The concept of knowledge in KM: A dimensional model

Forthcoming in the Journal of Knowledge Management, Volume 10, No 6, 2006

Bertolt Meyer[1] and Kozo Sugiyama[2]

[1]Department of Organizational and Social Psychology, Institute of Psychology,
Humboldt University Berlin
Unter den Linden 6, 10099 Berlin, Germany
bmeyer@psychologie.hu-berlin.de

[2] School of Knowledge Science, Japan Advanced Institute of Science and Technology
1-1 Asahidai, Nomi, Ishikawa 923-1292, Japan
sugi@jaist.ac.jp

Abstract

Purpose: To sharpen the concepts of tacit, implicit and explicit knowledge by linking them to findings from cognitive psychology and memory science and thus finding a possibility for measuring non-explicit knowledge.

Methodology/Approach: A review of KM and cognitive science literature leads to a dimensional model of knowledge types that links the concepts from KM to more specific concepts from psychology. One central assumption of the model was empirically tested and put into practice in one small-scale KM project.

Findings: The concepts in KM can be linked to concepts from psychology and thus receive theoretical support. The developed model enables psychometric access to a part of non-explicit knowledge through structural assessment techniques. Furthermore, the model has proven to be of value in a practical application in KM.

Research limitations: The experiment and the practical application are too small in scope to provide full support for the model. Further research is required.

Practical implications: A fraction of non-explicit knowledge can be measured with structural assessment techniques. This can be used in the quantitative evaluation of KM projects as these techniques allow the quantification of individual knowledge increase. Furthermore, a detailed analysis of individual project-relevant knowledge is useful for post-project analysis.

Originality: The paper integrates findings from several scientific fields for use in KM and presents a novel view of classic KM concepts. The developed model is of importance to both researchers and practitioners.

Keywords: tacit knowledge, implicit knowledge, explicit knowledge, model, framework, measuring knowledge

Category: Research paper

Introduction

The significance of knowledge as a vital resource for the world's economies has been underlined in science and politics (European Council, 2000; Stehr, 1994); it forms the basis for innovation and economic success (Davenport & Prusak, 1998; Drucker, 1993; Nonaka & Takeuchi, 1995; Scholl, 2004; Schreyögg & Geiger, 2003). Knowledge management (KM) is the strategy for creating, accessing and supporting this vital resource. However, the field of knowledge management is unstructured and scattered, Despres and Chauvel (2000) refer to it as a "patchwork" (p. 57).

The concept of tacit knowledge in particular (Polanyi, 1958, 1966) is credited with a key role in organizational performance (Nonaka & Konno, 1998; Nonaka & Takeuchi, 1995). It is at the same time one of the most blurred concepts in management literature (Busch, Richards, & Dampney, 2001) and there is an argument whether Polanyi, who coined the concept of tacit knowledge and Nonaka, who introduced it into knowledge management (Nonaka & Takeuchi, 1995), are actually referring to the same thing (Li & Gao, 2003). This uncertainty in regard to definition of the construct is contradictory to the agreement that "an increased focus on the handling of non-explicit knowledge might pose a considerable value-creating factor" (Forschungsinstitut für anwendungsorientierte Wissensverarbeitung (FAW), 2001, p. 7, own translation). Therefore further investigation and the development of a sound conceptual framework is necessary. It is the aim of this paper to link the concepts of individual implicit, explicit and tacit knowledge with findings from memory, cognition and knowledge science by developing a two-dimensional model of knowledge types. In this way, the concepts are not only sharpened but possibilities for their measurement are discussed. The paper concludes with an experiment that provides some empirical support for the model and with a brief report on an application of the model in practice.

The concept of knowledge

Tacit knowledge is difficult to define because there is no single, broadly accepted definition for the term 'knowledge'. The first philosophical attempt to define knowledge in Plato's dialogue of the Theaitetos (Eigler, 1990) described knowledge as "justified true belief". This introduces truth as a required feature of knowledge (in order to distinguish it from errors).
From the cognitive viewpoint, individual knowledge is simply the content of human long-term memory (Strube & Schlieder, 1998). One way of bringing the two views together is to include constructivist aspects. Since constructivism assumes that every individual mentally constructs their own environment based on their sensory input, there is no such thing as objectivity or absolute truth, because there is no objective depiction of reality (Forschungsinstitut für anwendungsorientierte Wissensverarbeitung (FAW), 2001). That is why the term 'viability' is introduced. "Actions, concepts and conceptual operations are viable if they fit to the intentions or descriptions for which they are used" (von Glasersfeld, 1996, p. 43, own translation). This allows the inclusion of an assessment in the concept of knowledge that does not require objective truth:

"Knowledge is not a picture or representation of reality; it is much more a map of those actions that reality permits. It is a repertoire of concepts, semantic relationships and actions or operations that have proven to be viable for the attainment of our goals" (von Glasersfeld, 1997, p. 202, own translation).

