Systems engineering methodologies, tacit knowledge and communities of practice

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Published on: 01 Apr 2005 - Ai & Society (Springer-Verlag)

Topics: Tacit knowledge, Knowledge engineering, Knowledge value chain, Personal knowledge management and Knowledge integration

AI & Soc (2005) 19: 159–180
DOI 10.1007/s00146-004-0312-3

ORIGINAL ARTICLE

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Received: 10 March 2004 / Accepted: 10 August 2004 / Published online: 30 September 2004

Abstract In the context of technology development and systems engineering, knowledge is typically treated as a complex information structure. In this view, knowledge can be stored in highly sophisticated data systems and processed by explicitly intelligent, software-based technologies. This paper argues that the current emphasis upon knowledge as information (or even data) is based upon a form of rationalism which is inappropriate for any comprehensive treatment of knowledge in the context of human-centred systems thinking. A human-centred perspective requires us to treat knowledge in human terms. The paper sets out the particular importance of tacit knowledge in this regard. It sets out two case studies which reveal the critical importance of a careful treatment of tacit knowledge for success in two complex, technology-driven projects.

Keywords Human-centred systems · Systems engineering · Methodologies · Knowledge

1 Introduction

Knowledge and knowing are fundamental to human existence and set us apart from other species. With the rise of ever more sophisticated information technology systems, engineers concerned with how notions of knowledge impinge upon technology design and development have primarily concerned themselves with how human knowledge can be codified, labelled and stored in an explicit and easily processed form. For example, disciplines such as requirements engineering provide approaches by which human knowledge that impinges upon the technology project can be made explicit and expressed in a formal language. This perspective has lead to important advances in areas such as database systems and artificial intelligence, and gave rise to systems engineering methodol-

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ogies such as SSADM, UML/UP and specification languages like Z. It has its roots in the philosophy of early enlightenment thinkers such as Leibnitz and more recently in the work of people such as Weizenbaum.[1] Since artificial intelligence enthusiasts first proposed neural networks in the 1950s, researchers have grappled with the problem of making soft- and hardware machines intelligent and knowledgeable. Whilst this research trajectory has been extremely important for the development of new generations of computer technology and related engineered systems, it has often lead to a confusion in the literature between notions of 'knowledge' and, on the other hand, theories of complex data structures.

The very idea that human knowledge can be stored in, and its processing replicated by, software machines ignores three thousand years of philosophical inquiry into the nature of knowledge and what it means to 'know'. This paper attempts to re-centre systems engineering knowledge research around the human as knower. In this paper, knowledge remains intrinsically human and the human and her knowledge are not separated. Instead, the paper explores how human knowers can be folded into a human-centred systems development and deployment process. It shows how the careful management of human knowledge as human knowledge is central to the success of technology-driven projects.

The paper firstly characterises current problems with the assumptions, which underpin many of the technology development and deployment methodologies currently in use. Secondly, the paper provides an overview of tacit knowledge exploring the key dimensions of tacit knowledge as set out in the recent literature. Thirdly, the paper offers two very different case studies in order to explore tacit knowledge in the context of human-centred approaches to technology deployment. The two stories expounded in these studies are each rooted in very different socio-economic, cultural and technological contexts. The juxtaposition of these two cases serves to highlight the universality of the principles set out in the paper. More importantly, it demonstrates the critical importance of tacit knowledge support processes for technology-driven projects.

[1]The perspective of a unified, reductionist logical modeling of reality addressed in this paper can be traced to the very beginnings of the enlightenment in the seventeenth century, and even to ancient Greek Platonism. Descartes was particularly concerned with creating a unified method by which to build a knowledge of the universe. Later Leibnitz set out to create and understand an exact language through mathematical formalisms. Many of these early Enlightenment thinkers sought to explore Divine perfection as they understood it (Leibnitz 2003). God had created a perfect machine we call the universe or nature. Through mathematics and a reductionist, empirical science Divine perfection could be explored. In Leibnitz, a core idea is that, for each individual, there is a complete notion knowable only to God, from which is deducible all the properties possessed by the individual at each moment in her history (Blackburn 1994). The foundations laid by people like Leibnitz, Berkeley and many others provided a basis for computational logic, and the rise of the computerised information processor. Their work ultimately lead to the development of mathematical approaches which in turn lead eventually to the 'reasoning machine', artificial intelligence, database systems, sophisticated programming languages and systems development methods. In these rationalisms the reduction of complex language structures to precise mathematical formalisms provided a means by which relatively primitive electronic circuits could process data according to very complex reasoning. This also lead to enormous progress in areas such as computational linguistics and natural language processing (e.g. Weizenbaum 1966; Bloc 1980).

2 The logic of methodology

Since the 1950s research in organisational behaviour has shown that logical rationality is often untenable as a comprehensive theory of human knowledge processing. It is often difficult to interpret rationally what is happening or what has happened in technology-driven projects and to make sense of the new realities that these technologies introduce (Stapleton 2001; Boland and Day 1989). The world is often so complex that it defies us to describe or understand it with our logical models, diagrams and documentation. At best, traditional methodological paradigms and metaphors represent a narrow view of information, and knowledge, in human settings. In spite of this, most systems development methods continue to require both the systems analyst and user to determine how information has been used, is currently being used and will be used in the future. This enduring perspective has been associated with a 'functional rationalism' in which technologists and systems engineers use methodologies in order to reduce human knowledge to a functional, machine-based language.

2.1 Functional rationalism

Functional rationalism, so prevalent in engineering and technology design methodology, is a legacy of a long and fruitful positivistic tradition within engineering and science which can be dated back as far as Descartes in the seventeenth century, and more recently to the philosophies of western European scientists such as A.J. Ayers (c.f. Ayers 1936), later adapted into various engineering methodologies, notations, architectures and other formalisms (e.g. see Chen 1976, 1980; Zoetekouw 1991; Zachman and Sowa 1992; Lewi et al. 1992; Dennis et al. 2002). Many of the activities that attempt to invoke technology-driven change in organisations are based upon functional rationalism (Stapleton 2000; Siddiqi 1994). It is possible to trace current perspectives to a Taylorist position vis a vis work design. In Taylor's management approach, humans are seen to be cogs in the organizational machine. For Taylor, human organisation was an engineering problem where the clear specification of tasks, the work methods and the work flow between individuals determined the most effective work designs (Cummings and Worley 1997). These work designs could be modeled according to precise, mathematical formalisms with each task allocated a certain amount of resources, time span etc. with which the worker completes the task. Time studies and other techniques could then be used to determine the exact resource requirements, whilst industrial engineers, analysts and others determine the best way to complete the overall process. It is readily apparent that this perspective relegates humans to the machine level, and the unique, inherent ability of humans to produce and apply knowledge for the benefit of the organization is not recognized within the process itself (Cooley 1987). This has become particularly apparent as the pace of organizational change has accelerated, and the ability of humans to adapt and learn has come to the fore. In Taylor, humans are passive slaves to the machine ideal. In change-management research organizations are seen as constantly in flux and undergoing almost continuous transformation (Cameron and Green 2004). Human flexibility and adaptability is critical to success in change initiatives and emphasises an action-orientation in which humans must become innovators: here the worker is creative and adaptable. The mechanistic approach embodied in Taylor and other similar perspectives has been deeply criticised by much of the organisational and systems literature in recent decades as an entirely incomplete and often ineffective way of creating a productive and effective organisation (c.f. Vickers 1973; Mintzberg 1973; Handy 1981; Morgan 1986; Steers and Black 1994). However, it still remains an important and prevalent metaphor in modern firms (Moss-Kanter 1994; Cameron and Green 2004).

