Systemic knowledge management in hydraulic systems: I. A postulate on paradigm shifts as a methodological tool

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ABSTRACT

Unravelling transparency among the various disciplines of science in the context of their evolving processes is a methodological problem and the focus of a series of two papers presented here. This first paper presents the concept of the paradigm as a generic problem-solving tool for creating transparency by postulating that a paradigm, after its formation, shifts through proliferating, norming and performing stages. Each stage is associated with generic features. A common conception of the paradigm is synonymous with frameworks in science and technology; this concept is revisited in this paper and is presented as a generic problem-solving framework. The paper argues that science selects and intertwines many paradigms and a paradigm is a particular form of evolution in action. In its pre-paradigm period there is randomness among the rudimentary components with no sense of direction. In its forming and proliferating stages, a paradigm is composed of workable components with a one-way flow of information subject to the law of natural selection. In the norming and performing stages, a conscious process of consolidation takes place among the components with emerging hierarchies and with influences on the orientation of the paradigm but without full determination of the overall direction. In this way, a picture emerges where science has generic foresight, the formation of which can be influenced but not be fixed. This paper substantiates this postulate through the paradigm of science and institutionalisation and the following paper substantiates it through hydraulic systems.

Key words | decision making, hydraulic systems, institutionalisation, paradigm and paradigm shifts, problem-solving methodology, systemic postulate knowledge management

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INTRODUCTION

Hydraulic systems often encompass technical and social dimensions with hierarchical organisations. Such systems involve a whole range of problems, and problem-solving is integral to their design, operation and rehabilitation. Problem-solving in science and technology is evidently a bridge between open-ended research tasks with few or no precedents and routine project tasks with an established precedent. Although there is a host of pragmatic problem-solving approaches offering practical solutions, they often suffer from (i) a lack of foresight due to overlooking the generic context of the problems, and (ii) are not necessarily intelligent, due to overlooking interconnections among the constituent components. There are many brands of problem-solving but a series of two papers is presented here on the application of 'systemic' approaches and 'knowledge management' to focus on (i) arbitrary arrangement of components, (ii) some workable arrangement of components, (iii) components interconnected with one another and with their context towards maximising their synergy, and (iv) rearrangement of the components to comply with prescribed requirements. These are depicted in Figure 1.

'Systemic knowledge management' is presented as a problem-solving methodology in paper I and applied to hydraulic systems in paper II. This methodology is associated with three dimensions: (i) the concept of 'paradigm',

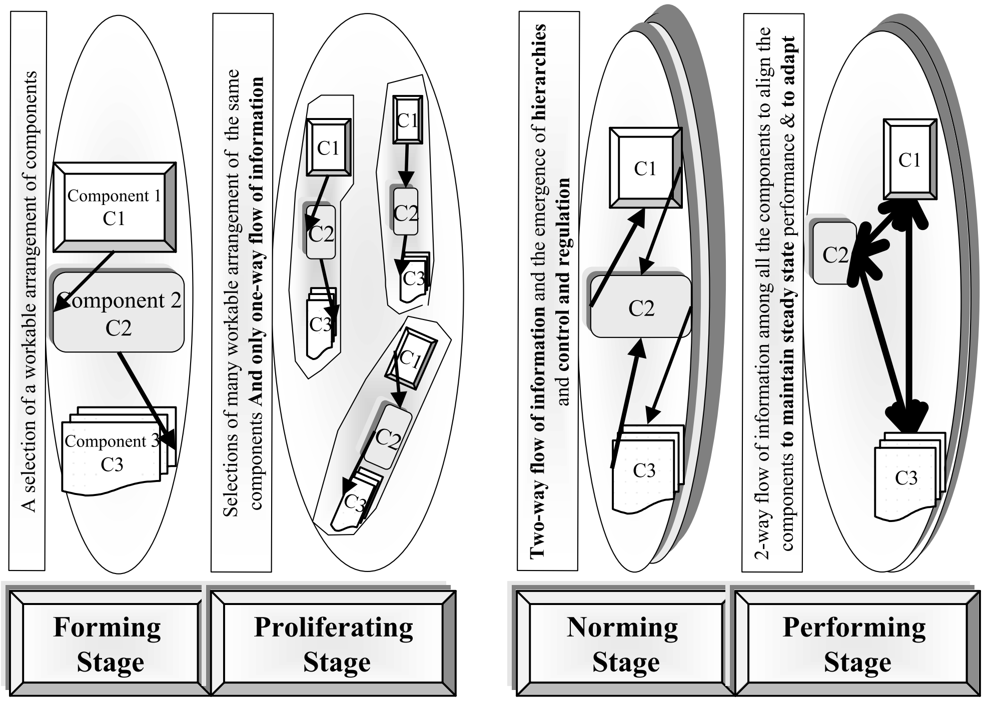

Figure 1 | The role of components in shifting paradigms.

originally presented by Kuhn (1962); (ii) the 'systemic' problem-solving methodology, as developed in systems science; and (iii) 'knowledge management,' developed in management science. As shown in Figure 2, the concept of paradigm is used as the roadmap to depict generic developments in science. Although systemic methodologies are applied widely as problem-solving tools, there is often no single solution in problem solving. One way of consolidating the solutions to a specific solution is through knowledge management by its key premises of categorising the systems for customisation of solutions, challenging inherent assumptions in decision-making and reorganisations as a way of adapting to subsequent changes. Paper I synthesises knowledge management with systemic methodologies and presents their paradigmatic contexts. This three-dimensional problem-solving is applied to hydraulic systems in Paper II (Khatibi 2003) and the writer is not aware of any previous research on their synthesis.