From this perspective, knowledge contains an assessment in the way that it contains maps of certain aspects of the world that proved to be viable.

Definition

At this point, we propose a general definition for knowledge that includes an aspect of assessment and that is applicable to both individual and organizational knowledge. We base this definition on Güldenberg's (1999) definition of knowledge as structural connectivity patterns and state:

Knowledge is defined as a set of structural connectivity patterns. Its contents have proven to be viable for the achievement of goals.

Based on constructivist assumptions, this definition avoids the term 'representation of reality'. It pays tribute to the fact that mental models of an individual are the result of a construction of environment, which can be very different from one individual to another (Opwis & Lüer, 1996). The term 'structural connectivity patterns' allows the inclusion of knowledge on different collective levels (individual and organizational), since organizational knowledge is embedded in the system or structure of the organization. The stress on the fact that knowledge has proven to be viable underlies the assessment that is a feature of human knowledge.

The connection between individual and organizational knowledge

Until now, we have only referred to individual knowledge. However knowledge management aims at improving both individual and organizational knowledge. Individual knowledge is a precondition for organizational knowledge which results from the publication of technical and/or individual knowledge and of its consolidation in organizational communication structures (Klimecki & Thomae, 2000). This consolidation of individual knowledge in organizational structures (e.g. in methods, models, documentation and culture) is also referred to as the organizational knowledge base (Rehäuser & Krcmar, 1996, p. 15). According to Damerow and Lefèvre (1998), such external representations have the same psychological functions as internal, individual representations and are based on the same mental capabilities. This individual knowledge enlarges the organizational knowledge base (Amelingmeyer, 2004, p. 122 ff.) and individual learning is a central element in organizational learning (Argyris & Schön, 1999, pp. 20 ff.). All in all, the organizational knowledge base, which comprises the very entity that KM seeks to optimize, is based on individual knowledge. Therefore, insights from the field of cognitive science and memory research can and should be integrated with aspects in knowledge management.

Non-explicit knowledge in KM literature

Individuals can perform actions without being able to explain them and they can explain actions without being capable of performing them (Dick & Wehner, 2002). From such observations, Polanyi (1958; 1966) concluded the existence of a silent dimension of knowledge which cannot be articulated: tacit knowledge. A similar typology is introduced by Spender (1996), who differentiates between implicit (produced through action) and explicit (produced through communication) knowledge. Polanyi himself distinguished between explicit knowledge and tacit knowledge according to the differentiation between *Können* (being able to do sth.) and *Wissen* (knowing) in the German language (Polanyi, 1985, p. 16). Similarly, articulable knowledge is referred to as explicit knowledge by Nonaka and Takeuchi (1995), knowledge that is difficult to articulate or cannot be articulated at all is referred to as tacit knowledge, too. Furthermore, they postulated a mechanism for converting implicit into explicit knowledge, thus fuelling the boom of knowledge management approaches (Schütt, 2003). However, Li and Gao (2003) argue that Nonaka's understanding of tacit knowledge differs from Polanyi's concept and criticise their synonymous use in literature. The authors stress that Nonaka and Takeuchi and Polanyi referred to two different observations in two fundamentally different cultural contexts. Polanyi studied European scientists, whereas Nonaka and Takeuchi studied factory workers in Japan. Li and Gao state:

> "It is out of Polanyi's argumentation for a careful differentiation between tacitness and implicitness, but from his terminology, tacitness is evidently different from impicitness [sic]. Implicitness, an other [sic] form of expressing knowing, does exist. It implies that one can articulate it but is unwilling to do that [...]. [...] When Nonaka and Takeuchi used Polanyi's dichotomy [...] we can see that actually what they mean by 'tacitness' includes 'implicitness'". (Li & Gao, 2003, p. 8)

The fact that implicit and tacit knowledge are described as two separate things and the hint at different levels of codifiability points towards a *dimensional* character of non-explicit knowledge (see also Kogut & Zander, 1992). The dimension spans between the poles explicit knowledge and tacit knowledge. Following Li and Gao, implicit knowledge lies somewhere in between. Knowledge elements can be classified into this continuum based on the degree of their codifiability (European Foundation for the Improvement of Living and Working Conditions, 2004), compare Figure 1.