Most systems engineering methodologies are based upon functionally rationalist premises. These premises have dominated systems engineering research and practise, a fact which is well documented elsewhere (Stapleton and Murphy 2002; Myers 1995; Klein and Hirschheim 1991). As we see in the last paragraph, the machine-based view embodied in functional rationalism relies upon an ability to reduce organisational activity into a set of rationalistic descriptions, which can be understood in logical terms. Specifications of business processes and/or software programming are constructed from these functional descriptions and resulting systems and processes embody the new concepts that management wishes to introduce into the organisation (Stapleton and Murphy 2003).

It has become apparent that traditional thinking regarding the creation and deployment of advanced technologies requires some revision. One major area of opportunity for progress is in the theory of technology development as a means by which new organisational realities can be created (e.g. see Strina and Honecker 2003; Brandt and Cernetic 1998). Instead of regarding technology development as the creation of new information technology artefacts, it is becoming evident that, in many cases, it has more to do with social reconfiguration and transfer (and challenging) of knowledge and assumptions in order to create a new social space (Moreton and Chester 1999; Stapleton 2000).

A major criticism is that the specific local context in which techniques and technology are deployed is ignored, leading to major problems on the ground (a good example is Cronk 2000). The functionally rationalistic approach, it is argued, assumes that one solution can fit all, that there is a methodological 'silver bullet' (Siddiqi 1994).

Post-modern approaches such as socio-linguistics and ethno-methodology have been strenuously advocated in Goguen (1993) and Goguen and Linde (1993). Wood and Wood-Harper (1993) argue that the rationalistic tradition within systems engineering methodologies have been reinforced by aspects of the requirements capture process. For example, demands for early and 'correct' specifications, the lack of notations for representing problem domain objectives and, perhaps most importantly, narrow, variety poor, one-way communication with the decision maker all reinforce and are based upon positivist thinking. A number of methodologies have appeared which attempt to overcome these difficulties by taking social issues into account (e.g. Checkland and Scholes 1990; Checkland 1999). However, a simple recognition that many requirement engineering activities are social is not enough. Advice such as 'get the support of senior management' and 'involve the end user' are inadequate to guide the development of complex technological systems (Hirschheim and Newman 1991).

The pre-eminence of functional rationalism in technology development and deployment methodologies ensures that the deep structures of 'knowledge' and 'knowing' are sometimes excluded from key discussions associated with the technology development and deployment process. This is particularly true regarding the modern emphasis upon knowledge processes and knowledge management systems. The very definitions of 'knowledge' in much of the science and technology literature belie a continuing over-concern with technological imperatives. For example, standard undergraduate course texts on knowledge management systems tell how knowledge management systems can capture essential knowledge through codified knowledge elements in complex decision making scenarios (e.g. Turban et al. 2001). In these approaches, knowledge is viewed as a complex data set, which, by utilising expert system processors, can provide the necessary information for process improvement consulting activities (for example). Here, 'knowledge' can be 'captured' using sophisticated diagramming techniques and subsequently 'stored' in information structures (essentially complex database structures). Reasoning in this way leads technologists to 'abstract' the 'key elements of reality' in order to obtain the information needed to construct the complex models. Indeed, this approach to knowledge capture is often found in both 'soft' and 'hard' systems approaches alike (Stapleton 2000). Too often the assumption is that essential knowledge is something which can be expressed and made explicit in functional, logical, models, which in turn can be reconfigured into functional specifications (a criticism levied at applications of Checkland's SSM methodology by Flynn 1992 and Stapleton 2001). Requirements engineering, a branch of systems engineering methodology concerned with capturing the users needs, has been primarily concerned with approaches which serve to clarify, simplify and make coherent the knowledge and decision making processes involved in organisational information processing. However, research into how organisations process information shows inherent ambiguities in the meanings, terms and decision-making processes (March and Olsen 1979; Weick 1995). These ambiguities and uncertainties are part of human information processing, and it is not possible to reduce or simplify them away without losing core meaning, and misunderstanding key aspects of the organisations behaviour. This has created deep problems within requirements engineering leading to many systems failures (Weick 1995; Stapleton 2001; Halpin and Stapleton 2002)

On closer inspection this perspective of knowledge as complex data structures is extremely unsophisticated, and is a product of the functionally rationalist perspective applied to the concept of knowing. It leads to the globalisation of notions such as 'best practise' in which one industry (such as the consultancy industry), society or culture can determine what is best for an entirely different industry, group or culture. It does not recognise that tacit knowledge is inherent in those who know what they are doing, who best understand what needs to be done, such as the skilled craftsperson and engineers whose stories are set out in the case studies in the second half of this paper. It ignores the inherent ambiguities, deep structures and cultural located-ness of knowledge itself. Human knowledge is not dislocated from its application domain and cultural context. Instead, human knowledge and decision making processes are deeply embedded in how we see ourselves and in our identity and sense of who we are (Weick 1995).

This paper argues that knowledge is far more than can be set out in codifiable form. It asserts that the functional rationalism of the knowledge management system is actually a complex data base in a rather thin disguise and does not consider the true reality of how knowledge works in practise. This paper shows the importance of the deep structures of knowledge and knowing for systems engineering. It reveals the critical importance of tacit knowledge forms, and through two case studies, indicates ways in which this tacit knowledge can be diffused in complex technology-driven projects.

But the paper goes further than this. In essence, this paper argues for a return to a deep philosophical debate amongst systems engineers and related disciplines concerning what is knowledge, what does it mean to 'know' and how can our academic and professional activities support the acquisition and application of knowledge.

The next section sets out the importance of tacit knowledge for human-centred systems approaches. This provides a theoretical basis for the discussion of two very different case studies of tacit knowledge transfer. The discussion and the case studies show the deep difficulties with a functionally rationalist perspective when it is applied to technology-related knowledge, and, in particular, to projects which focus upon knowledge as codifiable elements. Instead, we find that knowing is a deeply human activity and that the effective management of knowledge as part of a human-centred approach, is critical for the success of technology-driven projects.