Checkland (1981) presents this quotation 'science is an institutionalised set of activities'. This signifies that science and institutionalisation are intertwined. Arguably

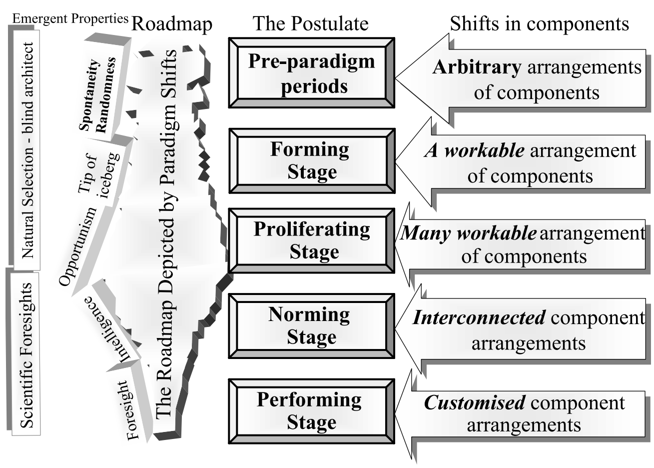

Figure 2 | Depiction of the postulate on paradigm shifts.

both are paradigms formed in the process of industrialisation, particularly during the Industrial Revolution (mid-18th–20th century) and are both constituent makers and an establishment of this period. These paradigms outlined in this paper have been shifting since then. Kuhn (1962) argues that, after the formation of a paradigm, its subsequent shifts are associated with characteristic features. According to him, after the formation, every problem is not solved but extensive research and development and a plethora of publications lead to a 'normal science' stage. Paper I takes a fresh look at the formation of paradigms and their subsequent shifts.

This paper postulates that a paradigm is formed and shifts through stages, each with characteristic features. This postulate is substantiated by the paradigms of science and institutionalisation. The implications of these paradigmatic stages are then substantiated in relation to hydraulic systems, giving examples on irrigation systems, municipal water supply systems and flood forecasting and warning systems. In order to gain a greater benefit, readers are prompted to interconnect the next section on the concept of paradigm with a parallel case related to their own experience or knowledge, e.g. the evolution in the motor industry towards environmentally friendly products or democratisation of political processes. Two definitions are presented at the outset of the paper concerning complexity and system. A system is an array of interconnected units towards a goal or purpose, whereas complexity refers to interconnected units without specifically referring to the goal or purpose.

PARADIGM—THE ROADMAP OF SCIENCE OR GENERIC DEVELOPMENTS

Kuhn used the term 'paradigm' in 1962 to describe the formation of scientific frameworks. According to him, after the formation of a paradigm it reaches the stage of normal science associated with some emerging inconsistencies. Kuhn then resorts to the Hegelian dichotomous dialectics as the basis to explain the shifts in existing paradigms or for the formation of new ones as a way of solving inconsistencies.

Kuhn's exposition of the concept of paradigm has a wide appeal in describing the nature of scientific activities during the period prior to the formation of a new paradigm, its formation and subsequent shifts. However, his 'constructivist' philosophy has been contested, where this doctrine regards scientific theories as social or intellectual constructs. Boyd (1992) presents an account of the differences among constructivism, realism and empiricism but in philosophical terms. The presentation here on the concept of paradigm differs from the exposition by Kuhn. The writer is not satisfied with a Hegelian speculation to explain the evolutionary processes in science.

The concepts addressed in this paper are neither concerned with Kuhn's constructivism nor with contentious aspects of philosophy. The writer's interpretation of the concept of paradigm is depicted in Figure 2 and this term is used as a roadmap to delineate the generic structure of science and technology. Any theory, concept or phenomenon can be viewed as a paradigm and therefore there can be many paradigms often interwoven together. It is postulated that paradigms often shift through 'forming', 'proliferation', 'norming' and 'performing' stages. These terms were used by Tuckman (1965) to describe the development of groups in social organisations but referred to 'proliferation' as 'storming'. Each stage is associated with generic features, as outlined below and is substantiated in the following sections. There appears to be no research describing stages in paradigm shifts.

Pre-paradigm periods

In this stage, researchers conceive problem areas as the 'tip of an iceberg'. Many possible components may emerge to solve each problem, normally with a saturation of a whole range of potential solutions. Each solution may fit a particular circumstance but is inherently arbitrary in its nature and does not offer any selective advantage.

The formation stage

A paradigm often emerges out of a diversity of potential arrangements of components. It is formed from time to time as a particular arrangement from the possible components often contrived in the pre-paradigm period. The selection of the particular components is normally spontaneous and follows the law of natural selection. This law is not confined to biology anymore but observed in other fields of science. The building block responsible for the selection is not easy to identify but depends on the specific problem area or paradigm. It is important to press the points that (i) any arrangement with a selective advantage can potentially be selected, (ii) without the selection, the paradigm does not exist, and (iii) the particular selection is formed by the virtue of offering a selective advantage. An important feature of natural selection is that it is a blind architect and this is reflected on forming paradigms. Thus (i), a forming paradigm, has no foresight and (ii) exists as long as its selective advantage prevails. An important feature of forming paradigms is that the interconnection of their constituent components implicitly contributes to the paradigm without any explicit knowledge of their full potentials. The interconnection of the components is tantamount to the establishment of a one-way flow of information through the components.