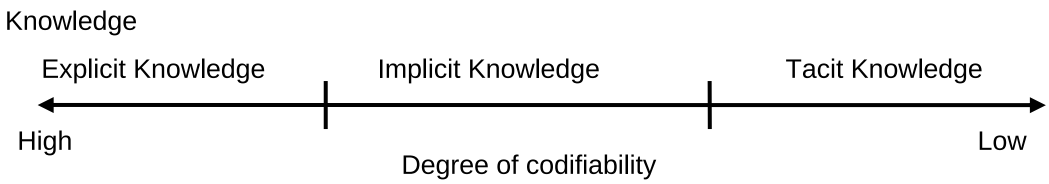

Figure 1: Dimensional classification of knowledge (based on European Foundation for the Improvement of Living and Working Conditions, 2004; Kogut & Zander, 1992; Li & Gao, 2003).

However, the above citation underlines the difficulty in clearly defining the constructs implicit and tacit knowledge. The following sections will therefore be used to elaborate on psychological and cognitive findings from the fields of memory research and cognitive science. This appears appropriate as Li and Gao, Polanyi and memory research refer to individual knowledge. These findings will then be integrated into the dimensional classification of knowledge, allowing a clearer definition and specification of non-explicit knowledge.

Models from memory research

In this section, findings from neuroscience and memory science are outlined that will each be connected to the concepts employed in KM. For the following descriptions, the definition for memory employed by Sinz (1979) is used:

> "The term memory describes the storage that depends on the learning of ontogenetically acquired information that selectively inserts itself into phylogenetical neuronal structures and can be recalled at any given point in time, e.g. that can be made available for situationally appropriate behaviour." (Sinz 1979, quoted in Markowitsch, 2002, own translation)

It can thus be argued that individual knowledge is stored in memory (Strube & Schlieder, 1998). Generally speaking, memory models either describe the structure of memory or the processes that are active in memory (Tulving, 2002). In the following, two common and extensive memory models are presented: the content-related memory model (Markowitsch, 1992, 1999, 2002; Squire & Frambach, 1990; Squire, Knowlton, & Musen, 1993; Tulving, 1972, 1995, 2002) and the multimodal theory of memory (Engelkamp, 1991; 1998; Engelkamp & Pechmann, 1993; Engelkamp & Zimmer, 1994). The latter includes both structure and processes; the former is a classification approach. After these two models are laid out, knowledge representation models that build on them are described. Afterwards, the models are incorporated into a dimensional system of memory types.

Content-related memory model

This memory model is based on neuroanatomical findings by Markowitsch (1992; 1999; 2002), Tulving (1972; 1995; 2002) and Squire and his colleague (Squire & Frambach, 1990; Squire et al., 1993).

Working memory

Firstly, the model postulates a memory with a short memory span of a few minutes that all information needs to pass through in order to be permanently stored in the long-term memory (Markowitsch, 2002, p. 85). It can be understood as that part of memory that is active at a certain point in time (Markowitsch, 2002, p. 85) and is therefore referred to as working memory.

Several findings indicate that the working memory is made up of several modality-specific subsystems, e.g. for verbally and visually coded information, that are coordinated by a central entity (see Squire et al., 1993 for an overview). The capacity of the verbal working memory is five (plus/minus two) informational units (chunks) (Markowitsch, 2002); the capacity of the visual working memory is assumed to be four objects that can have up to 16 memorable features (Vogel, Woodman, & Luck, 2001). On a neural level, network theories are most popular for describing memory processes (Markowitsch, 1999, 2002).

Long-term memory

Within long-term memory, where the maximum length of storage is practically unlimited, several different memory systems can be differentiated according to their content (long refers to a span beyond a minute, cf. Markowitsch, 1999). The youngest part of memory from an evolutional biological point of view is episodic memory (Tulving, 2002). “It consists of singular events that can be specified according to time and place.” (Markowitsch 2002, p. 88, own translation) Together with semantic memory that stores general facts about the world, it belongs to the declarative memory system. Episodic memory builds on semantic memory.