3 Tacit knowledge in human-centred systems

Tacit knowledge is defined as a body of unspoken intelligence (Baumard 1999) and an 'art hidden in the depth of the human soul' (Polanyi 1961). In Polanyi knowledge is an activity best described as a process of knowing typically based upon a knowledge tradition. It is derived from experience and is embodied in local practices and communities (Wong and Radcliffe 2000). Polanyi (1961, p. 93) defines it as 'knowing more than we can tell', referring to how we can know how to perform a certain task, but we cannot easily explain to another person(s) how to successfully perform that task.

Tacit knowledge is non-quantitative and dynamic. It is proprietary to the individuals concerned, and is continually being built upon and learnt (Howells 1996). Tacit knowledge is inherent in peoples' practice and know-how. It can only be articulated and transmitted through adept execution and, for example, through a learning cycle that involves demonstrating and emulating the 'teacher' (Fleck 1997). Furthermore, tacit knowledge is conveyed through the informal take-up of learned behaviours and procedures (Howells 1996; Roberts 2000). Therefore it is not possible to transfer tacit knowledge easily or directly, as tacit knowledge requires the individual to make changes to their existing behaviour (Howells 1996).

The non-communicability of tacit knowledge ensures that it is seen as an invaluable source of competitive advantage as it is unique to the particular context in which it is found (Quinn 1992). It is this reservoir of knowledge that the firm strives either to articulate or to maintain if it is to avoid imitation (Baumard 1999). If imitated the organisation or community would loose its advantage in the competitive market. However, to take advantage of tacit knowledge can also cause problems for organisations. The difficulty lies in retaining and leveraging such unstructured knowledge, which can easily seep out of the organisation if, for example, employees leave or are moved around within the organisation (Wong and Radcliffe 2000).

Alic (1993) describes how tacit knowledge is difficult to state precisely and cannot be explained or justified. From this it can be deduced that tacit knowledge is not easily distributed. For example, Wong and Radcliffe (2000) have stated that tacit knowledge consists of elements that can be successfully transferred via a demonstration process that is carried out by face-to-face contact between the user and the analyst. Indeed, an extensive literature argues that tacit knowledge can only be made known to other people through direct contact and socialisation (Baumard 1999; Fleck 1997; Grant and Gregory 1997; Howells 1996; Nonaka et al 1996; Roberts 2000; Wong and Radcliffe 2000; Cohen and Levinthal 1990; Polanyi 1961).

It is self-evident that any model of organisational knowledge must consider tacit knowledge. Therefore, as human-centred systems are deeply concerned with human-knowledge-in-action within an organisational context, it is important that tacit forms of knowledge be incorporated in any model of human centred-ness. The next section reviews the inherent link between human-centred-ness and knowledge centred-ness. The critical importance of non-codifiable, tacit knowledge is further elucidated leading to an argument which sets out the critical role of knowledge networks in human-centred systems.

4 Human-centred systems as 'knowledge systems'

In the 1980s and early 1990s there was a significant debate around the 'factory of the future' in which factory spaces would be largely unmanned environments comprising robots, information technology and other automated technologies. In this perspective, the primary role of humans was to provide indirect labour for the industrial/business process. As a counterpoint to this movement, an alternative view gained momentum which was more anthropocentric (Badham 1991). In this perspective the factory was to be a socio-technical space designed around human skill. Researchers in this sphere argued that the introduction of flexible and integrated technologies in an increasingly uncertain manufacturing environment would result in a general increase in workers' skills, responsibility and teamwork. Consequently, research projects were conducted which examined the affects of a human-centred approach in order to ascertain the extent to which such an approach could deliver a more effective socio-technical manufacturing system. The outcomes of these projects were very impressive. In the largest project of its kind in Europe, Esprit 1217, on-time delivery was increased from 31 to 86%, manufacturing lead time approximately halved and work in progress reduced by 45% with significant reductions in overtime. Surprisingly little has been done to replicate this approach across the manufacturing sector as a whole and the modern manufacturing facility has not universally adopted human-centred techniques. Furthermore, most research into modern manufacturing systems remains mechanistic in orientation, and the principles of human-centred-ness have not gained widespread recognition in either higher education curricula or engineering practise. This paper provides further evidence as to the importance of human-centred-ness to technology-driven projects across a very diverse range of activities. It calls upon the research and higher education community to significantly increase activity in this space, particularly in terms of human knowledge and knowledge networks.

The human-centred approach advocated in this paper focuses upon the activation of deep-seated knowledge as a key to the success of technology-driven projects. It recognises the limitations of functional rationalism and the need for a new theory of systems engineering which can inform human-centred approaches to technology-driven change. In order to incorporate 'knowledge-in-action' in a theory of human centred systems we need first to explore the relationship between stimuli and action. In functional rationalism, stimuli, questioning, decision making and action are intimately linked, a view which is unsupported by evidence of social decision making (March 1999; Feldman and March 1981; Weick 1982, 1985, 1995). Consequently, we also need a theory, which does not primarily focus upon the importance of decision to action, but instead incorporates tacit forms of knowledge and the ways in which these can inform action. In tacit forms of knowledge (as opposed to the codifiable knowledge stored in databanks)[2] the link to formal decision making is unclear. Instead, people act as they make sense of their ambiguous and complex life-world. This truism has been recognised for over 20 years in the organisational decision making literature (March 1999; Cohen et al. 1979) and has lead to a re-evaluation of how people actually use knowledge in the workplace and in their interactions with each other. In order to address this particular issue an approach is needed which incorporates community level sensemaking through which tacit knowledge can be diffused in such a way as to support the technology project whilst maintaining a human-centric perspective. The approach recommended here incorporates sensemaking approaches as set out elsewhere (Stapleton 1999) but focuses more upon the creation and support of communities of knowledge, called here knowledge networks.

The idea of knowledge networks finds its root in studies into the development and operation of 'communities of practice'. Research on communities of practice (Wenger 1998) has stressed the role of knowing in the pursuit of valued enterprises in the world. Wenger (1998, p. 46) argues that practice supports a communal memory that allows individuals to do their work without needing to know everything. In Wenger's model, the knowledge of a practice community is fluid, negotiated and evolving. Understanding and using this model requires a 'rich picture' of the social context and dynamics of knowing actions. Rogers and Kincaid (1981) similarly stressed the need to understand the flow and structure of personal influence within communities in order to focus interventions. The social context of 'knowing' in a community of craft practice may also engage tacit but strongly defended shared aesthetic and even ethical considerations (see Smith 1992). The personal influences of people in these knowledge networks coupled with the emphasis upon the social context in which knowledge is affected reminds us of the role of explicator expanded

[2]Indeed, it is more appropriate to call this knowledge 'information', for it does not fulfil the criteria commonly associated with knowledge (Roderick 1993).

upon elsewhere (Stapleton 1999), or the conceptual therapist in situations where it is difficult for people to make sense of the complex circumstances in which they find themselves (Weick 1982). It is possible to see how they support elements of sensemaking theory, whilst adapting it for the complex dynamics associated with communities of practise as mutually-supportive knowledge networks.