The proliferation stage

There may be two forms of proliferation: (i) different variations of the constituent components of a paradigm are arranged and offered to prevailing niche conditions; (ii) the forming paradigm proliferates laterally across different disciplines. The proliferation stage is spontaneous and is triggered in response to niche conditions. The features characterising the forming stage remain true in this stage with additional features as follows: (i) a critical mass of scientists is formed who subscribe to the paradigm in the form of a movement fostering intense interests for further research; (ii) this stage is associated with positive feedback, defined as the amplification of the influence of the paradigm compared with the pre-paradigm period; (iii) the flow of information in the proliferation stage of the paradigm is inevitably one-way, i.e. from researchers to end-users or end-users react to researchers but researchers are unable to react to end-users' needs; (iv) problem-solving at this stage is capable of selecting viable arrangements through treating the system one component at a time. Each selection makes up one output of the paradigm, in which the synergy of the interconnection among the components is neglected, including any interconnection between researchers and end-users. The paradigm and its outputs are opportunistic for exploiting niche conditions.

Commonality between forming and proliferating stages

The paradigms at these stages are reductive (see the definition in the next section). Further common features of both of these stages include the following: (i) the degree of organisation increases but spontaneity still remains significant; (ii) end-users react to the paradigm, which exploits the niche conditions and, as such, the degree of intelligence is still relatively low in the sense that the synergy among interconnected components of the paradigm is overlooked; (iii) failures are frequent but their impact is low in a background where there is an increasing transformation from this high frequency low impact to low frequency high impact. There is no perception of such a transformation at this stage; (iv) there is no regulation in these stages other than the slow regulatory role of natural selection; and (v) there are many barriers among the components, for the prime reason of ignoring their interconnection synergies.

The shift from the proliferating to norming stage

Cumulative scientific outcomes of a paradigm at the proliferation stage suffer from the effects of the law of diminishing return and also, as Kuhn makes the point for normal science, from some emerging inconsistencies; furthermore research programs diversify at the expense of leaving many issues unconsolidated. The shift away from the proliferation stage is inevitable and may take place spontaneously, fostered by an organisation, sparked off by events or realised through movements.

The norming stage

Norming is a process of movements, which often unravels consciously the barriers inherent in the proliferation stage. During this process, an important task is to problem-solve towards, or to develop the principles for, the performing stage. It is inherently related to transforming the implicit knowledge of the interconnectedness among the constituent components into explicit knowledge and exploitation of that knowledge. There is a realisation at this stage that more can be obtained from the problem area of the paradigm through the hierarchical organisation of the components but this is normally a process of two-way flow in information. Thus, problem-solving capabilities treat the whole, i.e. all the components in one hierarchy and all the hierarchies in one system with two-way flows of information. Such interconnectedness is referred to as holism, which facilitates a continual search for an insight into the synergy among constituent components and hierarchies (the writer refers to this as 'longitudinal holism') and among the various paradigms that can be interconnected (the writer refers to this as 'lateral holism'). The writer argues that many paradigms now are at their norming stage displaying the following features:

- The degree of organisation increases among the components and spontaneity reduces.
- Intelligence prevails and increases owing to adopting the strategy of interconnected components through proactive problem-solving approaches. This interconnectedness is generic and applies to various paradigms, reflecting its paradigmatic stages.

The performing stage

In the performing stage, *the solving of the problem of problem-solving* is matured. A fundamental requirement for the performing stage will probably be the capability to maintain steady performance and adapt to changing environmental states through feedback mechanisms. Such a capability can be gained through delivering 'customised solutions', defined as the capability to identify and implement a host of necessary arrangements or changes within the systems to comply with both external and internal boundary conditions. This capability is only possible if there is a two-way flow of information: (i) from the environment to the system, and (ii) from the system to the environment. In addition, the components can be rearranged or refined, each with a predictable outcome. For instance, sustainable development seems to be one key principle in shaping the direction of science towards its performing stage. However, it is hard to see how sustainable solutions can be delivered without the capability for the system responding to the environmental constraints and the beneficiaries of the system not responding to the limits of the system. Through the capability of delivering customised solutions with feedback loops, it is possible for the system to maintain steady performance and adapt to changing environments.

Arguably, many paradigms have not reached the performing stage, but ways of approaching this stage are in sight. There are many future outlooks seemingly desirable now and these are often expressed in terms of such attributes as flexibility, efficiency, proactive capabilities, customised solutions, sustainable solutions, 'civic science' and implementation of living and growing systems. These attributes are not mere expressions of desirable details but niceties essential for the performing stage of paradigms against a background where problem-solving approaches have the capability to ensure each of the above attributes. The concept of civic science is not explored here further but its importance is stressed. The term is proposed by Shannon & Antypas (1996) to democratise science and define it, as follows: '. . . civic science involves scientists as citizens and citizens as lay scientists in a process in which knowledge production is integrated . . .'.

Commonality among all the stages

The stages postulated on paradigm shifts are clearly generic and a roadmap to depict the frameworks of science and technology. The shifting of paradigms through generic stages, outlined above, embraces natural selection but is not confined by it. Sigmund (1993) states that 'Natural selection constructs without foresight. It improvises, using whatever happens to be around.'. This roadmap shows that this is particularly true for the forming and proliferating stages and, in the norming stage, 'trial-and-error' at worst and modelling at best are important ways to understand interconnectedness of the components and their synergy. At the performing stage, the knowledge of interconnectedness is firm and proactive. This roadmap is a high-level foresight offered by the postulate on paradigm shifts. This foresight is not independent of perception but a spontaneous outcome of the particular development. The foresight can serve science and technology with the following properties:

(i) Throughout the shifting from one stage to the next, the degree of spontaneity is reduced and that of organisation is increased.