According to Squire et. al, “Declarative Memory is fast, it is not always reliable (i.e. forgetting and retrieval failure can occur), and it is flexible in the sense that it is accessible to multiple response systems.” (Squire et al., 1993, p. 458)

The content-related memory model states that humans also possess reflexive or non-declarative memory. “Non-declarative memory is slow […] reliable and inflexible.” (Squire et al., 1993, p. 458) Reflexive memory is differentiated into three subsystems: procedural memory, the priming system and the part of memory that is responsible for conditioning. For the non-declarative memory systems, Squire synonymously employs the term “implicit memory” (Squire et al., 1993, p. 471). The procedural memory system contains skills and habits: “Skills are procedures (motor, perceptual and cognitive) for operating in the world; habits are dispositions and tendencies that are specific to a set of stimuli and guide behaviour.” (Squire et al., 1993, p. 471) Under certain conditions, these can be acquired unconsciously. It should be noted that procedural memory does also contain skills that are not on a motor level, but on a perceptive and/or a cognitive level (Squire et al., 1993, p. 472). Non-declarative memory can be acquired independently of declarative memory (Squire & Frambach, 1990). Figure 2 illustrates the model:

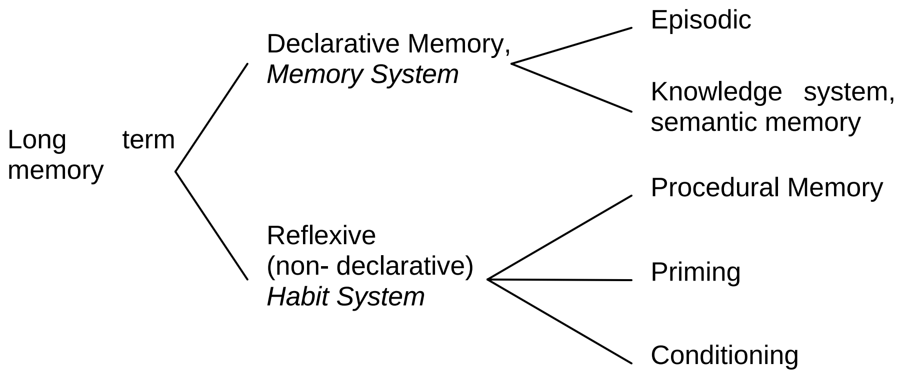

Figure 2: Overview of the content-related memory system (Markowitsch, 1999)

With reference to knowledge management, findings from experiments in learning artificial grammars are of special importance. In these experiments, subjects receive lists of meaningless words and are told that the syntax of these words does in fact follow a set of rules, which remain undisclosed. After the subjects are presented with ‘valid’ meaningless words, they are asked to decide whether previously unknown meaningless words obey the rules or not. Although subjects are unable to explain the grammatical rules on which their judgement is based, the number of correct decisions is above coincidence (Squire et al., 1993, p. 473 f.). In these kinds of tasks, it is impossible to determine whether subjects employ implicit knowledge in terms of procedural knowledge, or whether they employ incomplete or weak declarative knowledge (Squire et al., p. 474).
This statement implies that non-articulable knowledge can have two causes: it is either procedural or weak declarative. Both have in common that knowledge elements are accessed subconsciously. For this reason, Markowitsch rejects the synonymous use of procedural and implicit memory:

> “Implicit and explicit memory are not two different kinds of memory, they are different forms of expressing memory or phenomenologically different ways of retrieving specific events or experiences. Implicit means without making the actual content and its meaning conscious, explicit means including the associated connotations (time-spatial coordinate structure, the how, when and where of the encoding process). Explicit recall manifests the recalled information as an episode that can be personally experienced. The neural structural combinations that are responsible for implicit and explicit memory processing do differ.” (Markowitsch, 1999, p. 25, own translation)

Thus implicit memory describes an unconscious processing of memory contents, whereas the term explicit memory refers to a conscious mode of processing. Kluwe (in print) arrives at the same conclusion when he describes implicit knowledge as “superior performance in cognitive tasks based on an unconscious use of previously perceived and not intentionally stored information.” (p. 5, own translation) In an analogous way, Kluwe defines explicit knowledge as conscious recall of previously encoded information.
In addition to conscious and unconscious use of knowledge, there exists the phenomenon that previously acquired knowledge is not used at all. This so-called “inert knowl-

edge" (Renkl, 1996; Whitehead, 1929) is used to explain the discrepancy between knowledge and behaviour in pedagogy.

