners had to endure being spoken of in pejorative terms by mine owners, religious leaders and other 'outsiders' who endeavored to ensure that the workers conformed to a sober, pious and conscientious lifestyle. In this environment of class struggle and discrimination, Coalfields miners and their families 'adapted'[11] to the harsh conditions by cultivating a sense of solidarity as a defence against outsiders. This sense of solidarity is a form of order which was self-generated by mining families to give meaning and coherence to their social environment.

The emergence of world views

Emerging from the insider/outsider dialectic, and underpinning that process was the cultivation of male solidarity both as a means of bolstering working class masculinity and retaining dignity under threat from social discrimination by outsiders. This resulted in a pattern of beliefs and attendant way of life that has been labelled 'the larrikin response' (Metcalfe 1991). The idealized larrikin response[12] involves a celebration of behaviors outsiders criticize such as gambling, drinking and fighting. It includes suspicion of religion, education and law, and refusal to labor beyond worker-defined limits (Metcalfe 1991: 10).

Criticism from outsiders also provoked the emergence of an opposing world view which Metcalfe (1991) has labelled the 'respectable response.' This orientation, consistent with that of dominant economic, political and religious groups, involved recognition by miners that their present lifestyle was unacceptable but that this was not their fault or that they were willing to change their ways (Metcalfe 1991: 10). In recent years, the respectable orientation has included the belief that health can be maximized by reducing individual risk factors. The respectable group included men who endeavored to adhere to the sober, hardworking lifestyles advocated by the authorities, and women concerned that the larrikin lifestyle was detrimental to the health of their families.

The larrikin and respectable viewpoints interacted to produce local behaviors and outcomes not predictable on the basis of analyzing either group by itself. The larrikins created their coherence as a group through opposition to dominant groups and their local followers. Maintenance of the local order of insider solidarity generated antagonism toward educational opportunities and other cultural resources available in the wider community. This has implications for the tolerance of health education messages proffered by outsiders and for the success of a heart health program described below.

The larrikin world view is produced and validated through the construction of cultural practices, such as 'mateship,' which are acted out within compatible Coalfields settings – the pub, social club and football institutions. More generally, the world view of individuals is informed by perceptions of the everyday conditions of their lives, differing psychological and biological attributes, and household economic advantage or disadvantage. In a two-way process of causality, broad economic and political forces impinging on the Coalfields influence local interactions; local patterns feed back into the wider order and further unfold the complex dynamic social system.

In complex dynamic social systems, in which individuals make the most of prevailing circumstances, the tuning of interactions with others, both within and outside the group, results in the development of a form of order (Lewin 1993: 59). Such order in the Coalfields has emerged out of the interplay between attempts by the respectable group to undermine the larrikin orientation, and opposition by the larrikins to any encroachment on their valued patterns of life. Forces implicated in the process include the transition from underground to open cut mining, overall decline of the mining industry locally, the lack of technical and service-based jobs and subsequent unemployment, the advent of feminism and the increasing influence of the ecological paradigm.[13]

Within this context health promoters began efforts to reduce the incidence of heart disease morbidity and mortality amongst Coalfields residents in the early 1980's. Initially, women took on the role of 'change agents' in reply to warnings about the coronary heart disease epidemic. Their challenge was to alter facets of male culture such as eating large quantities of meat to gain strength for doing hard physical labor (Heading

1996: 338–348); to discourage smoking and drinking with mates; and to bring home heart health education messages circulating in the wider community. However, the strength of the ethos of male solidarity, the challenge (stimulation) of risk taking, the formation of gender relationships based on male dominance,[14] and male resistance to the introduction of ideas associated with the women's liberation movement[15] have reduced the ability of women to bring about change (see Heading 1996: 295–298, 338–348).

Similarly, initial efforts to stimulate community action in response to the epidemic were woefully inauspicious. Release of research findings about the epidemic produced a backlash seized upon by the local print media. Newspaper stories citing the University findings were written to suggest that the researchers had characterized Coalfields residents as 'fatties' who needed to change their lifestyle to reduce the risk of heart disease (*Newcastle Herald*, 8–10 January 1986). Unwittingly, public health research aimed at stimulating prevention appeared to reproduce historical discrimination by outsiders and set up the lines of resistance by 'insiders.'

