Changes to Theory Making about Systems Involving People: Meta-theoretical Analysis and Brain Research

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ABSTRACT

The paper describes how a meta-theoretical approach developed in Design Research points to weaknesses in systems theory. It identifies ways that new findings from brain research help address these weaknesses in systems involving humans. The paper suggests that including the findings of brain research marks the beginning of a new direction in Systems theory making.

Keywords: Systems, Cognition, Affect, Meta-theory, Brain Research, Epistemology

INTRODUCTION

There are many similarities between Systems and Design Research since their inception at a similar time and from similar origins (Love, 1995). Both fields are multi, cross and inter-disciplinary and focus on identifying future states involving humans, objects, environments, thoughts, motivations, intentions, decisions, perceptions, intuitions and actions. A large number of theories of Design Research are underpinned by systems theories, and this paper explores the reciprocal relationship: the implications *for* systems theories of developments in Design Research. The analyses in this paper are based on the author's earlier research into theories about designing and designs (see, for example, Love, 1999, Love, 2000d, Love, 1996, Love, 2000c, Love, 2000b, Love, 2000f, Love, 2001b, Love, 1995).

Many changes in Design Research reflect changes in Systems initiated by Flood and others (see, for example, Ackoff, 1991, Churchman, 1991, Flood and Carson, 1988, Flood, 1990, Flood and Jackson, 1991, Flood, 1995), perhaps most clearly evidenced in the writing of Coyne and associates (see, for example, Coyne, 1997, Coyne et al., 1992, Coyne and Snodgrass, 1992a, Coyne, 1991, Coyne, 1990, Coyne and Newton, 1992, Coyne and Snodgrass, 1991, Coyne and Snodgrass, 1992b, Coyne and Snodgrass, 1992c, Coyne and Snodgrass, 1993).

In the last 3 years, a substantial shift has seen Design Research increasing founded on a more detailed understanding of how individuals function, and how this shapes interactions between humans and with artefacts and environments. Previously, Design Research, like Systems, had mainly used the epistemologies of the Physical Sciences and the Humanities, deriving models and theories from generalised observations of human behaviour, processes and observable properties of objects and environments. The new direction is evident in the increasing use of protocol analyses of designers: a change from constructing theories exclusively on the basis of external objectively observable processes to including knowledge of human internal processes.

Systems methodologies and theories have moved from 'machine age' thinking to include sociological epistemologies (Churchman, 1991, Flood and Carson, 1988, Flood, 1990, Flood and Jackson, 1991, Flood, 1995, Ackoff, 1991, Checkland and Scholes, 1990). This paper points to reasons for a further change for Systems to include findings from brain research relating to the ways that human cognito-affective mechanisms shape people dependent systems.

SYSTEM THEORIES

This section sketches briefly those aspects of Systems that provide a context for this paper.

Four considerations differentiate systems theories from theories of other disciplines:

- A focus on boundaries and the flow of effects across boundaries
- Emphasis on targeting complex situations with definable elements inside and outside system boundaries
- Analyses aimed at difficult, ill-structured, ill-defined, or indeterminate problems
- The use of theories, methods, perspectives and analyses from any discipline in whatever ways suit the purpose in hand.

The field has a tradition of internal critique by experienced researchers and practitioners, and a history of new theories and perspectives being promptly developed in response to these critiques (see, for example, Beder, 1993, Churchman, 1991, Coyne et al., 1990, Flood, 1990, Flood and Jackson, 1991, Hubka and Eder, 1988, Joseph, 1996, Rastogi, 1992, Probert and Stephens, 1998). Researchers and practitioners have drawn on the findings and theories of other disciplines, especially Sociology, to enable systems analyses to be validly extended into new areas.

In early years, most systems theories, including those of associated fields such as Operational Research, were similar to engineering theories, e.g. the cybernetic Viable Systems Model of Beer (Espejo and Harnden, 1989). This presented epistemological difficulties because many theories targeted systems that depended on human activities and values, and human subjective factors are explicitly excluded by the epistemologies of the Physical Sciences. The need for a shift towards interpretive epistemologies and methodologies of Sociology and to some extent Psychology was argued Cassandra-like by researchers such as Churchman (1991) and Ackoff (1991), and became actualised and mainstream through the work of Flood and others(see, for example, Hutchinson et al., 1995) after increased attention to epistemological issues.

Systems theories and analyses apply to a wide variety of practical situations that separate into two streams.