It becomes evident that the concepts employed in KM are not contradictory to concepts in memory and cognitive science, but for a complete overview, a model needs to be presented that spans not only different types of memory but also different memory processes. The multimodal memory model (Engelkamp, 1991, 1998; Engelkamp & Pechmann, 1993; Engelkamp & Zimmer, 1994) is such a model and is introduced in the next section.

The multimodal memory model

This model includes both process and structural assumptions. In accordance with Tulving's differentiation between semantic and episodic memory, Engelkamp and colleagues introduce a multimodal memory model for *episodic memory processes.*

The actual memory model is based on the assumption of the existence of two orthogonal dimensions: sensory – motor and verbal – nonverbal. Within these two dimensions, the authors postulate a conceptual system linked to modality-specific entry and output systems (Engelkamp, 1998, p. 35), the so-called sensory-motor systems. Throughout interaction between the systems, information is represented on two different levels: the conceptual system operates independently from the modality of the input; on the sensory motor level, encoding is specific for the modality of input and output (see Figure 3).

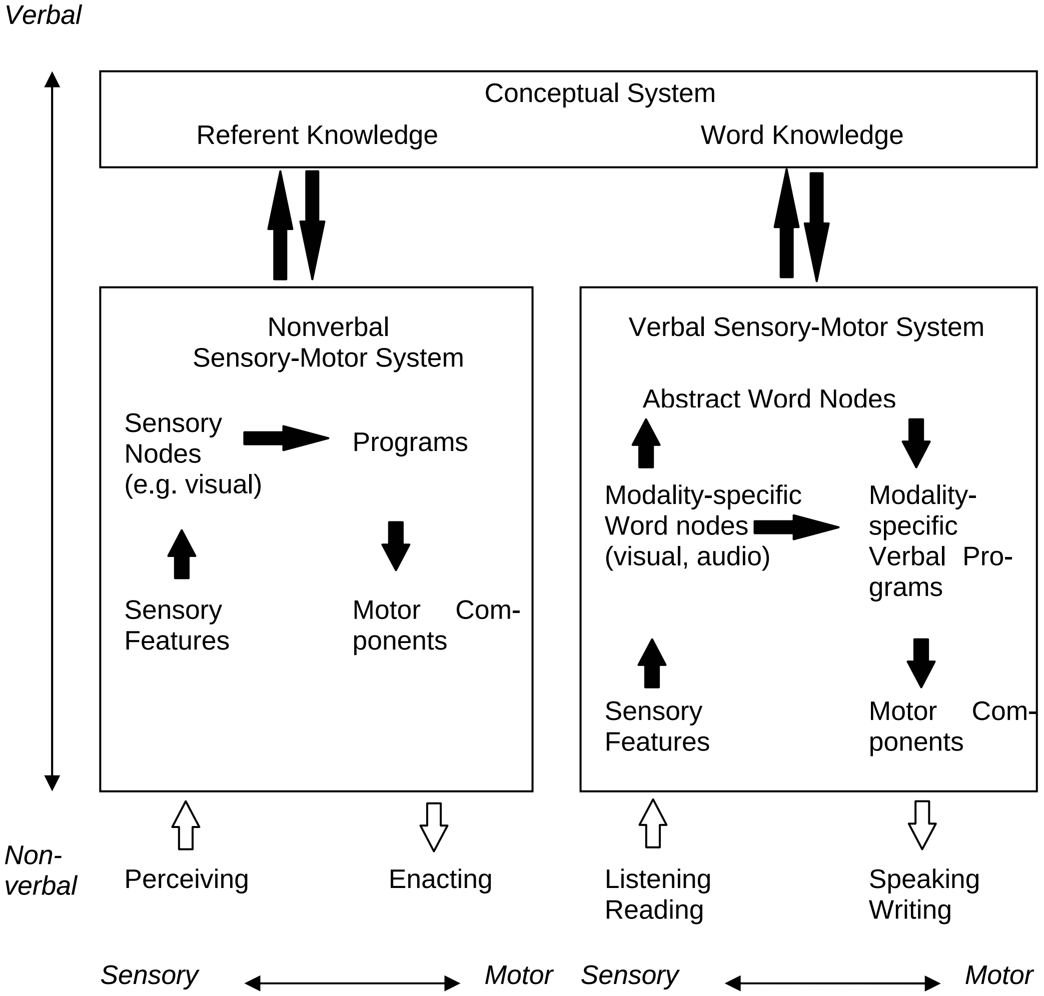

Figure 3: General architecture of the multimodal memory model (Engelkamp & Zimmer, 1994, p. 35)