In May 1990, University researchers with a Commonwealth grant for heart disease prevention and local Coalfields politicians organized a public forum designed to interest residents in forming a community coalition to develop local strategies for reducing heart disease. Although this attempt to engage broad community participation fell short of expectations, a Healthy Heart Committee was formed including researchers, health professionals and local government leaders, some of whom had been members of a previously active 'Healthy Heart Support Group.' The Support Group had formed in reply to publicity in 1986 about the elevated rates of heart disease mortality and combined active community people with a health worker who sought to raise awareness of the epidemic through talks to clubs, special meetings and cholesterol-screening activities (Higginbotham and Titheridge 1993). Subsequently, the Support Group and new committee joined forces to establish the Coalfields Healthy Heartbeat and immediately commissioned a needs survey to gauge the depth of concern (or lack thereof) about the heart disease epidemic. The 1991 needs survey revealed that a majority in the community believed that the individual, the family and the medical profession, in that order, should be responsible for heart disease prevention. There was little support for the idea that the community should be responsible for health. Indeed, about half the respondents felt that community groups should only get involved rarely, if at all. Furthermore, residents gave a relatively low ranking to worry about heart attack (i.e., 11 out of 17 social issues) (Higginbotham et al. 1993: 317).

Among a spectrum of activities aimed at encouraging local organizations to adopt heart health strategies, the most successful interventions were undertaken by Coalfields primary schools[16] (Williams and Plotnikoff 1995). School teachers and principals and other 'outsiders' have energetically acted as change agents. The schools promote healthy heart messages to children through integrated curricula, daily physical education and nutritious food choices at the school canteen. In turn, children carry these messages back home to parents and siblings.

Older Coalfields residents' reaction to heart health campaigns has been mixed. Heading's survey (1996) revealed that those who were most resistant to heart health messages were more likely to have lower educational levels and lower incomes, and to be male. Nevertheless, this group had *more* heart related food knowledge than those who accepted the validity of heart health messages. These men may be reluctant to act on their knowledge of heart health because the choice to align themselves with the views and activities of 'outsiders' does not, as yet, have as powerful an attraction as maintaining ties within their immediate social group. This finding illustrates the way in which the interplay between competing worldviews shapes perceptions and affects action.

One group of Coalfields residents who *are* interested in changing their lifestyle to reduce heart disease risk factors are those who have already experienced heart attacks. The everyday experience of disability, and perhaps imminent threat of losing one's life, appear sufficient to tip the balance toward adopting lifestyle changes advocated by health professionals and the women in their families at the expense of the loyalties to mateship culture. With encouragement from Coalfields Healthy Heartbeat, a thriving peer support network is now in place offering counselling and a rehabilitation program to heart patients and their families (Hunter Branch of Heart Support – Australia).

Conceptualizing the unfolding of worldviews

Table 2 displays factors driving the emergence of world views related to heart disease in the Coalfields described above. Historical interactions among components of the Coalfields social system are represented by arrows. The small arrows flowing down the table show the evolution of the Coalfields social system over time; the large arrows pointing inward show how influences from outside the Coalfields precipitated change to the social system at different historical moments. Six opposing "social attractors" are depicted in two inner columns; they represent the unfolding of world view components. The five elements in the center column itself are areas of change and flux in the social system which stimulate the formation of worldviews. Finally, emerging from the bottom of Table 2 are two substantive contemporary Coalfield world views: the "Larrikin Heart,"

Table 2. Evolution of world views related to coronary heart disease (CHD) among Coalfields men