- Stream A: ‘Soft’ systems approaches aimed at situations in which human behaviour impacts strongly, e.g. human organisations, human decision-making, management, ethics, designing.
- Stream B: ‘Hard’ systems approaches aimed at situations whose functioning is not strongly impacted by human activities, e.g. chemical process plant systems.

Broadly, the distinction is between ‘human organisational systems’ (Stream A) and ‘engineering systems’ (Stream B).

META-THEORETICAL ANALYSIS

In the mid-1990s, the author developed a meta-theoretical method for analysing the structure and development of theories in a single field and across fields. This method was based on earlier work by Reich (1994), Popper (1976), Franz (1994), Stegmuller (1976), Indurkhya (1992), Ullman (1992), Konda & associates (1992) and others (see, for examples, Love, 1998, Love, 2000e, Love, 2000d, Galle, 2001).

The method was developed to address the unusually wide breadth of fields of theory associated with Design Research, and, hence, likely to be well suited to analysing theories of Systems. Analyses using this meta-theoretical approach locate theories in a human context, especially focusing on human skills involved in addressing wicked problems and creating new knowledge and artefacts.

The meta-theoretical method consists of a generic hierarchical structure with a family of different forms for analyzing theory in different contexts and fields. Versions have been published for designing and designs, cognition, information systems, e-business education, and the inclusion of qualitative social, environmental and ethical factors in quantitatively based activities (see, for example, Love, 2001a, Love, 2000b, Love, 2000e, Love, 2000a, Love, 2001b). The core is a table with nine layers of abstractions that form a theoretical chain at one end grounded in the concreteness of reality and at the other end bounded by assumptions, beliefs and values about existence and reality. The lowest level focuses on the initial conversion of sensual perception of the world into concepts by naming phenomena: the first level of abstract cerebral processing. The highest level contains the human ontological or religious beliefs about existence and the nature of the core entities on which theory is made. Between these two— the conceptualisation of direct perceptions of 'reality' and beliefs about 'what is fundamental about existence'—are the co-dependent layers of theoretical and everyday abstractions that are stock in trade of communication and reflection in diverse occupations such as journalism, management, art, science, technology and academe.

The universality of this family of meta-theoretical hierarchies is in part due to theories and abstractions having generic properties that are relatively independent of what each theoretical abstraction represents, and in part due to the ubiquitousness of ‘designing’ (creating a plan for future action) and ‘researching’ (gathering information to support such planning) in most human endeavours. A relatively generic form of the hierarchy (Love, 2001b) is outlined in Table 1:

Table 1: Meta-theoretical hierarchy of concepts and theories about situations involving human activities

Level	**Classification**	**Description**
1	Ontological issues	The ontological basis for theory making. This level includes the human values and fundamental assumptions of researchers, designers and those involved in critiques of theory.
2	Epistemological issues	The critical study of the nature, grounds, limits and criteria for validity of knowledge. This is the level that contains the relationships between ontology and theory
3	General theories	Theories that seek to describe human activities and their relationship to designed objects and human environments.
4	Theories about human internal processes and collaboration	Theories about the reasoning and cognising of individuals involved in designing and researching, of collaboration in teams, and socio-cultural effects on individuals’ behaviours.
5	Theories	Theories about the underlying structure of processes of

	about the structure of processes	designing and researching based on domain, culture, artefact type and other similar attributes and circumstances.
6	Design and research methods	Theories about, and proposals for, methods and techniques of designing and researching
7	Theories about mechanisms of choice	Theories about the ways that choices are made by designers and researchers between different elements, designed objects, processes, systems or other types of possibility.
8	Theories about the behaviour of elements	Theories about the behaviour of elements that may be incorporated into designed objects, processes and systems
9	Initial conception and labelling of reality	The level at which humans' descriptions of objects, processes and systems are coined, e.g. 'a vacuum cleaner', a 'database', 'sitting' at a 'desk', 'hearing' 'noise', and 'watching' 'sunsets'.

This meta-theoretical approach gives rise to several inferences/axioms:

- A theory at any level of abstraction describes patterns in theories at lower levels and depends on theoretical abstractions at higher levels.
- For a theory to be well justified it should be possible to identify it as a part of a complete chain with elements in all of the levels. (Theories and concepts often have possible relationships with more than one abstraction at neighbouring levels, and this usually results in a cascade of relationships increasing with the distance between levels.)
- Different disciplines have different distributions across the hierarchy. (e.g. Engineering theories are mainly found in levels 7 and 8). All disciplines, however, would be expected to contain elements at all levels if they are to be complete in terms of the structure and dynamics of their theories.