Sensory motor systems are differentiated into sensor and motor systems. For simple items such as single concepts or actions, the authors assume a strict separation of memory content into different subsystems. Complex material is based on several modalities and thus on several subsystems. Sensory motor knowledge preserves experiences close to perception and behaviour. Referent knowledge combines concepts into propositions (compare next section).

One speciality of Engelkamp's model is the assumed lack of connection between verbal sensory motor system and nonverbal sensory motor systems. The authors assume that an access from the verbal sensory motor system to the nonverbal sensory motor system requires participation of the conceptual system (Engelkamp, 1991, p. 8).

In order to make an action verbally explicit, a reference to a motor program must be present in the conceptual system that must be connected to a word node in the verbal sensory-motor system. Only if this word node is connected to a modality-specific verbal program, can verbalization take place. Explicit knowledge about acting requires a connection of all three systems with regard to a specific content. If someone is capable of performing an action without being able to verbalize it, this can have two reasons:

The sensory nodes, e.g. visual nodes, are directly connected to motor programs in the nonverbal sensory motor system. Such content that is related to a single subsystem can only occur for simple stimuli and actions (see above). An example would be turning the head towards a face we recognize in a crowd. The face is the visual sensory node which was activated by perceiving the face; it is directly connected to the motor program for turning the head. Knowledge regarding face recognition is accessed without any use of the conceptual system and is thus not codifiable. This type of knowledge can be labelled *embodied knowledge*.

The performance of complex acquired tasks that are difficult to verbalize includes both the nonverbal sensory-motor system and connected referent knowledge within the conceptual system. Conceptual knowledge does not include knowledge of words, or known words are not connected to the word nodes in the verbal sensory-motor system. The connection between the conceptual system and the verbal system, which was established during learning, may have faded over time since the verbal sensory-motor system is no longer required after learning in order to perform the action. Actual performance of the action requires only the conceptual and the nonverbal sensory-motor system.

Due to the inclusion of actions and behaviour in the memory model, the multimodal memory model is capable of explaining differing levels of verbalization of behaviour that can be observed. Non-explicit knowledge acquired over time that was compiled into automated actions, such as the expert mastery of a musical instrument, can be explained as a disassociation of the verbal sensory-motor system for that particular action or concept.

All in all, the models based on Tulving and Markowitsch and the model based on Engelkamp and Zimmer can explain the existence of memory content which is not consciously accessible. In Tulving and Markowitsch's model, this can either be procedural knowledge or unconscious access to (weak) declarative knowledge. In Engelkamp and Zimmer's model, sensory-motor systems without connection to the conceptual system or to the verbal sensory-motor system are active.

The phenomenon of non-explicit knowledge from the realm of KM thus finds its correspondence in memory psychology. However, the cognitive dimension of procedural knowledge and the reference to semantic network structures in previous sections do require the introduction of higher-level concepts of representation. These will be outlined in the following section, prior to introducing the model.

Cognitive models for knowledge representation

Until now, different memory structures and their relationships have been described. Knowledge organization goes beyond this level; it deals with how semantic structures and productions are actually organized.
Two forms of knowledge representations are propositional representation systems and rule-based representation systems (Opwis & Lüer, 1996). They will be briefly described in this section.

Propositional representation systems

Propositional representation systems represent "verbally articulable information with the help of special symbol structures, so-called propositions" (Opwis & Lüer, 1996, p. 349, own translation). Two famous propositional systems are semantic networks and cognitive schemes. Semantic networks are formally depicted as graphs in which nodes represent linguistic units and edges represent linguistic relations. This approach is primarily based on Quillian (1968), who assumed a networked organization of individual semantic knowledge. A problem with semantic networks is their limited expressiveness and the fact that they do not include methods for dealing with objects in memory. This criticism can be met with an advancement of semantic networks: cognitive schemata. They refer to a heterogeneous group of pre-structured representational formats. The two most popular types of cognitive schemata are frames and scripts (Strube & Schlieder, 1998).

