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ON KNOWLEDGE LEVEL THEORIES AND THE KNOWLEDGE MANAGEMENT OF DESIGNING

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"*Experience alone, without theory, teaches management nothing about what to do to improve quality and competitive position, nor how to do it*."
(Page 19 of Deming, 1986)

1. Introduction

The design and engineering of new products is, today, facing new and difficult challenges as a result of the globalisation of markets and the rapid development of new technologies. To be competitive, companies must be more efficient, more responsive, more exible, more adaptable, innovate more, and achieve greater levels of quality and service. They must become Intelligent Enterprises, (Friedman et al., 1997; Pinchot & Pinchot, 1994; Quinn, 1992).

The intelligent enterprise is an organisation which acts effectively and efficiently in the present and is, at the same time, capable of dealing with the challenges of the future. Its competences are a function of the knowledge it has available at the workplace and embedded in its capabilities as an enterprise. How intelligent an enterprise is, thus depends upon how well it manages its knowledge, (Wiig, 1994).
Current methods and techniques in Knowledge Management (KM) practice are essentially based upon experience and empirical studies. The KM community (and literature) uses a sur-prisingly weak notion of knowledge, often equating it with information or corporate memory, for example. This results in the KM methods and techniques being informal, imprecise, and difficult to apply effectively, (Wiig, 1999). So far there have been few attempts to develop any appro-priate and usable theory of knowledge, despite the fact that this could significantly strengthen and improve KM methods and practices, (Deming, 1986; Wiig, 1994).

2. Knowledge, Knowledge Level, and Knowledge Engineering

Knowledge has been a subject of fundamental interest and attention in Artificial Intelligence since its earliest days, particularly in the area of expert or knowledge based systems. Newell (1982) presented the Knowledge Level as a new level of abstraction in computer and cognitive systems. He placed it directly above the Symbol Level, and argued that it is needed to properly understand and specify the problem solving behaviour of an intelligent agent. For Newell this Knowledge Level formed an important component of his theory of cognition in both human and artificial agents.

According to Newell, at the Knowledge Level (KL), an intelligent agent is composed of goals, actions, and a body. The medium at the KL, the composition of the body, is knowledge (what the agent knows), and the law of behaviour is the principle of rationality: an agent uses its knowledge to select one or more of its actions to achieve its goals. As Newell (1982) observes, from this definition of the Knowledge Level, it follows that knowledge is intimately linked with rationality, so that we can say that systems that are observed to act rationally can be said to have knowledge, and to have knowledge is to have a capacity to act rationally. In other words, the concept of knowledge that underlies the Knowledge Level is a competence notion. Knowledge, according to Newell, is a capacity for rational action.

In presenting the Knowledge Level, Newell did not think he was presenting anything new to the Artificial Intelligence (AI) community. Rather he referred to its presentation as a rational reconstruction, a making explicit, of a concept of knowledge that had been developed and used since the earliest days of AI, albeit tacitly or implicitly, and for some, at least, unknowingly. Knowledge as a capacity for rational action is thus to be understood as the concept of knowledge adopted and used in AI. It is, however, important to note that though widely adopted and used in AI, this concept of knowledge is radically different from the more conventional, or Classical, concept of knowledge we have from the fields of Epistemology and the Philosophy of Knowledge. These characterise knowledge as justified true belief, a concept we find first in Plato's (c.428– c.348 BC) "Meno, Phaedo, and Theaetetus" (one of Plato's so called Early Dialogues featuring Socrates).

Compared to the Classical concept of knowledge, Newell's concept of knowledge has two important advantages for AI: first, knowledge as a capacity for rational action is a practical concept of knowledge which is not hard to use; and, second, it escapes from the problems that epistemologists and philosophers continue to struggle with concerning the applicability of the concept of knowledge as justified true belief, and it logical adequacy.

The practicality of knowledge as a capacity for rational action has been well used and well demonstrated in recent years with the development of modern Knowledge Engineering (KE) methods, such as CommonKADS, for example, (Schreiber et al., 1999).