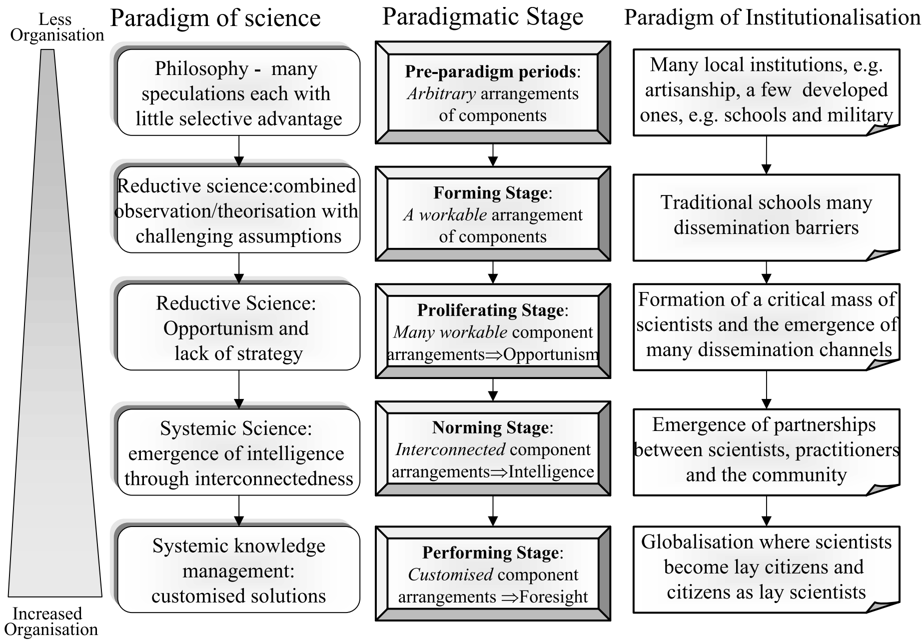

Figure 3 | The paradigm of science and its shifts.

(ii) The first two stages are reactive and lack foresight but the latter two are proactive with 'spontaneous foresight'. Spontaneous foresight may appear vague but this is used as another expression for emergent properties as explained in the Comments section.

(iii) 'Normal science' as described by Kuhn is a prominent feature of the proliferating stage but this is managed conscientiously in norming and performing stages.

The roadmap from the formation of a paradigm to its normal science stage in Kuhn's exposition of paradigm is an impressionistic picture, necessitating rethinking. The postulate presented in this paper represents a first attempt to develop a high-level roadmap. In spite of its contentions, Kuhn's exposition offers a degree of transparency in science and the postulate on the stages of paradigm shifts as presented in this paper contributes to maintaining transparency.

Substantiation of the postulate

The above presentations on the postulate that paradigms shift through generic stages must be substantiated. The paradigms of science and institutionalisation are used to substantiate the postulate and these are presented in the next section. These stages are expected to prevail in hydraulics as a branch of science, and in each field of hydraulics. Paper II present cases in hydraulics, including an outline of the shifts in irrigation systems, water supply systems and a detailed account of the norming stages of the paradigm shift in flood forecasting and warning.

The point to press is that a different picture emerges when a complexity or a system is viewed through paradigm shifts rather than in Kuhn's account. For instance, the practice of flood forecasting has been developing since the mid-20th century based on hydrological/conceptual techniques using conservation of mass alone. Intense research activities on different mathematical representations of transforming rainfall into runoff have created a plethora of techniques. By Kuhn's account, this area of expertise is now at its normal science stage. Various studies have shown that no single hydrological/conceptual forecasting technique may outperform the others. Although further research is not expected to create new knowledge, knowledge management offers a way forward to add value by extracting knowledge from

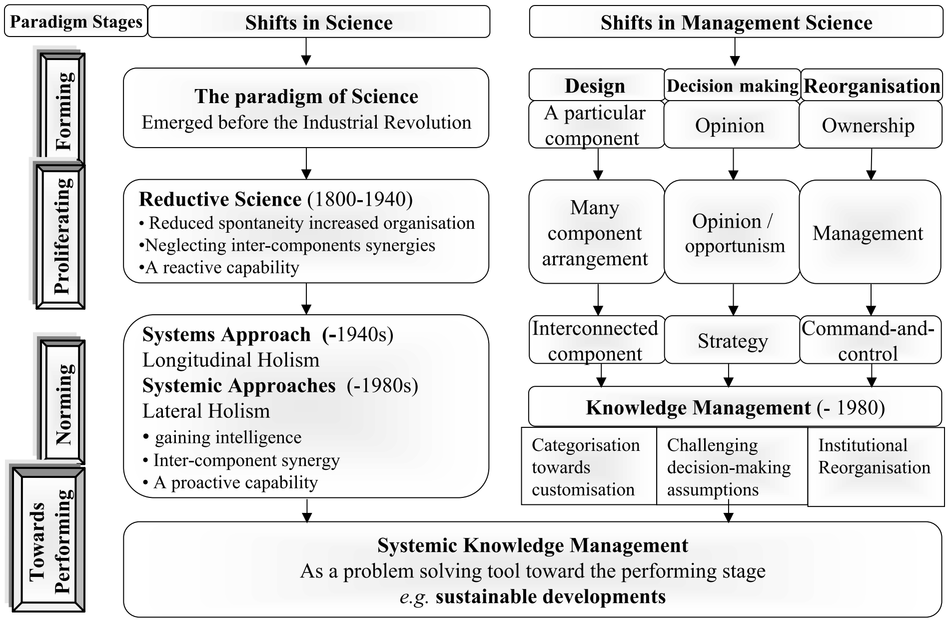

Figure 4 | Paradigm shifts related to systemic knowledge management.

existing research outputs. Further details are presented in the next section and Paper II (Khatibi, in press).

THE PARADIGMS OF SCIENCE AND INSTITUTIONALISATION

The paradigms of science and institutionalisation are used to substantiate the postulate and these are presented in this section and depicted in Figures 3 and 4.