Frames are data structures in which experiences are generalized and that represent circumstances and expected coherences from a certain realm of reality (Schnotz, 1994). These representations contain constants and vacancies that store probabilities for other schemata that can be inserted. In this way, a schema is an instantiable class of a situation. A proposition is a structure that is created on instantiation of a schema.

A script is a frame for a situation involving several actions, much like a film script for standard situations. The most famous example is the script for a restaurant visit, in which certain behaviour such as waiting to be seated, being seated, receiving the menu, ordering, eating, paying and leaving are organized in a sequential manner. Scripts allow economic information processing that is steered by expectations.

Rule-based representational models

This form of knowledge representation assumes concurring processes within a production system. Contrary to cognitive schemata, production systems claim separate storages for declarative and procedural knowledge. A production rule or production connects a condition to an action. Declarative knowledge consists of data structures processed in working memory. Processing takes place by applying production rules to the content of the working memory (Schnotz, 1994). Declarative knowledge is represented as a semantic network with edges and nodes and is stored in the declarative long-term memory. The nodes of the network are knowledge units, the edges between them correspond to certain relations between these units (Schnotz, 1994, p. 96). Declarative knowledge elements are associated through productions containing them. This leads to the assumption that knowledge of many actions or differing patterns of behaviour leads to a higher degree of connectedness between declarative knowledge elements.

All in all, propositional representation systems and rule-based representational models describe individual knowledge representations and knowledge processes on a higher level than the models in the previous section. Note that a network organization of knowledge is central to all models that have been described in this paper so far.

Structural Knowledge

Since network organization is a central characteristic underlying the models discussed, its organization is introduced as an independent characteristic of knowledge: Structural Knowledge. It is "[…] the knowledge of how concepts are interrelated" (Jonassen, Beissner, & Yacci, 1993, p. 4). It is a "[…] hypothetical construct referring to the organization of the relationships of concepts in long-term memory" (Shavelson, 1972, pp. 226-227, quoted in Jonassen et al, 1993). The authors further state:

> "Structural Knowledge is also known as cognitive structure, the pattern of relationships among concepts in memory (Preece, 1976) […]. Structural knowledge has also been referred to as internal connectedness, integrative understanding or conceptual knowledge." (Jonassen et al., 1993, pp. 4 f.)

This conceptual structure facilitates between declarative and procedural knowledge and thus conditions the acquisition of procedural knowledge. According to Jonassen et al, blanks within cognitive schemata are references to other schemata. In this way, the interrelations between cognitive schemata can be seen as a semantic network with schemata as nodes. This view is consistent with Quillian's concept of semantic memory.

Jonassen et al. assume that structural knowledge is always explicit, i.e. the connections between concepts can always be expressed. However, there are empirical findings indicating structural knowledge can be non-explicit. Rothe and Warning (1991) tried to elicitate the structural knowledge of experts in a limited specified knowledge domain through the structure-laying technique (Scheele & Groeben, 1984). It turned out that the number of nodes and their labels were similar among subjects while the labelling of the edges with Klix' standard semantic relations (Klix, 1984) differed to a great extent. Rothe and Warning concluded that their subjects generally had substantial difficulties in naming the edges between knowledge nodes. This leads to the assumption that access to structural knowledge can be implicit in Tulving's sense, i.e. present but not consciously accessed. This assumption is supported by Davis, Curtis and Tschetter (2003) who assume that the elicitation of structural knowledge (structural assessment) also captures non-explicit knowledge. The authors state that tacit knowledge is comprised of the subtle interrelations between concepts and explicitly indicate the possibility of measuring at least a part of tacit knowledge by structural assessment. Lee, Choi and Choe (2002) follow this approach by attempting to capture the organizational members' tacit knowledge through knowledge structure elicitation techniques.

To sum up, the connections in semantic memory can be interpreted as an independent type of knowledge (structural knowledge). They can be accessed either consciously or unconsciously and can thus be non-explicit knowledge (see above). Structural knowledge can be elicitated through several different methods (see Jonassen at al. for an overview).