To Wenger, practice is tied up with 'doing' in a historical and social context which gives structure and meaning to action ''...practice is always social practice...'' (Wenger 1998, p. 47). This is not a new idea[3], and the dynamic complexity of the role of tradition in practice cultures was very well articulated by the Scandinavian 'Dialogue' school in the 1980s. Smith (1992) showed how reference to shared but unarticulated tacit knowledge within practice cultures facilitated the communication of complex ideas. In a very real sense, such cultures are 'knowledge networks'.

The human-centred concept of 'knowledge networking' emphasises the transfer of tacit knowledge through a combination of 'learning by doing', human mediation, group working, social networking, personal dialogue, and through personal contacts, seminars, conferences and workshops. Social and professional actors act as mediators to transfer both codified knowledge and contextual tacit knowledge within varied social and professional settings (Gill 1997, 2002). Where traditional rites of passage, apprenticeships and similar socio-cultural mechanisms once played a central role as means of learning, diffusion of skills and the transfer and emulation of knowledge, it is increasingly possible to enable situationally appropriate knowledge networks facilitated by imaginative application of information and communication technologies (ICTs).

The design of knowledge networks must take into account the fact that they are dominated by implicit social relationships and structures which may or may not be hierarchical in nature. Networks which serve 'here-and-now' needs may nevertheless include 'legacy' components related to problems or social practices which have long since ceased to exist. Each node in a network comprises knowledge embodied in people, and the nodes are linked by social practices and constrained by social, temporal and spatial factors. Each node can serve as a resource to other nodes. Networks can intersect and they may do so at more than one node. Local community needs will be served by different networks than those which address problems on a global scale, but they may nevertheless have access to the wider networks. Knowledge Networks are therefore complex, heterogeneous and distributed, and their knowledge must be seen as 'process', not as 'content'. Indeed, any attempt to isolate specific components is likely to fail. Brown and Duguid (1999, p. 106) note the need to ''...think of knowledge less like an assemblage of discrete parts and more like a watercolour painting. As each new colour is added, it blends with the others to produce the final effect, in which the contributing parts become indivisible...''.

[3]It was clearly foreshadowed in some of the earliest writings of Karl Marx—see, for example, the German Ideology.

5 Summary

The shift away from a static mentalist and individualist textbook definition of knowledge as 'justifiable true belief' and towards a socio-dynamic view of knowledge (or, rather, of 'knowing') has profound implications for the design of information systems. To intervene effectively and positively in a knowledge network or community of practice requires informed action at a variety of levels. This implies understanding the social dynamics of knowing, rather than simply attempting to codify accessible propositional elements of knowledge.

The remainder of this paper sets out two very different case studies in which management of the engineering space as a 'knowledge system' was crucial. By juxta-positioning these two stories, the authors draw the reader's attention to the inter-cultural, primitive and essential importance of the possibilities opened up by the theory set out in the preceding section.

6 Case studies in knowledge and technology

This section explores two case studies conducted by the authors. These studies describe entirely different human contexts. In one the experiences of a community of artisans in northern India is explored. In the second the experiences of people in an electrical engineering manufacturing plant is described. These two communities are very different in terms of their cultural, social and economic context. However, by setting the two stories against each other, it is possible to see how each case dealt with the introduction of new technologies and illustrates the importance of addressing issues associated with tacit knowledge in each context. The stories serve to demonstrate how, in two very different circumstances, the careful management of tacit knowledge was key to the successful introduction of new technology. Each case provides lessons for engineers and technologists trying to come to grips with the management and support of organisational knowledge, and for those who wish to ensure that new knowledge is created without obliterating or devaluing 'old' knowledge. Each story illustrates the importance of moving beyond a functionally rationalistic paradigm, and returns the reader to the heart of debates about knowledge and knowing: the human context. Together the case studies reveal both the locally specific nature of tacit knowledge, as well as the importance of the universal principles associated with human-centred approaches to technology deployment.

6.1 Case study one: interventions in traditional Indian brassware manufacturing in West Bengal

The first case study sets out the experiences of a community of artisans in West Bengal. It explores what happens when ancient technologies and processes are reconfigured. It illustrates the deep value of ancient knowledge and shows how tacit knowledge support processes are often critical in such contexts.[4]

[4]For more information on Indian artisans see Welch (1986).

6.1.1 Background

This case study emerged from the EU-India Cross-Cultural Innovation Network Project, in which one of the authors[5] was a partner for four years from 1999–2003. Coordinated by The University of Brighton (UK) in partnership with Indian partners in Delhi, Punjab, and Gujarat, and European partners from Wales, Germany, Denmark and Italy, the project examined ways of networking knowledge across cultures in order to establish and evaluate links between research and development, work processes and a wide range of enterprises.

6.1.2 The context

The ancient craft of dhokra (*cire perdue*, or *lost wax*) metal casting was once widespread throughout India, but is now restricted to a small number of groups of traditional artisans in widely dispersed locations. Although there is a small but increasing demand for dhokra work from urban Indian families, as well as in the tourist trade, the craft is threatened with extinction. Most of the remaining dhokra communities are extremely poor, and their economic condition has caused many families to leave the craft to find waged employment in local manufacturing centres or in metropolitan centres such as Kolkata (Calcutta).

One significant nucleus of the craft exists among related groups of families in Bikna Village (Bankura) and nearby Dariapur, in West Bengal, India. These communities have been the subject of an action research project initiated and coordinated by the Indian CSIR (Council for Scientific and Industrial Research) agency NISTADS (National Institute for Science, Technology and Development Studies). It involved replacing an ancient traditional but inefficient metal-foundry technique with another which is almost as ancient but more efficient. The impact of this apparently simple change has been both profound and rapid, not only on the dhokra practice itself, but also on the material prosperity, self-esteem and creative confidence of the artisans (Smith and Kochhar 2003).

6.1.3 The problem

Beautifully adapted to the conditions of a original nomadic lifestyle abandoned many years ago, the dhokra technology had not adapted to the circumstances of a settled way of life. The failure of the Bankura Dhokra Karmakars to modify their technology probably contributed to their creative and economic decline over the past 50 years.

The traditional practice, which apparently goes back to the very dawn of metalworking, involved creating a mould by building a wax model on a clay core. The wax model is then coated with layers of clay to form a mould bearing a detailed impression of the model. If the wax is replaced by molten metal, the casting will show all the detail of the original model.

The traditional casting process involved building a crude furnace in a convenient open space, simply using loose bricks. The fire was made using cowdung and bought charcoal. Completed moulds were laid in the fire, with the cup downwards. When the mould was judged to be ready, it was removed from the

[5] For more information on this project see Smith (2002).

fire using tongs or a pair of green sticks. It was inverted, so that the metal cup was at the top, allowing molten brass to run down into the mould space. The process was wasteful of fuel and led to the complete loss of the modelling medium (either beeswax or a natural resin called *dhuna*). In the old lifestyle context of nomadic forest-dwelling, this would not have mattered, since the natural products were readily at hand. In the new context, of settled village life where raw materials had to be bought, the practice was economically disastrous.