The pre-paradigm period

The etymology of the word 'science' is not the subject here but it has an evolving meaning. Its usage as 'to know' with a variety of connotations is old, as for instance in the Middle Ages 'the seven (liberal) sciences' were often used synonymously with 'the seven liberal arts' (Grammar, Logic, Rhetoric, Arithmetic, Music, Geometry and Astronomy). The connotation of science, as a body of knowledge acquired by study, research and training, is of recent origin and synonymous with natural and physical science since the 19th century; for instance in the 17th and 18th centuries the notion usually expressed by science was commonly expressed by philosophy. Prior to the common usage of science, philosophy was the wellspring of ideas and concepts including science as well as the various shades of idealism, materialism, empiricism and many other '-isms'. Philosophy still remains productive but still thriving on speculation by tradition.

The formation stage—reductive science

Reductive science, as a problem-solving methodology, has broken the tradition of speculation since the 16th century. Speculation was a typical symptom of philosophy prior to the reductionism and this still remains a norm in philosophy. Reductive science emerged from the integration of observation and theory into a problem-solving methodology through breaking down a system into its constituent components and individually analysing each component. The analysis normally explains complexities through a cycle of activities comprising the following postulates:

- an objective methodology (theory) is built on assumptions,

- the complexity is decomposed into components at a lower level,
- a set of logical operations is carried out often through the aid of mathematics to obtain results,
- a sample of quantities is observed corresponding to some of the results, and
- the assumptions are challenged through comparing the results with the observation to determine any need for a cyclic refinement of the assumptions.

The selective advantage of this integration was the ability to challenge the assumptions. This advantage was subtle and was selected through a movement by consensus but not through a formal declaration. The challenging mechanism in reductive science is the simplest of many other possible mechanisms, as will be discussed later. However, many institutions were formed to ensure the establishment and development of science, including proliferation of universities (some of which date back to the Middle Ages), research stations, refereed journals and various forms of delivering lectures and conferences.

Proliferation stage—reductive science

The works of some of the thinkers prior to the common usage of the term 'science' would be regarded as philosophical but others should be regarded retrospectively as scientific. Thus, scientists of those days might not have realised they were scientists, as this way of referencing is retrospective and would be novel to them. However, those (retrospective) scientists were engaged in observation and theorisation as well as challenging their assumptions. The selective advantage of this problem-solving methodology is subtle and the characteristic of many spontaneously formed paradigms. Ziman (1991) expresses this in a different context that the sources of invention turn out to be extraordinarily subtle and episodic, revealing little more than the diversity of human behaviour in unfamiliar circumstances. This paper attributes the strength of reductive science to simple principles of combining observation and theorisation and to challenging their assumptions, and indeed these are subtle and their outcomes remarkable. Owing to this advantage of reductive science, more and more scientists joined the movement created by the methodology.

The strength of the paradigm of reductionism was on simplicity and objectivity conferring the ability to challenge the inherent assumptions. These strengths, associated with mathematical descriptions of many problems in physical science, created an outstanding impact. The success of reductionism is undeniable; Medawar & Medawar (1977) assert that it is 'the most successful explanatory technique that has ever been used in science'.

From the proliferating to the norming stage

Science was 'reductive' and often confined to 'hard' systems until the emergence of information technology and of systems theory originating in biology by Bertalanffy. Reductionism overlooks inter-component synergies and suffers from blind spots between the interfaces of various systems. Thus, reductionism is opportunist and lacks a strategic approach. Reductionism had two main impacts: (i) liberation of many degrees of freedom by harnessing a wide range of energy forms, and (ii) creation and accumulation of adverse impacts (e.g. encroachments onto floodplains without compensating for their hydraulic and habitat functions), which emerged as conflicts inherited by the present generation. In response to such impacts, science has increasingly embraced 'holism' since the 1940s, which was rooted in systems science based on the General Systems Theory presented by Bertalanffy (1940). The impact of holism was far-reaching but was neither an ultimate solution nor instantly proclaimed. True holistic approaches have been emerging since the 1980s and 1990s with the outcome of systemic approaches as the integration of reductionism and holism.

The mathematical capability embodied in reductive science was largely limited to manual computations, which imposed limitations on the realisation of a full advantage of detailed theoretical capabilities matured prior to the 1950s. These limitations were addressed by two paradigmatic movements: (i) the advent of modern computation, which made it possible to solve complex theoretical equations, and (ii) systems approaches, as a result of which system-wide modelling emerged as a new paradigm and transformed modelling into a new design tool. The paradigms of systems and modelling are the subject matter of a separate paper under preparation by the writer.

The norming stage—systemic stage

The systems approach to problem-solving is built on Bertalanffy's General Systems Theory, according to which a sociotechnical system may be divided into open and closed systems. Synonymous with systems is the ability to break them into components or building blocks, as in reductionism. A systems methodology may be expressed by the following postulates:

- Complexity is organised hierarchically.
- Lower hierarchies are 'closed systems' in the sense that they contain inherently increasing entropy (see Khatibi (1997) for a further discussion on entropy). Higher hierarchies are open in the sense that there are feedback loops to regulate the inherently increasing entropy associated with both closed-system lower hierarchies and open-system higher hierarchies.
- Feedback loops maintain the flow of information from higher to lower hierarchies and within a higher hierarchy, thus enabling control and regulation.
- Each hierarchy is a synthesis of a finite and often a few simple components, which are bound together by certain rules. These components may be referred to as 'simplicities'.
- The components of a higher hierarchy are a composition of components of lower hierarchies but there are emergent properties at a higher level which are absent in the lower ones.
- The complexity of a system is a composition of its hierarchies. In this sense, complexity is a system without referring to its goals or purposes.