EXTERNAL INFLUENCES	SOCIAL ATTRACTORS	AREAS OF CHANGE	SOCIAL ATTRACTORS	EXTERNAL INFLUENCES
		Pre-1940s Socio-Economic Discrimination		
Late 19th century: Cultural Symbols, Fatalism/ Hedonism	→	**Insider-Outsider Solidarity**	←	Late 19th century: Social & Geographical Isolation
	⇙ Male Solidarity "Larrikin" Response ⇘		⇘ "Respectable" Response ⇙	
1970's Decline in Mining, High Unemployment	→	**Gender Relationships**	←	1970's Feminism, Health Promotion
	⇙ Groups Resistant to Health Messages ⇘		⇘ Groups Receptive to Health Messages ⇙	
1980's Ecological Paradigm, Decline in Trade Unions	→	**Different Views of Risk**	←	1980's Epidemiology of Coalfields Heart Disease
	⇙ Anti-Authoritarian group, Communitarian Beliefs ⇘		⇘ Healthy Heartbeat Group, Individual Responsibility for Health ⇙	
		Community Activation ⇙ ⇘		
"Larrikin Heart" World View: Elevated CHD			**"Healthy Heart" World View: CHD Declining**	

associated with elevated rates of heart disease, and the "Healthy Heart" world view with practices promoting rates of disease declining toward the population norm.

Table 2 conveys the evolution of world views across time using complexity theory principles. Identifiable aspects of the world views are conceptualized in complexity theory terms as 'social attractors': enduring sets of shared beliefs and practices which give the social system an emergent order at different historical moments.[17] A feature of non-linear systems is their possession of more than one attractor depending upon historical continuity and present environment.[18] Thus the complex Coalfields social system is viewed as two parallel streams of interacting forces which, from time to time, crystallize into identifiable components of a world view (i.e., a social attractor). Table 2 illustrates opposing social attractors that have emerged since the late nineteenth century: the larrikin and respectable outlooks, involving male solidarity and women as change agents; resistance or acceptance of health promotion campaigns; and communitarian beliefs (emphasizing what is "good" for the community as a whole) versus individual responsibility for health.

Complexity theory claims that spontaneous order and organization can come from flux and disorder in natural systems. Social attractors emerge from either side of the central column in Table 2 listing significant areas of change in the system. Change is the catalyst for people to adopt a position, to formulate a view or to align themselves in relation to others. External influences both precipitate and are subsequently affected by these changes. Coalfields social attractors have emerged from flux and disorder caused by the clash of views of insiders and outsiders; by differing interpretations of gender relations; by the dissemination of alternate ideas relating to health 'risk'; and by differing opportunities to participate in community groups.[19]

The most recent example of social attractors shown in Table 2 involves the mobilization of community groups. Evolving from the respectable strand is the institutionalization of heart disease prevention in the form of the Coalfields Healthy Heartbeat storefront office in the Coalfields Community Center. The office has two employees, undertakes a large number of activities guided by a local management committee, and operates under the auspices of a well-established charitable foundation. Although locally managed, the program embodies an outward orientation, seeking support, ideas, information and working relationships with a variety of educational, medical, research and community organizations.

A contrasting social attractor from the larrikin strand tradition takes the form of an "Anti-Authoritarian" (see below) community group mobilized in 1994 to fight the development of an aluminium dross smelter close to homes and schools. Objections to the dross plant arose because its by-products are considered hazardous to health. Like the healthy heart committee, this citizens' group was created to protect and maintain health. However, for opponents of the dross smelter, the emphasis is less on individual responsibility for health than on industry and government responsibility towards the community (i.e., a communitarian belief).

A clash has occurred between the anti-dross group and those supporting the proposed smelter development. Supporters within the community include some local councillors, the Chamber of Commerce and citizens who believe the plant will reduce unemployment in the region (Sorenson 1994b). One councillor suggested that the 150–200 anti-dross protesters were "a vocal minority compared with the 15,000 plus people who lived in the township" (*Newcastle Herald*, 3 November 1994). However, the lower profile of supporters makes the actual number difficult to gauge.[20] What is evident is that the views of the pro-dross group are compatible with those of the respectable strand.

A significant insight from the streams of social attractors in Table 2 is that earlier world views underlie the formation of present day perceptions in the Coalfields and determine the form of community action adopted. An enduring theme in the larrikin worldview is rejection of authoritarian outsider-imposed threats to lifestyle.[21] This is a prominent concern of the anti-dross campaigners. Another campaign element with historical connections is concern for the environment.[22] The 1991 needs survey found that 61% of Coalfields residents felt that the environment was an area of 'worry' and, along with local pollution, ranked high as a problem (Higginbotham et al. 1993: 317).