The story of the Bikna dhokra craftspeople took a different turn when NISTADS became involved on their behalf. Funding was secured for Bengal Engineering College to design and develop a fuel-efficient permanent furnace under the management of Dr. A.K. Mukopadhyay, NISTADS resident scientist in Bankura. The new technology was enthusiastically adopted by Netai, a brazier from Petrasayer in Bankura District. NISTADS helped Netai to obtain a bank loan to modernise his facilities. He was subsequently able to obtain substantial production orders for cast brassware: a fact which was well known to the Bikna artisans.

However, despite this knowledge, and despite Netai's obvious prosperity, the Bikna families made no move to adopt the new technology. Although this could possibly be seen as laggard conservativism, a field visit in November 2000 by David Smith and Rajesh Kochhar used focus groups and camera interviews to reveal a much more complex state of affairs. The issue was not one of inherent resistance to change per se, but rather on the technocentric focus and the lack of attention to knowledge dynamics during the first attempt to change working practices. In these interviews it became clear that three primary factors were critical to a successful technology-driven project.

Firstly there was the issue of poverty. No detailed study had been carried out of the micro-economics of dhokra production at Bikna, but such evidence as there was pointed to the fact that the nett money earnings of the artisans were very low indeed. They could not raise the finance to pay for a permanent furnace except by borrowing from a local moneylender at interest rates of around 2% per day.

Second was the question of the sociodynamics of the craft. Despite his evident prosperity, Netai was not regarded by the bulk of the practice community as a good role-model. His craftmanship was not admired in any case, but his location in Petrasayer, some hours' journey from Bikna, put him outside a tight-knit circle of closely related families. He was simply not part of the relevant knowledge system.

A third, and perhaps decisive, factor concerned the extent to which the Bikna artisans' sense of identity was and is invested in the integrity and status of their craft. Netai's success ultimately rested on the abandonment of the dhokra craft as such. Although Netai still made dhokra items to order, the bulk of his income now came from the mass-production of low craft-content industrial items. But the identity and self-esteem of the artisans of Bikna was deeply invested in their craft, and the core group of families at Bikna were deeply committed to dhokra making. Any change which effectively meant the death of the craft was almost unthinkable.

It was clear that the solution lay in adopting a human-centred collaborative design approach. NISTADS immediately initiated a project to develop an efficient furnace for Bikna village using the local knowledge network. A meeting was arranged with Juddha and Mahdav Karmakar, two of the most senior and highly respected artisans in the village. The object was to collaborate with the craftsmen in achieving a furnace design which would not only be technically appropriate, but where there would be a sense of ownership. An experimental furnace was built in Bikna during December 2000. NISTADS agreed to finance the development, but made it a condition that the furnace should be a community resource, rather than the property of a single artisan or his immediate family.

It was expected that the introduction of a new furnace technology would catalyse major changes in the dhokra craft at Bikna. What was not anticipated, however, was the speed and extent of this change. The advantages of the new furnace were so apparent to the Bikna artisans that the old traditional way of doing things was changed within the space of a few months. But whereas it had been anticipated that take-up of the new furnace would follow a classic technology transfer profile, the new furnace was adopted almost immediately by all of the families. One ingenious '*bricoleur*' discovered that it was possible to run a (rather ramshackle) lead from a mains point to drive an electric fan which could be used to speed up firing of the furnace. The arrangement had to be seen to be believed! Completely unexpectedly, the inefficient 'nomad' furnace was relegated to the secondary role of pre-firing charcoal for charging the new furnace heating scrap brass (this makes it brittle and easier to break up), and, interestingly, for baking the moulds.

The introduction of the new furnaces has had an immediate beneficial impact on the output of the better artisans. It is now possible to maintain effective control over the casting of artefacts containing relatively large amounts of brass. New products have been created, such as the 'polybonga' (based on a popular terracotta form). This has encouraged a renewal of creative confidence, and craftsmen like Dhiren Karmakar have begun to develop quite stunning works of original artistry. Equally importantly, however, they are able to concentrate once more on the quality of their products. They see this as more important than developing new products. Dhiren is happy making the traditional dhokra repertoire, and believes there is a market for it if high quality can be maintained.

6.1.4 Developing a knowledge archiving strategy

The success of the new furnace introduced a new problem: that of the status of the now-redundant tacit knowledge associated with the previous craft practices. The Bikna artisans embody countless generations of knowledge, and this knowledge is part of the cultural heritage not only of India but of the world. Whatever direction the craft takes in the future, it would be tragic if all this knowledge and the accumulated wisdom of millennia were to be lost. The problem is the extent to which this can be documented, archived and communicated. Like most traditional craftspeople, the dhokra artisans of Bikna have no formal system of apprenticeship: craft training as such does not exist. The craft is, to coin a phrase, 'learned by being'. Children in Bikna grow up in an environment where the dhokra craft is everywhere around them. Every spare corner of the village is taken up by drying moulds or artefacts in various stages of preparation, and the routine of the craft is part of the daily rhythm of the village. There has never been any need for a formal exposition of procedures other than is exemplified continually and socially. This makes their knowledge very vulnerable. As Polanyi (1958) observed "...an art which has fallen into disuse for the period of a generation is lost...". The complexities faced by this Indian community could only be made sense of through the development and deployment of an appropriate technology AND a knowledge network through which explication could be assured. The community-level sensemaking support processes ensured that key tacit knowledge was leveraged, whilst the new technology so critical for the economic survival of the community was adopted effectively.

As Smith and Hall (2001) had previously demonstrated, multimedia technologies make it possible to develop adequate representations of skilled performance mediated by the artisan him- or herself. Particularly valuable in this respect is the capacity of multimedia systems to use a full range of modalities of description, including video, sound, still image, conventional text and technical diagrams. In combination with so-called 'naturalistic knowledge engineering' (Bell and Hardiman 1989), this technology makes it possible to present very complex information in a variety of formats and contexts.

As stated in an earlier section, 'knowledge engineering' is conventionally associated with the formal explication of procedural knowledge through the construction of complex rule-driven 'expert systems'. However, in this project many practical aspects of skilled performance were simply not amenable to complete formal explication. This is typical of tacit knowledge. It was not possible, therefore, to create a set of rules, which fully determined the practice domain. The fundamental task was, therefore, to capture and represent tacit knowledge in a way that could be interpreted and assimilated in appropriate practice community contexts. In addition, it was essential to do this in a way that did not interpose layers of translation and re-interpretation.

The development of a multimedia knowledge archive for the Bankura dhokra makers is still in progress, but a considerable body of digital video, sound and still images has been accumulated and catalogued. The domain name 'bankurahorse.com' was purchased and an initial holding web site has been specifically designed to facilitate access across the low-bandwidth systems typically installed in India. The people of Bikna village are delighted by their 'dotcom' and are continuing to contribute to the growing knowledge base.