The above postulates specifically define the systems problem-solving method and these postulates together continually maintain an insight into the whole system. The strength of this problem-solving method is in its explanation of the emergent properties of open systems, which consist of (i) maintaining steady performance and (ii) adapting to change. The writer believes that the postulates are not yet complete and there is a need for further development, such as the place of systems approaches within the stages of paradigm shifts. There is also a lack of provision for interacting systems but this has given rise to systemic problem-solving, as outlined below.

One problem with systems approaches is that holism is often well developed within a system (longitudinal holism) but when many systems interact, each system is often treated in a reductive way (a lack of lateral holism). This problem is solved by systemic problem-solving, which interconnects the various systems through interfaces, such that traditional holism and reductionism are interconnected. According to Vickers (1981) 'systemic thinking removes the apparent antithesis' (where thesis and antithesis are reductionism and holism).

One definition of 'systemic' is presented by the Open Systems Group (1981), as follows. 'Loosely speaking', one looks at 'situations, topics, problems etc., as a complex of interacting parts which can be divided into specific systems and within these, subsystems, and if necessary into sub-subsystems, and so on. Identification of these various systems is followed by an examination of the relationships among them, including the flows of influences, materials and energy and the routes these take among and within the systems involved'. Such complexes of systems are qualified by the term 'systemic'.

There is another perspective for defining systemic problem-solving. Consider a river system, which may accommodate a whole range of flow states such as floods, drainage, water resources, low flows, navigation, water quality, sediment transport, habitat, etc. In a systems approach, the river is considered as a sociotechnical system with only one of the above flow states but this is a reductive problem-solving approach in disguise. In reality, many of these problem areas interact with one another and, in a systemic problem-solving approach, as many of these problem areas should be considered together as necessary. While in natural systems an understanding of the interfaces between the interacting systems is the key for systemic problem-solving, it is argued that in sociotechnical systems the key is knowledge management, as is presented next.

Towards the performing stage—knowledge management

The writer holds that, at the norming stage of a paradigm, knowledge management is the key towards seeking the performing stages of that particular paradigm, else the norming stage can be prolonged and suffer from trail-and-error procedures. Drucker (1998) presents knowledge management in a wide range of management perspectives. Implicit in his presentation are the following premises of knowledge management: (i) *categorisation* for the customisation of technical products, (ii) *challenging* the assumptions involved in decision-making, and (iii) *restructuring institutional settings* for knowledge-creation. Following Drucker, this paper recognises the roles of categorisation, decision-making and institutional reorganisation as fundamental components of knowledge management. Knowledge management in management science is an outcome of information technology. However, definitions and concepts in knowledge management have diversified. For instance, Nonaka (1998) presents metaphors, analogies and models as a methodology for knowledge-creation. Arguably, each of categorisation, decision-making and institutional reorganisation may be regarded as a paradigm, as depicted in Figure 4 and detailed below.

Customisation of design solutions within their paradigmatic context

Arguably, design is a paradigm and customised solutions mark its performing stage. The key for customisation of solutions is categorisation/classification/abstraction (but these are not exactly synonymous) and this, in turn, is the key for knowledge management. Categorisation is a stage that can be reached only through proactive research and development programs. Categorisation is the management of the differences in individual values and is therefore not spontaneous. The customisation of design solutions is reached through the following paradigm shifts:

(i) Arbitrary arrangements of rudimentary forms of some of the components normally exist in the pre-paradigm period but their selections do not offer any selective advantage, e.g. many doctrines of philosophy.

(ii) A particular arrangement of the components identified by trial-and-error procedures is selected when it offers a selective advantage, e.g. the selection and combination of observation and theorisation in reductive science.

(iii) The various arrangements of the components proliferate opportunistically, e.g. the creation of many disciplines of reductive science.

(iv) At the norming stage, studying the interconnections among the components reveals the inter-component synergy and creates strategic and intelligent capabilities, e.g. holism.

(v) At the performing stage, there emerges the capability for customised solutions based on purposefully re-arranging the components to comply with the conditions imposed internally and externally, e.g. the emergence of many living and growing products and systems, such as the Internet. The role of categorisation at this stage is irreplaceable. This is because categorisation can create different levels of resolution for a better understanding of the paradigm.

Decision-making

Decision-making has also undergone paradigm shifts. In the context of organisations, Drucker argues that opinion was the basis of decisions in the era prior to information technology and the outcome was opportunistic. Information technology made it possible to strengthen opinions by database analyses and to replace opportunism with strategies. However, in many organisations, substantial databases are used for control rather than creating new knowledge. In response to this, a new culture is emerging, where information is regarded as data endowed with relevance and purpose and knowledge is the machinery to transform data into information. Under the umbrella of knowledge management, there is proactive institutional leverage to challenge assumptions.

The issue of challenging assumptions/decisions may appear different in various disciplines but their paradigmatic stages are arguably similar. Challenging assumptions in science has undergone paradigmatic shifts, with the following paradigmatic stages:

(i) Prior to the formation of the paradigm of science, pure reason and pure observation and a host of shades of these two pure approaches emerged as mechanisms for verification, leading to many speculative doctrines of philosophy.

(ii) Reductive science was formed by challenging the assumption through a cycle of activities by comparing the scientifically obtained results with measurements to determine any need for a cyclic refinement of the assumptions.

(iii) In the systemic stage feedback mechanisms were introduced to many systems to regulate and control their performance. A whole range of other approaches was also developed for a better control and these include risk/value management, quality assurance and total quality management.

(iv) Many of the tools for challenging assumptions in a scientific framework have already emerged. However, the assumptions can be challenged if a framework is created, as discussed below, to continually create new knowledge and align the organisation with its environmental requirements. The role of categorisation cannot be overemphasised in this process.