These all take Newell's concept of knowledge as a common starting point. They have, however, modified Newell's original view of the Knowledge Level, to make it more useful in supporting the Knowledge Level modeling of expert behaviour. These KE developments of the KL are important, and can be summarised as involving three basic changes to Newell's original proposal:

1. All cognitive connotations and implications are dropped.
2. The KL is decoupled from the Symbol Level and taken to exist independently of the computer system levels below it.
3. Different types of knowledge are defined, which play different roles in the (modelled) expert behaviour, in contrast to knowledge being one amorphous undistinguished body, as Newell defined it.

The first two of these changes allow the Knowledge Level to be used as a useful level of abstraction, without necessarily committing to cognition being a property of a physical symbol system, as Newell believed. They remove a much debated aspect, but leave a powerful abstrac-tion. The third change, makes the KL much more useful in modeling real expert or human problem solving behaviour. It allows KL models to have structure, which, in turn, can be used to model and specify important aspects of real knowledge-based systems. In CommonKADS, for example, we have domain knowledge, task knowledge, and inference knowledge. The effective application of these different types of knowledge, the roles they play, and the ways they relate, are embodied in a set of principles for the KL modeling of expertise, which make knowledge engineering a well defined modeling activity similar to other software engineering methods and practices.

3. The Knowledge Management of Designing

The principle aims of modern KE methods, such as CommonKADS, are to provide a method and tools for making explicit the knowledge used in some knowledge intensive task. KE modeling has mostly been an empirical activity, but more recently a number of attempts have begun to develop Knowledge Level theories of the different kinds of expert activities. These are intended to offer theoretical support to the KE modeling process, and thus improve and strengthen the models that are developed, (Smithers, 1996).

Essentially the same argument can be made for KM methods and techniques. If these adopted a clear well defined concept of knowledge, such as Newell's, it would become possible to develop

Knowledge Level theories of the different intelligent enterprise activities to support their more effective and efficient knowledge management, (Smithers, 1988). KM is about ensuring that the right knowledge is available at the right time and in the right place in a functioning enterprise or organisation. A theoretical understanding of what kinds of knowledge are needed, what roles they play, and how they relate and interact could both be used to identify what knowledge infrastructure is therefore needed, and to to explain and justify why and how it is supposed to work. A theoretical understanding of the knowledge involved could also be used to identify, diagnose and repair failures and weaknesses in KM practices.

Designing is one of the most fundamental activities of any product creating intelligent enterprise. $K_L D^{E}_{v1}$ (Knowledge Level Designing as Exploration), (Smithers, 1998), is a descriptive Knowledge Level theory of designing which explicitly identifies the necessary and sufficient knowledge types involved in any designing, the roles these different kinds of knowledge play in designing, and how they are related. $K_L D^{E}_{v1}$ has been developed originally to provide theoretical support for the KE modeling of particular kinds of designing, but in the same way, it could also offer theoretical support, justification, and explanation, for the knowledge management of designing.

3.1 $K_L D^{E}_{v1}$: A Knowledge Level Theory of Designing

As a general theory, $K_L D^{E}_{v1}$ characterises designing as an exploration of what is possible, rather than as a search for what is needed. (See (Smithers, 1998) for a detailed explanation.) It identifies two basic classes of knowledge, knowledge that is used in designing, and knowledge that is created during designing. The component types of knowledge, in these two basic classes, each play one of three different roles in the design process, and stand in one or more of four different relations between knowledge types.

The three different roles and the four different relations are defined below.

Knowledge Type Roles

A *Supporting* role	Rol.sp.
A *Constructing* role	Rol.cn
A *State maintaing* role	Rol.sm

Knowledge Type Relations

Embedded in	Rel.em.
Supports	Rel.sp.
Used in (the construction of)	Rel.uc
Increments and/or modifies	Rel.im

The class of used or existing knowledge is composed of three basic types of knowledge, each of which embed further (sub) component types of knowledge used in designing. The class of used knowledge types is defined below, together with their respective roles and relations.