6.2 Case study two: the introduction of a computer-aided design (CAD) system into an electrical engineering manufacturing site in Ireland

In the Bankura case study, we saw an attempted technology transfer failing until it was re-conceptualised as a human-centred intervention in an established practice culture. On the surface, the world of the people of West Bengal is a long way from the realities of an electrical engineering facility in the Republic of Ireland. However, the following case study will show how the appropriate management of the tacit knowledge that resided in the very experienced engineers who were close to retirement, ensured the success of a particularly sensitive technology. We shall see that, like the people of Bengal, the engineers were also a knowledge network which needed to be carefully managed if the knowledge was to be successfully retained during the introduction of the new technology. In this case the process of engineering design is highly knowledge intensive. By focussing upon the tacit knowledge present in the organisation, management was able to ensure that, instead of devaluing (or even removing) the knowledge, it was incorporated into a new social process that arose on foot of the technology implementation project. It again highlights the importance of treating the introduction of new technology as a context for the creation of a new social system, and highlights the critical importance of a human-centred view.

6.2.1 Background

Company X is a large multi-national operating electrical engineering manufacturing site in the Republic of Ireland. The manufacturing site studied here employed approximately 150 people in the manufacture of electrical products for the European market. The production and engineering processes at the plant involved some of the most advanced automation systems around, and the business was run using enterprise resource planning systems, an advanced data collection system and robotics. The production facility is heavily unionised and has been in operation in Ireland for 40 years, experiencing industrial relations difficulties from time to time, which were often associated with the introduction of new technology.

6.2.2 The context

A study into the organisational impact of complex technological systems, explored the experiences of an engineering group in this firm who introduced a new CAD tool. Some of the engineers working in the facility were there since the facility was opened in the 1950s. Consequently, there was a very large body of tacit knowledge within the group. This was recognised by the personnel/manufacturing resources manager who was ultimately responsible for the change process, of which the introduction of the new CAD system was one component. This manager, D, had worked for years as an engineer at this firm, and then moved over to personnel. One interviewee told how: "His predecessor had spent years in and out of the labour court. ...The companies position was that you must pay in industrial relations problems now for new technology otherwise labour costs will increase forever, and you would stop development of the firm. It was brought to a head when D came in".

The new manager had a complex problem to resolve. Firstly, he knew that the company's policy in this case would not work. He recognised that 40 years of engineering knowledge would be lost to the firm. Simply replacing an aging engineering group with new graduates would set the company back decades in terms of expertise. On the other hand, he knew that the new CAD system had to be introduced, and that there would be enormous resistance. Quoting D, "We had to avoid extremes. We needed both the level of experience of the existing engineers and the energy of the youngsters. We had one guy, for example, who was a good designer, with 40 years design experience. But, he couldn't use a PC."

The feeling was that the firm couldn't lose him with all his knowledge and skill. Furthermore, engineers at his stage of career were close to retirement, and had little to gain in attending training courses and education programmes designed to get them up-to-speed with the new technology. But the company felt that they had to introduce the new technology, and that it would create a lot of resistance amongst people who had little to lose in not adopting it. This was the dilemma faced by manager D.

6.2.3 *Developing a knowledge retention strategy*

Manager D knew that he could not bully people into using the new technology. He also knew that he could not risk losing the support of the older engineers who they might need to bring in from time to time after retirement, and whose knowledge had to be inculcated into the organisation. D did a number of things:

– Subsidised the older engineers to buy home PCs
– Introduced a logbook based system which was non-computerised
– Worked hard to build the trust and good will of people for the new system
– Succeeded in establishing a 'chemistry' in the team
– Introduced a new position—'senior engineer'

This strategy was designed to retain knowledge within the organisation, whilst simultaneously successfully introducing the new technology into the group. This strategy worked as follows:

Subsidised home PC This was designed to address people's fear of the new technology. An essential factor here was the fear of using personal computer-based tools. The engineers had drafted designs on papers for decades and were recognised as a very successful and competent design group. The introduction of new technology threatened this. By providing the engineers with subsidised home computers they could play with them at home and become familiar with the technology. Furthermore, they could keep the system for their personal enjoyment and become familiar with a technology that was now quite ubiquitous in Ireland.

This also sent out another message. It demonstrated clearly that the company was willing to invest personally in the people involved. By doing this it showed to the engineers that, if they were willing to cooperate with the firm, their jobs were likely to be secured. Interviewees described this as a significant 'psychological and philosophical change'. The money wasn't as important as the willingness to invest in the people. Small bonuses were also provided in this respect to key people who were seen to be 'key players'.

Non-computerised log-book system This provided a work around solution in case the system failed, again addressing fears associated with the new technology. Also, by providing both a computerised and non-computerised approach, it addressed problems associated with the 'insensitivity of youngsters', i.e. the older engineers had access to equivalent technology at home, and had a non-computerised solution that was useful to the group and of which the 'youngsters' would have no knowledge. This neutralised potentially dysfunctional power imbalances in the group.

Trust, good will and ownership D recognised that in order for people to be committed to the project, and for them to have a stake in its success, goodwill and trust had to be inculcated. He saw this as a central plank of the strategy. As one interviewee put it, "if you treat an employee unfairly you can undo years of work".

Chemistry When recruiting personnel, and organising sub-groups, D tried to 'get the chemistry right' between people. This meant placing certain people together, and was described as something which required patience.

The senior engineer role This position was created in order to establish the seniority of the older engineers. It was the key to the retention of tacit knowledge. By creating the senior engineer position D could ensure senior managers acted as mentors for the new engineers. Furthermore, it meant that the new engineers, who found it easier to familiarise themselves with the new technology, could perform most of the CAD work under the guidance of the senior engineer. This effectively reduced the amount of computer-based work the senior engineer had to perform, whilst ensuring that the design skills of the senior engineer were learnt by the new staff.

6.2.4 Human-centred technology deployment

By combining these elements with technical instruction and a solid technical deployment of the new system, the engineering group was able to train up new engineers in the CAD system, whilst simultaneously passing much of the older engineers tacit knowledge to the novices. By adopting a human-centred approach to the technology deployment problem, the organisation was able to utilise a new technology project to ensure that important tacit knowledge was diffused in the firm. It is apparent that this was achieved through establishing a knowledge network amongst the engineering group. This network of engineers, with their different but complimentary knowledge, provided a basis for the application of actionable knowledge in the design engineering process. It also created a sensemaking support process when difficulties arose amongst less experienced engineers.

7 Interpretations

7.1 Case study one

There were two components to the problem faced in case study one. Firstly, there was the failed attempt to modernise an ancient but declining craft practice in order to help increase the material prosperity of the artisan community. Secondly, there was the matter of archiving the knowledge embedded in their craft practices.