Reorganisations

Reorganisation is a modern feature of many modern institutional arrangements. These arrangements were often formed during or after the Industrial Revolution. According to Drucker, the first modern enterprises were formed after the Civil War in the USA and the Franco-Prussian War in Europe (1861–5 and 1870, respectively). However, in the years 1895–1905, management was distinguished from ownership in Germany. In the years 1920–50, the command-and-control model of organisation proliferated worldwide, distinguishing policy from operations. Since the 1980s, knowledge management is challenging this structure, in which knowledge is replacing non-value-adding management units with alignments among goal-oriented specialists or knowledge-owners. The key features of the shifts are:

- Enterprises organised individuals under one institution towards the motivations of the owner and later of the management with little interconnection among the individuals.
- The command-and-control model ensured a one way flow of information.
- Information technology ensured a two-way flow of information but without any alignment.
- Knowledge management signifies a two-way flow: (i) goal-orientation among knowledge owners to align the organisation with the environment, and (ii) knowledge creation to ensure that the organisation can maintain the delivery of customised solutions.

Overview of knowledge management

Two of the three premises of knowledge management presented above are strikingly analogous to the postulates of reductive science. Reductive science breaks down the complexity into components and, similarly, categorisation breaks down a whole range of complexities into categories, where one category differs from the next by a generic differential or a step of differences. The assumptions in reductive science delineate the border between arbitrariness and science and therefore challenging the assumptions is the key for reductive science. Likewise, decisions in an organisational setting delineate between arbitrariness and knowledge and therefore knowledge management is a mechanism to firm up the decisions through data, information and a continual process of knowledge creation. Reorganisation, a premise of knowledge management, realigns the environmental requirements expressed through goal-orientation with knowledge creation but there is no analogy for this in reductive science since information in reductive science flows from the system to the environment.

The paradigm of institutionalisation

Institutionalisation is almost intertwined with science and with many systems and as such it is a paradigm, shifting. It can have many connotations and that for knowledge management is presented above. Institutionalisation in relation to science can be viewed from a number of perspectives, including educational establishments for the study of science, research into the creation of new science, learned organisations cross-fertilising practice and research, refereed journals and other forms of written communications, oral communications through conferences, evening lectures and workshops. Institutionalisation in relation to practice is also diverse and includes consultancy, contracting, governmental departments, agencies and research institutes.

Each of the above institutional arrangements is undergoing paradigm shifts. For instance, it may be argued that research organisations and methodologies represent an important part of the institutional arrangements for the creation of new science. Institutional arrangements for science are shifting. In the pre-science era, researchers were a handful of wise individuals who enjoyed wealth and freedom not enjoyed by everyone. As the paradigm of reductive science gradually removed many of the barriers normally associated with the pre-science era, more and more individuals joined the ranks of science and technology. At this stage, the development of science was still dependent on many individuals who tended to create organisational settings for their research. In the periods of systemic science, individual researchers tend to create partnerships with one another and with end users and the community.

COMMENTS

The presentation of the paradigm of science and its shifts largely substantiate the postulate given in this paper. In the previous section it was argued that the postulate offered spontaneous foresight but the phrase was acknowledged to be vague. The postulate of stages associated with any paradigm is, in fact, a depiction of foresight in science and this foresight is simply the emergent property of the postulate. The foresight emerges when a collective view is taken of the role of component in the shifting stages of a paradigm. At the forming and proliferating stages, man uses his intelligence in reaction to nature and therefore the outcome is opportunistic. At the norming and performing stages, man uses his intelligence to partially uncover better arrangements of the components and to partially catalyse better processes. In any case, the outcome did not exist before and what emerges as a results of these particular selections is purely an emergent property and spontaneous.

Also, the processes involved in performing stages are not spontaneous and must be created consciously. The outcome is a selection even though selected consciously and this is what makes paradigm different from evolution. It is argued here that science and technology are intertwined social and intellectual constructs through selecting many paradigms 'layer-by-layer'. At the forming and proliferating stages, a paradigm is evolution in action, where the remark by Dawkins (1999) is emphasised that 'evolution is blind to the future'; whereas at the norming and performing stages, the paradigm has a foresight with the following properties:

- the foresight is an outcome of its making processes and not fixed, and
- the foresight is spontaneous and will emerge as an emergent property.

The experience at the norming stage shows that enormous energy is invested on transforming the culture of 'doing things better' as a characteristic of the reductive science into 'doing things better as well as doing better things' as a characteristic of systems science. Doing better things is intimately related to knowledge management and the delivery of customised solutions. Experience shows that it gets harder from delivering a system as a workable arrangement of components to customised solutions but arguably systemic knowledge management can ease the situation.

This paper has not put enough emphasis on the pre-paradigm periods. It suffices to mention that this period was likened to the tip of an iceberg above water. In this period, researchers and entrepreneurs perceive the tip and intensify their activities. This culture of intensive activities increases the likelihood of finding one workable arrangement leading to the formation of a paradigm. Another issue not tackled by this paper is the post-paradigm period. The writer argues, without attempting to substantiate it, that the various customised solutions of a paradigm are capable of creating a new culture and of fermenting the conditions for the formation of new paradigms, with a finer resolution, although the resolution cannot be made infinitely fine. This is another philosophical issue that is not discussed here.

The ability to break down a complexity into its lower order building blocks is a focal point at the reductive stage of a paradigm (i.e. the forming and proliferating stages). The writer argues that the ability to challenge the assumptions is equally important and must not be overlooked. Reductive science devised simple cyclic reviews, often through a manual procedure. This simple framework was the foundation of objectivity in science. The writer is not aware of treating this issue as a scientific/philosophical issue and therefore presents his own interpretations of the subject. A paper is under preparation, postulating that truth and challenging truth are two intertwined paradigms. The strife in the formation of these paradigms goes back to pre-history but the success is not related to a single scientific discovery. In fact these paradigms are also shifting through stages but these are not discussed in this paper.