META-THEORETICAL ANALYSIS OF THEORIES IN THE SYSTEMS FIELD

The above methodology was originally developed to address problems that resulted from the uncoordinated development of theories about designing and designs which occurred because theories were developed in different domains and many theories were implicitly and explicitly domain specific (Love, 1998). The body of systems theories suffers from similar problems (Love, 1995, Flood and Carson, 1988, Flood, 1990, Hubka and Eder, 1988). The similarities between Systems and Design Research imply that meta-theoretically analysing theories of Systems may offer useful insights. An alternative meta-theoretical analysis of systems theories was described by Flood (1990), but his analyses focused almost exclusively on epistemological perspectives rather than the structure and dynamics of theory making. The meta-theoretical hierarchy described in this paper helps answer question such as 'What would a complete and well justified body of theory about systems look like? The weakness of Flood's approach (and its strength in its context) is the way his approach answers more limited questions such as 'Which epistemological/ontological theories are appropriate to particular classes of systems problems?'

Table 2 below sketches out the distribution of systems theories in the meta-theoretical hierarchy of Table 1. The contents of Table 2 are illustrative only and not meant to be complete. Streams A and B refer to whether systems are dependent or independent of subjective human behaviour.

Table 2:A Meta-theoretical Taxonomy of Systems Theories

Level	Description	Systems Theories
1	The ontological basis for theory making. This level includes the human values and fundamental assumptions of researchers, designers and those involved in critiques of theory.	Stream A: Values that underpin human action, research creativity, theory making and analysis. / Ethical and aesthetical positions Stream B: Axioms/fundamental characteristics of 'objects' in systems theories and in reality, e.g. 'system', 'relationship', 'object'.
2	The critical study of the nature, grounds, limits and criteria for validity of knowledge. This is the level that contains the relationships between ontology and theory	Stream A: Epistemologies of Sociology, Social Theory. Stream B: Epistemologies of the Natural Sciences and Engineering
3	General theories that seek to describe human activities and their relationship to designed objects and human environments.	Stream A: General theories about human activities are defined in terms of the standardised models of input and output vectors and connections of elements that form part of a system representation of a situation involving humans, e.g. General Systems Theory/ Viable System Model/Soft Systems Methodology. Meta-theoretical representations such as the Total Systems Intervention model offer a model of relationships between other general theories. Stream B: Not relevant – see level 8
4	Theories about the reasoning and cognising of individuals involved in designing and researching, of collaboration in teams, and socio-cultural effects on individuals' behaviours.	Stream A: Usually tacitly rely on undefined representations of internal human processes. Social processes are defined in terms of inputs and outputs of system elements that represent individuals, groups or organisational roles mediated by understandings furnished mainly by sociological constructs. Stream B: Human cognition ignored or tacitly defined in terms of properties of objects, e.g. theories involving web form

		designs that assume that the users cognition is isomorphic with the way the form is laid out and the ways a form interacts with other web pages.
5	Theories about the underlying structure of processes of designing and researching based on domain, culture, artefact type and other similar attributes and circumstances.	Stream A: Information-based processes described in systemic terms. Theories of information acquisition and use based on sociological and psychological epistemologies. Stream B: Defined in terms of the properties of and relationships between non-transcendental objects.
6	Theories about methods and techniques (of designing and researching)	Stream A: Information based methods of information creation and sharing that take into account social theories and focus on empirically accessible properties of the objects, processes and systems being researched. Stream B: Information based to automating designing and researching that focus on the empirically accessible properties of the objects, processes and systems being researched.
7	Theories about the ways that choices are made by designers and researchers between different elements, designed objects, processes, systems or other types of possibility.	Stream A: Theories about choices include human social factors that shape decision-making processes and often also are defined in terms of rational and bounded rational, deterministic, logical and fuzzy-logical and search-based processes that primarily focus on object and system properties. Stream B: Rational and bounded rational, deterministic, logical and fuzzy-logical and search-based decision making processes that primarily focus on object and system properties.
8	Theories about the behaviour of elements that may be incorporated into designed objects, processes and systems	Stream A: Interpretive, post positivist, subjective, human constructed cognitive and affective theories: commonly defined in terms of the gross empirical characteristics of social arrangements and interactions and object properties. Stream B: Scientific, engineering, positivist and ‘hard’ systems theories

9	The level at which humans' descriptions of objects, processes and systems are coined, e.g. 'a vacuum cleaner', a 'database', 'sitting' at a 'desk', 'hearing' 'noise', and 'watching' 'sunsets'.	Stream A: Labelling of human situations, relationships, factors acting on relationships, arrangements between humans and organisational types based mainly on scientific and social constructivist epistemologies. Stream B: Scientifically-based labelling of objects, categories of objects and relationships between objects and classes of objects.