Two insights were crucial here. Firstly, an analysis of the technology transfer in terms of the human-centred-ness principle led to a shift in intervention strategy from a techno-centric to a socio-cultural perspective. Secondly, the knowledge networking principle led to the rejection of any attempt to represent the tacit knowledge of the artisans in propositional terms. Instead, multimedia technologies were used to emulate some aspects of traditional knowledge representation which could be interpreted in the light of tacit knowledge frameworks available in appropriate nodes of other intersecting networks.

7.2 Case study two

The critical managerial insight in case study two was to perceive the problem in terms of a human centred system. Manager D did not view the new system as a technology system in which humans must be accommodated, but rather the technology was to be embedded into a human way of functioning. Such a shift of perception is at the heart of the human-centred systems approach.

For the company in case study two, it is apparent that the management of tacit knowledge was of fundamental importance to the management of the social impact of the new technology. If this knowledge type had been omitted from consideration Manager D recognised that the company would be set back decades and valuable expertise gained during that time would be lost.

Like the Indian project, it is evident that there was no attempt to codify or make explicit the complex, deep-structured tacit knowledge, which had been built up over decades of design work by the experienced engineers. It was recognised that the introduction of the new technology afforded an opportunity to acknowledge this knowledge explicitly (by creating the senior engineer post). Through this process of empowerment plus the re-organisation of the design-engineering group as part of the technology implementation, the organisation successfully leveraged the entire process. Again, the shift from a techno-centric perspective to a socio-cultural perspective ensured the projects success. Also, the creation of a knowledge network, especially the connections created between senior and junior engineers ensured the diffusion of knowledge between the groups. It helped create knowledge-in-action processes, in this case the action context was the design engineering function, but the same approach could be applied to other functions in this firm. Importantly, the tacit knowledge built up over many years remained a central part of the design engineering process after an apparently incompatible technology had been implemented. In short, the success of this system was due to the human-centred nature of the deployment process and would certainly not have succeeded if a traditional techno-centric approach had been adopted.

7.3 General observations from both case studies

The two quite different cases of technology-transfer and knowledge management represent and exemplify the human-centred approach to information systems design. Both could only be adequately understood in terms of human activity systems, rather than as technological systems. In both cases, the transfer and implementation of new technologies was facilitated by actions based on an understanding of the social dynamics of knowledge and of human purposes within communities of practice. The recognition of tacit knowledge as a critical aspect of the technology deployment process ensured the success of each project, whether it was the implementation of an ancient brassware technology in India, or an advanced CAD technology in Ireland.

8 Conclusion

This paper set out to show the importance of tacit knowledge in technology deployment activities. In doing this it addresses itself to deep-seated problems with assumptions of functional rationalism: a set of assumptions which currently dominate systems engineering methodologies. The two case studies presented here explore the experiences of two very different communities as communities of knowledge, i.e. knowledge networks. It reveals how the tacit knowledge and concomitant knowledge network perspectives provide a very rich understanding of technology development and deployment as human-centred systems activities. From both a theoretical and practical perspective, tacit knowledge was seen to inform human-centred systems engineering and technology deployment activities in both case studies. It shows that by addressing tacit knowledge a wide range of technology development and deployment initiatives are far more likely to be successful.

The paper also indicates the need for new trajectories in human-centred systems research, as well as systems engineering methodology research. Finally, the paper reveals the need for systems engineering researchers to refocus away from knowledge as complex data elements and return to the centre of all important explorations of knowledge since ancient Greece: ourselves.

Acknowledgements The authors wish to gratefully acknowledge the support provided by the Indian CSIR (Council for Scientific and Industrial Research) agency NISTADS (National Institute for Science, Technology and Development Studies) for the case study in West Bengal. The authors gratefully acknowledge support provided by Enterprise Ireland and the British Council for interinstitute collaboration. We also greatly appreciated the comments of the reviewers which significantly strengthened the argumentation and provided very useful references which were omitted in the initial version.

References

Alic JA (1993) Technical knowledge and technology diffusion: new issues for US government policy. Technol Anal Strategic Manage 5(4):369–384

Ayers AJ (1936) Language, truth and logic: the classic text which founded logical positivism and modern British philosophy. Victor Gollanez, London. Reprinted in 1991 by Penguin Books, Middlesex

Badham R (1991) CAD CAM and human centred design. University of Wollongong science and technology analysis research programme. Wollongong, Australia

Baumard P (1999) Tacit knowledge in organisations. Sage, London

Bell J, Hardiman RJ (1989) The third role—the naturalistic knowledge engineer. In: Diaper D (ed) Knowledge elicitation, principles, techniques and applications. Ellis Horwood, Chichester, pp 49–85

Blackburn S (1994) Oxford dictionary of philosophy. OUP, Oxford

Bloc L (1980) Representation and processing of natural language. Natural communication with computers. Carl Hanser, Munich

Boland R, Day W (1989) The experience of systems design: a hermeneutic of organisational action. Scand J Manage 5(2):87–104

Brandt D, Cernetic J (1998) Human-centred approaches to control and information technology: European experiences. AI Soc 12(1):2–20

Brown JS, Duguid P (1999) The social life of information. Harvard Business School Press, Cambridge

Cameron E, Green M (2004) Making sense of change management. Kogan Page, London

Checkland P (1999) Systems thinking, systems practice. Wiley, England

Checkland P, Scholes J (1990) Soft systems methodology in action. Wiley, New York

Chen P (1976) The entity relationship model—toward a unified view of data. ACM Transact Database Syst 1(1):9–36

Chen P (1980) Entity-relationship approach to systems analysis and design. North Holland, Amsterdam

Cohen WM, Levinthal DA (1990) Absorptive capacity: a new perspective on learning and innovation. Adm Sci Quart 35:128–152
Cohen DK, March J, Olsen JP (1979) People, problems, solutions and the ambiguity of relevance. In: March JG, Olsen JP (eds) Decision making in organisations. Universitetsforlaget, Bergen
Cooley M (1987) Architect or bee? The human price of technology. Hogarth, London
Cronk L (2000) Reciprocity & the power of giving. In: Spradley F, McCurdy D (eds) Conformity & conflict. Allyn & Bacon, MA, pp 157-163
Cummings TG, Worley CG (1997) Organisational development and change. Southwestern University Press, Ohio
Dennis A, Haley-Wixom B, Tegarden D (2002) Systems analysis and design: an object oriented approach with UML. Wiley, New York

Feldman MS, March JG (1981) Information in organisation as symbol and signal. Adm Sci Quart 26:171–86

Fleck J (1997) Contingent knowledge and technology development. Technol Anal Strategic Manage 9(4):383–397
Flynn P (1992) Information systems requirements. McGraw Hill, New York
Gill KS (1997) Knowledge networking and social cohesion in the information society. Res Report Study European Commission, University of Brighton, UK, pp 1–65