CONCLUSION

Dyson (1989) remarks that 'Science is not a monolithic body of doctrine. Science is a culture, constantly growing and changing'. The doctrine of paradigm presented by Kuhn in 1962 captures these changes in descriptive language. This paper revisits Kuhn's doctrine and uses the term paradigm as a concept to explain the changes in science and technology. Paper I presents a postulate on the formation of a paradigm associated with subsequent shifts through proliferation, norming and performing stages. It is shown that, following the pre-paradigm period, a workable arrangement of some of the rudimentary components of a 'would-be' paradigm is often the basis for its formation. After the formation of a paradigm, the various arrangements of its components are proliferated. In the pre-paradigm periods and during the forming and proliferating stages, the paradigm follows the law of natural selection and in this way the paradigm is evolution in action.

A paradigm in its norming stage is a conscious process for a better insight into inter-component synergies. At the performing stage, customised solutions are deliverable through systemic knowledge management by determining the arrangement of the components in a sociotechncial context, so that the products of the paradigm comply with the changes imposed by the environment. It is clear that, after the formation of a paradigm, the subsequent body of knowledge is not homogeneous but the shifts depict a roadmap with generic stages. This roadmap is referred to as the foresight of science. The information on the immediate future of this foresight is firmer than the information on the forefront of the foresight. The forefront of the foresight is still subject to natural selection.

Science is seen here as a layer-by-later selection of a whole range of paradigms. A particular problem area of science is more consolidated if its constituent paradigms are consistently at the same paradigmatic stage. Conversely, a paradigm formed in one field of science will shift laterally to the other fields but there may be phase lags between the lateral spread from one discipline to another and these lags act as barriers. Paradigm shifts can reveal some of these barriers.

This paper presents three dimensions to problem-solving, as follows: (i) using the concept of paradigm shifts as a roadmap for depicting generic developments, (ii) application of the systemic problem-solving methodology, and (iii) knowledge management. The intertwining of these dimensions is referred to as systemic knowledge management. The postulate on generic stages of paradigm shifts creates transparency among the various paradigms. It is further argued that systemic problem-solving is an integration of reductionism and holism. The concept of paradigm shifts is the main focus of Paper I and postulates that paradigms shift as follows:

- A paradigm is formed following the law of natural selection under spontaneous pre-paradigm conditions.
- It shifts through stages of proliferation, norming and performing through which spontaneity is reduced but not entirely eliminated.

- At the norming stage, the components of a paradigm become interconnected through two-way flow of information producing intelligence on existing conditions. A foresight also emerges towards performing stages to deliver customised solutions.

This paper outlined some of the aspects of knowledge management. Although no new methods are presented, it is argued that there are new emergent properties to be identified when problem-solving methodologies are refined. The core of this paper is as follows:

- The generic developments associated with systems can be identified through the concept of paradigm where their complexity is likely to be systemic.
- Each complexity may be decomposed into hierarchies through systems approaches.
- Problemsolving evolves through paradigmatic stages and at the systemic stage, knowledge management offers a new impetus.
- Arguably science is at the norming stage, which is a conscious process and can be expedited through systemic knowledge management.

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REFERENCES

Bertalanffy, L. von 1940 The organisation considered as a physical system; reprinted in *General Systems Theory*, Braziller, New York.

Boyd, R. 1992 On the current status of scientific realism. In: *The Philosophy of Science* (eds. Boyd, Gasper & Trout). MIT Press, Cambridge, MA, pp. 195–224.

Checkland, P. B. 1981 Science and the systems movement. *Systems Behaviour*, 3rd edn. Open University set book, edited by Open Systems Group, 3rd Edition, Harper & Row.

Dawkins, R. 1999 *The Selfish Gene*, Oxford University Press, reprinted in 1999, p. 8.

Drucker, P. F. 1998 The coming of new organisations. *Harvard Business Review on Knowledge Management*.

Dyson, F. 1989 *Infinite In All Directions*. Penguin Books, London, p. 10.

Khatibi, R. H. 1997 Hydraulic character of flood drainage systems Part 1: Hydraulic basis. *Proc. Inst. Civil Engrs. Wat. Marit. Energy*, 124.

Khatibi, R. H. 2003 Systemic knowledge management in hydraulic systems: II Application to hydraulic systems. *J. Hydroinformatics*. In press.

Kuhn, T. S. 1962 *The Structure of Scientific Revolution*, 3rd edn. The University of Chicago Press, Chicago.

Medawar, P. B. & Medawar, J. S. 1977 *The Life Science*. Wildwood House, London.

Nonaka, I. 1998 The knowledge-creating company. *Harvard Business Review on Knowledge Management*.

Open Systems Group (OSG) 1981 *Systems Behaviour*, 3rd edn. Open University set book, edited by Open Systems Group, p. 14. Harper & Row.

Shannon, M. A. & Antypas, A. R. 1996 Civic science is democracy in action. *Northwest Sci.* **70**(1), 66–69.

Sigmund, K. 1993 *Games of Life*. Oxford University Press, Oxford, p. 5.

Tuckman, B. W. 1965. Development sequence in small groups. *Psychol. Bull.* **63**, 384.

Vickers, G. (1981) Some implications of systems thinking. *Systems Behaviour*, 3rd edn. Open University set book, edited by Open Systems Group. Harper & Row.

Ziman, J. 1991 *Reliable Knowledge*. Cambridge University Press, Cambridge.