The above meta-theoretical sketch points to three characteristics of systems theory making:

1. Systems theories presume and depend on theories of human cognition but these are rarely explicitly defined.
2. There is little attention given to the internal human systems that provide the mechanisms that implement (and hence shape) cognition in individual humans. This lack of attention to theories at this level in the hierarchy suggests a systemic weakness of systems theory making – especially for Stream A theories.
3. There is a lack of attention to systems that relate human affect, cognition, intentionality and agency. These issues form the systemic foundations for theories that involve management, incentive, motivation, judgement, choice, peer-pressure and other processes that depend on human feelings.
4. The lack of theories in relation to individual human internal cognito-affective systems has resulted in distortions in other areas of systems theory to cover this omission.

Systems theories have adapted to circumscribe the lack of adequate theories in relation to human cognito-affective processes. This has occurred, for example, through the development of tacitly held models of individual human cognition implicitly defined by observations of humans en masse, or by tacitly defining human cognition in terms of properties of and relationships between objects, (e.g. defining thinking about a situation in terms of the logical relationships embedded in it). There is a spectrum at one end of which are rational, deterministic, and behavioural models of human cognition and action, and, at the other, interpretive theories that assume human understanding and associated cognitive processes and actions result from internal individual-specific constructed systems whose development has been strongly shaped by social factors. In both cases, these address human cognition issues in a second-hand manner, and at a significant distance.

NEW DIRECTIONS IN SYSTEMS THEORY

The above meta-theoretical analyses suggest that Systems would benefit from greater attention to human cognition. This is not straightforward, however, because theories of cognition are themselves undergoing radical revision. This is partly a consequence of the trend away from the mechanistic rationalist theories that formed a cornerstone of early Artificial Intelligence and Cognitive Science theories (e.g. Newell and Simon, 1972, Newell, 1990) and towards the inclusion of affective processes (Picard, 1997). More significantly, radical changes are due to new findings from brain research that potentially render irrelevant and obsolete many theories of cognition inferred from human behaviour. This has ramifications for systems theories that implicitly or tacitly depend on such theories.

A practical example of the ways these new findings impact on theory is brain scanning in the area of early childhood education. The findings of brain research completely replace many education/child development theories that previously informed the choice of pedagogical approaches to address developmental delay. Brain scanning shows immediately and directly which approaches are successful because it immediately reveals detailed changes in brain structure and function, rather than having to infer these internal changes second-hand from observations of behaviour. Another example is their effect of brain research findings on musical education theories based on the theory of music (similar to the way that mathematics education theories are based on the structure of mathematical theories). Early steps in brain research in music skill development suggest that focussing on tone skills (rather than for example, skills in rhythm, playing or music theory) is the key educational factor that results in brain changes that are characteristic of competent musicians (Ohnishi et al., 2001). This finding provides a useful heuristic, but, more importantly, it potentially renders obsolete the body of existing theory and epistemology relating to this aspect of music education.

The implication is that similar outcomes to those in Education would be expected in Systems. Both are deeply dependent on human cognition and affective processes, and in both existing theories address these issues second-hand by inferring them from externally observable behaviour – a process recognised as epistemologically problematic (Phillips, 1987). In these and similar fields, it is likely that new findings from brain research will replace inferred theories of cognition with directly observed and measured models of neural mechanisms.

These new developments in brain research and the associated implications for cognito-affective theories offers the possibility of addressing areas of weakness in systems theories relating to the ways that they represent situations that depend on the feelings, values and thought systems of individual humans. This does not, however, imply a move to biological determinism. Understanding the mechanisms – even of cognito-affective processes that actualise the relationship between an individual’s thoughts and their feelings and values – does not offer a one-to-one correspondence between context and action. These new understandings do, however, potentially allow the boundaries of systems involving humans to be located at some theoretical distance inside the humans involved. This change has additional ramifications for cybernetic systems theories because it allows the variety in human internal systems to be included in systems analyses that utilise Ashby’s Law.