For most of the twentieth century trade unionism and socialist ideologies were prominent in the Coalfields (Turner 1979, 1983). A downturn in mining, reduction in blue-collar jobs generally and rising unemployment have eroded the influence of trade unions. Given these declines, and the pre-existing concern for the environment, it is not surprising that the anti-dross campaigners have adopted the ecological paradigm to press home their argument that Coalfields residents must mobilize to fight against outsider-imposed threats to their quality of life. While this activism is directed toward a health-related issue, connections with earlier industrial struggles are apparent. One Coalfields resident explicitly linked the current fight against the proposed dross plant to a famous industrial conflict nearly seventy years earlier.

> The fathers and grandfathers [of both towns] fought at Rothbury[23] against oppression. Why are we not united against pollution? (Wright 1994: 7)

In the same manner that trade unionist struggles were aimed at increasing participation in decisions affecting their lifestyles, contemporary activists continue the call for participatory democracy, rather than imposed or authoritarian decision-making:

> The people of [the Coalfields] have demonstrated great courage and tenacity in their bid to stop the progress of an industry that they believe will be detrimental to their health and lifestyle. Politicians, whether they be of local, State or Federal persuasion, should remember that they represent the people (Johnson 1994: 7).

A pattern is also evident in the involvement of former prominent mining union leaders, some of whom are in their seventies and eighties (*Newcastle Herald*, 13 October 1994: 3). A smooth transition has been made from leading the miners in industrial disputes against mine owners and allied politicians to leading community activists in their struggle against the owners of the proposed aluminium plant and politicians in favor of the development. Indeed, the number of socialists and communists embracing environmental concerns has led their opponents to label them ‘watermelons’: green on the outside but red inside.

CONCLUSION

Complexity theory provides a framework for identifying dynamic processes that constitute world views in the Coalfields. It offers us insights into the emergence of this complex social system through an analysis of the interplay of industrial history, heart disease risk factors, gender relations, and community responses to the epidemic as well as to the health promotion campaigns aimed at its alleviation. The recurrence of patterned forms of order displayed in Table 2 suggests future directions for heart health interventions in the region. One inference to be drawn from these recurrences is that initiatives to reduce coronary heart disease amongst high risk groups, who may be identified with the “larrikin heart” world view, will be most successful if they involve self-generated action similar to that carried out by residents protesting against the dross plant. A health project can unleash energy available in this community if it develops as a local response to health needs ‘insiders’ perceive as relevant on the basis of their pre-existing world views. Conversely, it is futile to approach the “larrikin heart” with an outsider-imposed disease control program; the anti-authoritarian ethos underlying the larrikin tradition rejects authoritarian solutions, no matter how well-intentioned they may be.

Furthermore, the concept of a ‘dissipative structure’ provides a useful analogy for the way in which the embodied self maintains integrity by interacting with the environment. As illustrated in Figure 3, the larrikin response

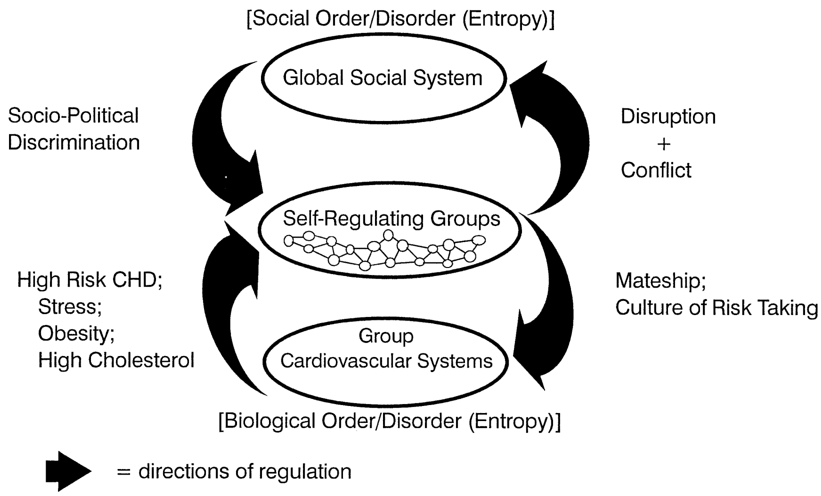

Figure 3 The Larrikin Heart as a way of transforming disorder.