Types of *used* knowledge

Knowledge type		Role	Relations
General context knowledge	K.gc		
Knowledge of the domain or domains	K.dm	Rol.sp	Rel.em{K.gc}
Knowledge of the customer/client context	K.cc	Rol.sp	Rel.em{K.gc}
Knowledge of the needs and desires that motivate the designing	K.nd	Rol.sp	Rel.em{K.gc}
Knowledge of design practice context; business, artistic, personal, institutional, or social styles, customs, or cultures	K.pc	Rol.sp	Rel.em{K.gc}

Types of *used* knowledge - continued

Knowledge type		Role	Relations
Exploration knowledge	K.ex		
Knowledge of requirements formation, recognition, and development	K.r	Rol.cn	Rel.em{K.ex}
Knowledge of well formed problem definition, modification ,and revision	K.p	Rol.cn	Rel.em{K.ex}
Knowledge of solution finding	K.s	Rol.cn	Rel.em{K.ex}
Knowledge of solution evaluation	K.e	Rol.cn	Rel.em{K.ex}
Analysis knowledge	K.an	Rol.cn	Rel.em{K.e}
Simulation knowledge	K.sm	Rol.cn	Rel.em{K.e}
Prototyping knowledge	K.an	Rol.cn	Rel.em{K.e}
Knowledge of local plan formation	K.lp	Rol.cn	Rel.em{K.ex}
Design knowledge	K.dk		
Knowledge of design description formation and modification	K.dd	Rol.cn	Rel.em{K.dk}
Knowledge of design documentation	K.dc	Rol.cn	Rel.em{K.dk}
Knowledge of design rational maintance	K.dr	Rol.sp	Rel.em{K.dc}
Knowledge of design presentation preparation	K.dq	Rol.cn	Rel.em{K.dk}

The class of created knowledge types is defined below, together with their respective roles and relations.

Types of *created* knowledge

Knowledge type		Role	Relations
Knowledge of the current set of requirements and their status	C.r	Rol.sm	Rel.sp{C.p}
Knowledge of the problems so far defined, their status, and organisation	C.p	Rol.sm	Rel.sp{C.s}
Knowledge of the problem solutions so fer generated, their status and organisation	C.s	Rol.sm	Rel.sp{C.e}
Knowledge of the solution evaluations produced so far	C.e	Rol.sm	Rel.sp{C.dd}
Knowledge of the analyses produced so far	C.an	Rol.sm	Rel.sp{C.e}
Knowledge of the simulations so far	C.sm	Rol.sm	Rel.sp{C.e}
Knowledge of the prototypes built so far	C.pr	Rol.sm	Rel.sp{C.e}
Knowledge of the local plans developed so far, their status, and organisation	C.lp	Rol.sm	Rel.sp{C.p}
Knowledge of the design descriptions developed so far, their status, and organisation	C.dd	Rol.sm	Rel.sp{C.de}
Knowledge of the design documentation produced so far	C.de	Rol.sm	Rel.sp{C.dd}
Knowledge of the design rational maintained so far	C.dr	Rol.sm	Rel.sp{C.de}
Knowledge of the design presentations prepared so far	C.dq	Rol.sm	Rel.sp{C.de}
Knowledge of the history of the designing so far	C.dh	Rol.sm	Rel.sp{C.de}

The different types of knowledge each define a particular kind of competence to act rationally. As a whole they define what the necessary and sufficient kinds of competences needed in any designing. Many of the type of knowledge identified above are not, however, generally recognised by designers or their managers: they identify types of knowledge that are often only implicit in some actual designing activity. By making them explicit, $K_LD^E{}_{v1}$ offers a theoretical basis for actively managing all the kinds of knowledge used and generated in any designing, not just the knowledge that is explicitly observable or simply presumed to be involved. It also offers a theoretical basis for understanding what knowledge (ie competences) need to be maintained so as to sustain an effective designing capability within an enterprise. This, in turn, can form a basis for designing and implementing effective knowledge management tools and infrastructures of designing.

The theoretical basis of this explicit identification of all the different kinds of knowledge involved in designing also means that $K_LD^E{}_{v1}$ could be used to monitor and assess the quality of any actual designing, in terms of the knowledge used and generated, and to help diagnose problems and failures in designing.

A Knowledge Level theory of designing, such as $K_LD^E{}_{v1}$, could thus provide a theoretical foundation for managers to improve and sustain the quality and competiveness of designing in their enterprise.

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