The above changes mark a significant move onward in systems theory development as existing theories are replaced with new theories based on new and epistemologically different forms of knowledge. It represents a step in the progression of system theory development: ‘machine age’ → ‘sociological epistemologies’ → ‘cognito-affective human activities’.

SUMMARY

This paper has sketched out a meta-theoretical analysis of systems theories and pointed to potential weaknesses likely to be addressed by new knowledge emerging as a result brain research.

This change is more than superficial because it is likely to result in epistemologically different foundations for substantial areas of systems theory. It implies the start of a new era in Systems theory making.

REFERENCES

Ackoff, R. L. (1991) 'The Future of Operational Research is Past', In *Critical Systems Thinking: Directed Readings,* (Ed, Flood, R. L.) Wiley, Chichester, UK.

Beder, S. (1993) 'Pipelines and Paradigms', *Transactions of the Institution of Engineers, Australia; Multi-Disciplinary Engineering,* **CE35**(1)**,** pp. 79-85.

Checkland, P. and Scholes, J. (1990) *Soft Systems Methodology in Action,* John Wiley & Sons, Chichester, UK.

Churchman, C. W. (1991) 'Operations Research as a Profession', In *Critical Systems Thinking*, (Eds, Flood, R. and Jackson, M. C.) John Wiley & Sons, Chichester, UK, pp. 19-40.

Coyne, R. (1997) 'Creativity as commonplace', *Design Studies,* **18**(2)**,** pp. 135-142.

Coyne, R., Snodgrass, A. and Martin, D. (1992) *Metaphors in the Design Studio* (Working Paper Report Number). Faculty of Architecture University of Sydney, Sydney

Coyne, R. and Snodgrass, A. B. (1992a) *Problem Setting within Prevalent Metaphors of Design - Working Report* (Working paper Report Number). Faculty of Architecture, University of Sydney, Sydney

Coyne, R. D. (1990) *Learning without explanations: Design Education and Models of Cognition* (Working paper Report Number). Design Computing Unit, University of Sydney, Sydney

Coyne, R. D. (1991) 'Objectivity in the design process', *Environment and Planning B: Planning and Design,* **18**361–371.

Coyne, R. D. and Newton, S. (1992) *Metaphors Computers and Architectural Education* (Working Paper Report Number). Dept of Architectural and Design Science University of Sydney, Sydney

Coyne, R. D., Rosenman, M. A., Radford, Balachandran, M. and Gero, J. (1990) *Knowledge based design systems,* Addison-Wesley Publishing Company, Reading MA.

Coyne, R. D. and Snodgrass, A. (1991) 'Is designing mysterious? Challenging the dual knowledge thesis', *Design Studies,* **12**(3)**,** pp. 124-131.

Coyne, R. D. and Snodgrass, A. (1992b) 'Cooperation and Individualism in Design', *Environment and Planning B: Planning and Design,* **18**.

Coyne, R. D. and Snodgrass, A. (1992c) *Problem Setting within Prevalent Metaphors of Design* (Working Paper Report Number). Department of Architecture and Design Science University of Sydney, Sydney, NSW

Coyne, R. D. and Snodgrass, A. (1993) 'Rescuing CAD from Rationalism', *Design Studies,* **14**(2)**,** pp. 100-123.

Espejo, R. and Harnden, R. (Eds.) (1989) *The Viable System Model: Interpretations and Applications of Stafford Beer's VSM,* John Wiley & Sons.

Flood, R. (1995) 'Solving Problem Solving: TSI - A new problem solving system for Management', In *Systems for the Future*, (Eds, Hutchinson, W., Metcalf, S., Standing, C. and Williams, M.) Edith Cowan University, Perth, WA, pp. 1-16.

Flood, R. L. (1990) *Liberating Systems Theory,* Plenum Press, New York.

Flood, R. L. and Carson, E. R. (1988) *Dealing with Complexity: An Introduction to the Theory and Application of System Science,* Plenum Press, New York.

Flood, R. L. and Jackson, M. C. (1991) *Creative Problem Solving: Total Systems Intervention,* John Wiley & Sons Ltd., Chichester, UK.

Franz, J. M. (1994) 'A critical framework for methodological research in architecture', *Design Studies,* **15**(4)**,** pp. 443-447.

Galle, P. (2001) 'Metatheory in Practice', *Design Studies,* **22**(1)**,** pp. 101-102.

Hubka, V. and Eder, W. E. (1988) *Theory of Technical Systems,* Springer-Verlag, Berlin.