Gill KS (2002) Knowledge networking in cross-cultural settings. AI Soc 16(3):252–277
Goguen J (1993) Social issues in requirements engineering. IEEE international symposium on requirements engineering, (RE 93), IEEE Computer Society Press, Los Alamitos, California, pp 194-197
Goguen J, Linde C (1993) Techniques for requirements elicitation. IEEE international symposium on requirements engineering, (RE 93), IEEE Computer Society Press, Los Alamitos, California, pp 152-164

Grant EB, Gregory MJ (1997) Tacit knowledge, the life cycle and international manufacturing transfer. Technol Anal Strategic Manage 9(2):149–160
Handy C (1981) Understanding organisations. Penguin Books, Middlesex
Halpin L, Stapleton L (2002) Towards a revised framework of management theory and practise in uncertain, chaotic environments: managing post-implementation in large-scale information systems projects. In: Proceedings of the Irish Academy of Management. Waterford Institute of Technology, Waterford, Ireland

Hirschheim RA, Newman M (1991) Symbolism and information systems development: myth, metaphor and magic. Inf Syst Res 2(1):29-62

Howells J (1996) Tacit knowledge, innovation and technology transfer. Technol Anal Strategic Manage 8(2):91–106

Klein HK, Hirschheim RA (1991) Rationality concepts in information system development methodologies. Account Manage Inf Technol 2(2):157–166
Leibnitz WG (2003) New essays concerning human understanding. Kessinger, Whitefish, Montana
Lewi J, de Vlaminck K, Steegmans E, Van Horebeek I (1992) Software development by LL(1) syntax description. Wiley, New York
March JG (1999) The pursuit of organisational intelligence. Blackwell Business, MA
March JG, Olsen JP (1979) Organisational choice under ambiguity. In: March JG, Olsen JP (eds) Ambiguity and choice in organisations. Universitetsforlaget, Bergen
Mintzberg H (1973) The nature of managerial work. Harper & Row, New York
Moreton R, Chester M (1999) Reconciling the human, organisational and technical factors of IS development. In: Zupancic J, Wojtkowski W, Wojtkowski WG, Wrycza S (eds) Evolution and challenge in systems development. Kluwer Academic/Plenum, New York, pp 389-404
Morgan G (1986) Images of organisations. Sage, CA

Moss-Kanter R (1994) The change masters: corporate entrepreneurs at work. Routledge, London

Myers MD (1995) Dialectical hermeneutics: a theoretical framework for the implementation of information systems. Inf Syst J 51–70

Nonaka I, Takeuchi H, Umemoto K (1996) A theory of organisational knowledge creation. IJTM Spec Publ Unlearning Learn 11(7/8):833–845

Polanyi M (1958) Personal knowledge: towards a post-critical philosophy. University of Chicago Press, Chicago

Polanyi M (1961) Knowing and being. Mind NS 70:458–470

Quinn JB (1992) Intelligent enterprise: a knowledge and service based paradigm or industry. Free Press, New York

Roberts J (2000) From know-how to show-how? questioning the role of information and communication technologies in knowledge transfer. Technol Anal Strategic Manage 12(4):429–443

Roderick R (1993) The self under siege. The Teaching Company, Chantilly, Virginia

Rogers EM, Kincaid DL (1981) Communication networks: towards a new paradigm for research. Free Press, New York

Siddiqi J (1994) Challenging universal truths of requirements engineering. IEEE Software, March, pp 18–20

Smith DJ (1992) The psychology of apprenticeship. In: Göranzon B, Florin M (eds) Skill and education: reflection and experience. Springer, London, pp 83–100

Smith DJ (2002) Communicating tacit knowledge across cultures: a multimedia archive of the Bankura Dhokra craft industry of West Bengal as a case of the artificial. In: Negrotti M (ed) The first yearbook of the artificial. Peter Lang, Berne

Smith DJ, Hall J (2001) Multimedia know-how archiving in aviation industry training. In: Brandt D, Cerenetic J (ed) Proceedings of the 7th IFAC symposium on automation based on human skill: joint design of technology and organisation. Elesevier, Oxford

Smith DJ, Kochhar R (2003) The dhokra artisans of Bankura and Dariapur, West Bengal: a case study and knowledge archive of technological change in progress. AI Soc 16

Sowa J, Zachman J (1992) Extending and formalising the framework for information systems architecture. IBM Syst J 31:3 (reprint)

Stapleton L (2000) From information systems in social settings to information systems as social settings. In: Brandt D, Cerenetic J (eds) Proceedings of the 7th IFAC symposium on automation based on human skill: joint design of technology and organisation. VDI/VDE-Gesellschaft Mess- und Automatisierrungstechnik (GMA), Dusseldorf, pp 25–29

Stapleton L (1999) Information systems development as interlocking spirals of sensemaking. In: Zupancic J, Wojtkowski W, Wojtkowski WG, Wrycza S (eds) Evolution and challenges in systems development. Kluwer Academic/Plenum, New York, pp 389-404

Stapleton L (2001) Information systems development: an empirical study of Irish manufacturing firms. Business information systems. University College, Cork

Stapleton L, Murphy C (2002) Examining non-representation in engineering notations: empirical evidence for the ontological incompleteness of the functionally-rational modelling paradigm. Proceedings of the IFAC world congress 2002, North Holland, Elsevier

Stapleton, Murphy C (2003) Revisiting the nature of information systems: the urgent need for a crisis in IS theoretical discourse. T Int Inf Syst 1(4)

Steers JS, Black RM (1994) Organisational behaviour. Harper Collins College, New York

Strina G, Honecker N (2003) Changing socio-technical systems: the case of the John Deere plant. In: Brandt D (ed) Human-centred system design: first-people, second—organisation, third—technology. ARMT, Aachen

Turban E, McLean E, Wetherbe J (2001) Information technology management. Wiley, New York

Vickers G (1973) Making institutions work. Associated Business Programmes, London

Weick K (1982) Management of organisational change amongst loosely-coupled systems. In: Goodman P et al. (eds) Change in organisations. Jossey Bass, San Francisco, pp 375–408

Weick K (1985) Cosmos vs. chaos: sense and nonsense in electronic contexts. Organisational Dyn 14(2):51–64
Weick K (1995) Sense-making in organisations. Sage, CA

Weizenbaum J (1966) ELIZA—a computer program for the study of natural language communications between man and machine. Commun ACM 9(1)
Welch SC (1986) India, art and culture. Mapin, New Delhi
Wenger E (1998) Communities of practice: learning, meaning and identity. Cambridge University Press, Cambridge

Wong WLP, Radcliffe DF (2000) The tacit nature of design knowledge. Technol Anal Strategic Manage 10(2):247–265

Wood JRG, Wood-Harper T (1993) Information technology in support of individual decision making. J Inf Syst April 3(2):85-102
Zoetekouw D (1991) An overview of formal semantics specification methods. In: Petrie C (ed) Proceedings of the first international conference of enterprise integration modelling. MIT Press, MA