is viewed as a way of transforming disorder, arising from social discrimination (a form of perturbation), into order via the construction of supportive social relations and a positive self image. ‘Social entropy’ is exported to the environment through disrupting work patterns, antagonizing ‘respectables’ and refusing to live a ‘rational’ lifestyle. However, a by-product of this process is an increase in ‘biological entropy.’ The human body takes in energy from social relations and from products made meaningful by those social relations (e.g., camaraderie, mateship, drinking, eating certain foods such as meat, smoking, gambling, risk taking and masculine bonding). However, unless the waste products of this process (cholesterol, stress, obesity, addiction) can be exported (through exercise, diet, drugs, relaxation or therapy, for example) they are stored in the body, increasing the risk of cardiovascular disease or other losses to self-regulation.

In essence, self-regulation towards coherence and order in the social system produces an opposite process in the biological system: a disruption in biological self-regulation towards the disorder of heart disease. Is this a unique dynamic found in the Coalfields or a process underlying other health problems in other local environments? We believe that the Coalfields example illustrates how well complexity theory can be applied to the explication of health problems. Indeed, the transdisciplinary approach may well prove useful in other complex health situations where there is a failure of current thinking to understand the local dynamics of disease patterns and the absence of remediation through existing health care institutions and policies. One potentially fruitful area is explicating the inability of western models of health services to improve the health status of indigenous people, such as Aboriginal Australians and Native Americans.

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NOTES

1. For a fuller discussion of these theories see Higginbotham and Albrecht (1996).
2. Greene (1994: 537) reviews contrasting views on this issue. He notes that Guba and Lincoln contest the mixing of inquiry approaches at the paradigm level. They argue that it is not possible for the researcher to simultaneously bring to bear both the 'objectivist detachment of conventional science' and the 'subjectivist involvement of interpretivism.' On the other hand, Patton argues that 'objectivist' and 'subjectivist' methods can be used together unproblematically, based on "practical need and situational responsiveness rather than the consonance of a set of methods with any particular philosophical paradigm".
3. We take the position that objective events occur which a critical mass of people define as a 'problem' (e.g., child deaths from diarrhea). We acknowledge the role of human agency in interpreting and defining these events as a problem. We proceed from the assumption that a 'problem' exists in transdisciplinary space and is affected by a set of interlinking factors which must be teased out by the researcher. The aim of the transdisciplinary researcher is to define the problem in ways that maximize the drawing together of multiple perspectives to address that problem.
4. We make no new claims about complexity theory, our intention is to summarize the main developments that we believe can be applied to a transdisciplinary view of human health.
5. Already theorists have applied the concept of an attractor to cultural evolution and the structure of cities (see Lewin 1993: 21; Dyke 1988: 358).
6. Levins and his colleagues in the Harvard Working Group on New and Resurgent Diseases (1995) are also developing ideas concerning complexity and transdisciplinary thinking in health research, although we did not have access to their ideas during the preparation of this paper.
7. Various hypotheses have been put forward linking psycho-social factors and CHD. Poverty and social disadvantage have been associated with CHD in studies in many countries. In Australia, low socio-economic status men and women are 54% and 124% respectively more likely to die from CHD than their higher socio-economic counterparts (Plotnikoff 1994 chap. 2: 20).
8. Stress associated with certain lifestyles, occupations or low educational attainment has been linked to elevated mortality from CHD. William Dressler's (1990) theory states that education by itself is related to cardiovascular disease mortality. His research in several cultures suggests that lack of congruence between education and other

circumstances in the individual's life creates stress resulting in elevated blood pressure. Another suggestion is that occupational work demands, especially time pressures, are an element in the 'occupationally enforced' Type A personality. Type A people are those who consistently struggle against time, events and other people (see Friedman & DiMatteo's 1986 review). While personality traits such as anger and hostility have been linked to heart disease, the relationship is not yet fully understood.