Hutchinson, W., Metcalf, S., Standing, C. and Williams, M. (Eds.) (1995) *Systems for the Future,* Edith Cowan University.

Indurkhya, B. (1992) *Metaphor and Cognition,* Kluwer Academic Publishers, Dordrecht.

Joseph, S. (1996) 'Design systems and paradigms', *Design Studies,* **17**(3)**,** pp. 227-239.

Konda, S., Monarch, I., Sargent, P. and Subrahmanian, E. (1992) 'Shared Memory in Design: A Unifying Theme for Research and Practice', *Research in Engineering Design,* **4**23-42.

Love, T. (1995) 'Systems models and engineering design theory', In *Systems for the Future*, (Eds, Hutchinson, W., Metcalf, S., Standing, C. and Williams, M.) Edith Cowan University, Perth Western Australia, pp. 238–246.

Love, T. (1996) 'Social, environmental and ethical factors: their implications for design theory', In *Design for People*, (Eds, Groves, M. A. and Wong, S.) Edith Cowan University, Perth, pp. 199-206.
Love, T. (1998) *Social, Environmental and Ethical Factors in Engineering Design Theory: a Post positivist Approach,* Praxis Education, Perth, Western Australia.
Love, T. (1999) 'Values role in computer assisted designing', *International Journal of Design Computing,* **1**.
Love, T. (2000a) 'Computerised Affective Design Cognition', *International Journal of Design Computing,* **2**.
Love, T. (2000b) 'Educating e-business designers: some implications of a post-positivist theory of design cognition', In *Working for e-business: challenges of the new e-conomy*, (Ed, Stoney, S.) We-B Research Centre, School of Management Information Systems, Edith Cowan University, Perth.
Love, T. (2000c) 'Educating those involved in changing human futures: a more coherent programme for design education', In *Re-inventing Design Education in the University*, (Eds, Swann, C. and Young, E.) School of Design, Curtin University of Technology, Perth, pp. 242-248.
Love, T. (2000d) 'A Meta-Theoretical Basis for Design Theory', In *Doctoral Education in Design*, (Eds, Durling, D. and Friedman, K.) La Clusaz, France.
Love, T. (2000e) 'Philosophy of Design: a meta-theoretical structure for design theory', *Design Studies,* **21**(3)**,** pp. 293-313.
Love, T. (2000f) 'Research and Practice in the University Education of Designers', *Curtin Journal of Design,* **5** 16-20.
Love, T. (2001a) *Affective Information Systems: Contributions to IS from Design Research - We-B Research Seminar* (ppt files for seminar presentation of working paper Report Number). We-b Research Centre, ECU, Perth, WA
Love, T. (2001b) *Design Research & Management Information Systems: Symbiotic Factors* (Working paper Report Number). Edith Cowan University, Perth
Newell, A. (1990) *Unified Theories of Cognition,* Harvard University Press, Cambridge, Mass.
Newell, A. and Simon, H. A. (1972) *Human Problem Solving,* Prentice-Hall, N. Jersey, USA.
Ohnishi, T., Matsuda, H., Asada, T., Aruga, M., Hirakata, M., Nishikawa, M., Katoh, A. and Imabayashi, E. (2001) 'Functional Anatomy of Musical Perception in Musicians', *Cerebral Cortex,* **11**(8)**,** pp. 754-760.
Phillips, D. C. (1987) *Philosophy Science and Social Inquiry,* Pergamon Press, Oxford.
Picard, R. W. (1997) *Bibliography from Affective Computing*, [html file]. M.I.T. Available: http://www.media.mit.edu/affect/AC_bibliography.html [2001, May]
Popper, K. (1976) *Unended Quest,* Open Court, Illinois.
Probert, S., K. and Stephens, R. (1998) 'Philosophical Aspects of Information Systems: Why? Wherefore? and Where Next?', *Systemist,* **20**(Dec)**,** pp. 3-5.
Rastogi, P. N. (1992) *Policy analysis and problem-solving for social systems : toward understanding, monitoring, and managing complex real world problems,* Sage Publications, New Delhi ; Newbury Park, Calif.
Reich, Y. (1994) 'Layered models of research methodologies', *Artificial Intelligence in Engineering Design and Manufacturing,* **8** 263-274.
Stegmüller, W. (1976) *The Structure and Dynamics of Theories,* Springer-Verlag, New York.
Ullman, D. G. (1992) 'A Taxonomy for Mechanical Design', *Research in Engineering Design,* **3** 179-189.