9. We have by no means exhaustively examined all elements of influence impacting on CHD. Areas for further research include whether or not the construction of self influences decision-making relating to CHD; and the possible impact of workplace stress on CHD (see for examples, Knutsson et al. 1986 and Siegrist et al. 1990).
10. A large percentage of Coalfields residents is descended from British and particularly Welsh miners who immigrated to Australia in the early part of this century. In 1954, for example, 16.2% of people in the town of Kurri Kurri were born in the UK (Metcalfe 1988: 7). It has been hypothesized that because many people in the Coalfields are descended from relatively small areas of Wales and Northern England there may be an unusually high prevalence of recessive genes associated with heart disease risk (Malcolm 1993: 103).
11. The concept of adaptation is highly contested. In this context, we use Alland's "mini-max" model of adaptation as a useful construct for describing the responses of a population to cultural dynamics operating at local, national and international levels. Some researchers define adaptation to mean "perfect fit," an "ideal adjustment" or a "solution without problems." However, according to Alland, at best, an adaptive strategy minimizes risks and maximizes benefits. But rarely are risks avoided altogether (Alland 1970; McElroy 1990b: 381). In adapting their worldview and lifestyle to achieve 'fitness' (i.e., making the most of the socio-political circumstances), Coalfields residents have adopted strategies which increased their risk of contracting heart and other diseases.
12. We do not intend to suggest that these views are attributable to individual miners. Metcalfe (1988: 76) has emphasised that the larrikin-respectable categories are "ideal types," drawn from cultural models which miners created to make sense of their lives. Individuals can draw on aspects of either or both responses, selectively mobilizing a range of ideas which do not necessarily appear rational or consistent to outsiders.
13. Influences such as this are known as "perturbations" to the system in complexity theory (Goerner 1994: 48).
14. According to Metcalfe (1988: 181), "Aggressive masculinity became an expression of miners' solidarity, and misogyny could double as a mark of loyalty to workmates".
15. Prior to the mid 1970s, gender relations formed on the basis of males as breadwinners and females as home makers were largely uncontested. By 1980, the effects of the women's liberation movement were evident in resentment by women about past practices such as the exclusion of married women from the paid workforce: a policy which had been endorsed by the majority of the community, both male and female, in previous eras (Metcalfe 1988: 37–39).
16. Freeman et al. (1990) have reported that children living in low-economic status areas are likely to have higher levels in childhood of factors associated in adults with risk of CHD. Barker et al. (1992; 1989) have suggested that adult disease (including CHD) may have its origins in fetal and childhood experiences.
17. A social attractor is not a mathematical device but a social device to assist in the description of patterns which emerge after iterations of an apparently random system. In the Coalfields, social attractors are empirically described patterns which emerged

from triangulating data from historical archives, participant observation, needs and attitude surveys and statistics from the MONICA Project.

18. The human heart is a non-linear system which has two attractors (Firth 1991: 1567). Even though most people assume the heart beat is regular, and therefore might conclude that it has an "oscillating attractor," in fact, Firth notes, the healthy heartbeat is actually slightly irregular, suggesting it has a "chaotic attractor." But the heart must also have a "fixed point attractor" (cardiac arrest) which can be 'kicked' from its normal state by an electrical shock; it may also be kicked back again via resuscitation. A 'kick' is always needed to induce switching between trajectories. The 'kick' attracts nearby trajectories (Firth 1991: 1567).
19. Bak and Chen's discussion of Self-Organised Criticality (1991: 26–33) is relevant to the process of interactive evolution illustrated by the spiral diagram.
20. It was reported that "Dross plant objectors outnumbered supporters of the project when the two groups met noisily on the lawn outside the council chambers last night" (Sorenson 1994a: 1).
21. This is best illustrated by miners' participation in trade unions and an acceptance of Socialist and Communist ideologies (Metcalfe 1991; Turner 1974: 352; 1979; 1983).
22. From the 1920s the environmental concerns of miners in the Coalfields were expressed as 'ecological socialism' (Metcalfe 1988: 204).
23. In 1929, an attempt by coal owners to reduce wages of miners in defiance of a court ruling led to a lock-out in the Northern Coalfields of NSW which lasted 15 months. The re-opening of a mine at Rothbury with non-union labor precipitated a riot between miners and police during which one miner was killed. This incident was followed by a period of extreme industrial turmoil in the Coalfields, and left a legacy of bitterness amongst mining families (Turner 1974: 412).

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