Integration into a dimensional model

After all relevant terms have been introduced, we return to the concepts from KM in order to connect them with the concepts outlined. The dimensional figure of knowledge codifiability presented earlier is replaced by a more detailed model by the end of this section, which is based on Schindler (2002) who states that the transition between explicit and non-explicit knowledge is fluid. In his model, the right pole of the dimension is assigned to non-articulable tacit knowledge that includes capabilities such as maintaining balance and face recognition. This corresponds to purely sensory-motor memory contents in Engelkamp and Zimmer's model (see above). Since this knowledge is rooted into fundamental neurological mechanisms and is inherited, it is therefore beyond the scope of KM. Schindler takes the next two sections of his dimension from Nonaka and Takeuchi (1995):

> "[…] tacit knowledge can be segmented into two dimensions. The first is the technical dimension, which encompasses the kind of informal and hard-to-pin-down skills or crafts captured in the term 'know-how'. [...] At the same time tacit knowledge contains an important cognitive dimension. It consists of schemata, mental models, beliefs, and perceptions so ingrained that we take them for granted." (Nonaka & Takeuchi, 1995, p. 8)

Thus the technical dimension corresponds to procedural knowledge in the non-reflexive memory system in Markowitsch's model (compare Figure 2). It is acquired through motor skill learning for which well-established theories exist (Fitts & Posner, 1979). The third part of Schindler's dimensional model of non-explicit knowledge model corresponds to the cognitive dimension of tacit knowledge (compare Figure 4).

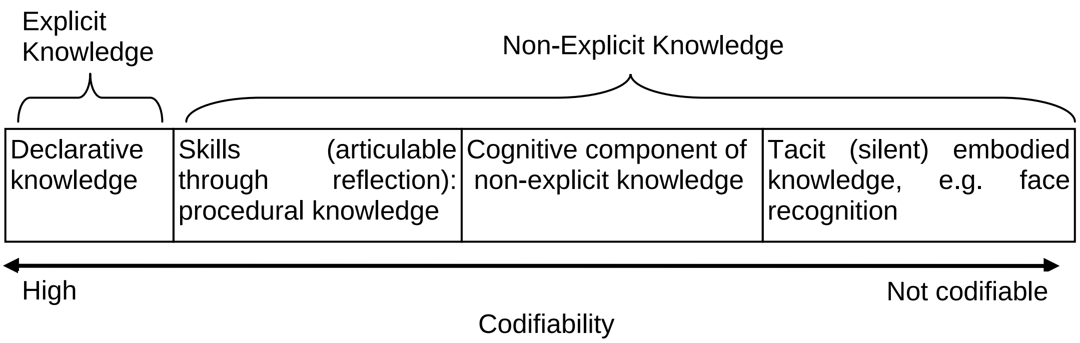

Figure 4: Dimensional knowledge classification according to Schindler (2002)

Extended dimensional model

As noted earlier, from the psychological viewpoint, implicit and explicit memory are different ways of using memory content: either consciously or unconsciously. At the same time, it was stated that knowledge can be articulated in varying degrees (see above). Both features can be seen as dimensions that span an area, onto which the different knowledge types can be mapped. This knowledge map also allows the inclusion of Nonaka and Polanyi's concepts that span several knowledge types.

With reference to the different types of knowledge introduced in previous sections, Polanyi's *tacit knowledge* can be equated with embodied knowledge and procedural knowledge. Polanyi made no reference to conscious or unconscious use; he only referred to knowledge that cannot be articulated.

Li and Gao stress that Nonaka's concept of tacit knowledge extends *beyond* Polanyi's view (see above). We thus assume that it is Nonaka's cognitive part of tacit knowledge that surpasses Polanyi and that it does include all unconscious uses of memory, inde-

pendent of the fact that they could possibly be verbalized. In this way, unconscious access to structural knowledge and weak declarative knowledge would be mapped to Nonaka's concept of tacit knowledge, but not to that of Polanyi. This assumption is supported by the fact that Nonaka and Takeuchi do assume that non-explicit knowledge elements can be made explicit through appropriate techniques.
According to Nonaka and Takeuchi, explicit knowledge can always be verbalized. Since verbalization requires conscious access to memory contents, declarative knowledge (both semantic and episodic) and the conscious use of structural knowledge can be connected with this concept. The model is summarized in Figure 5.

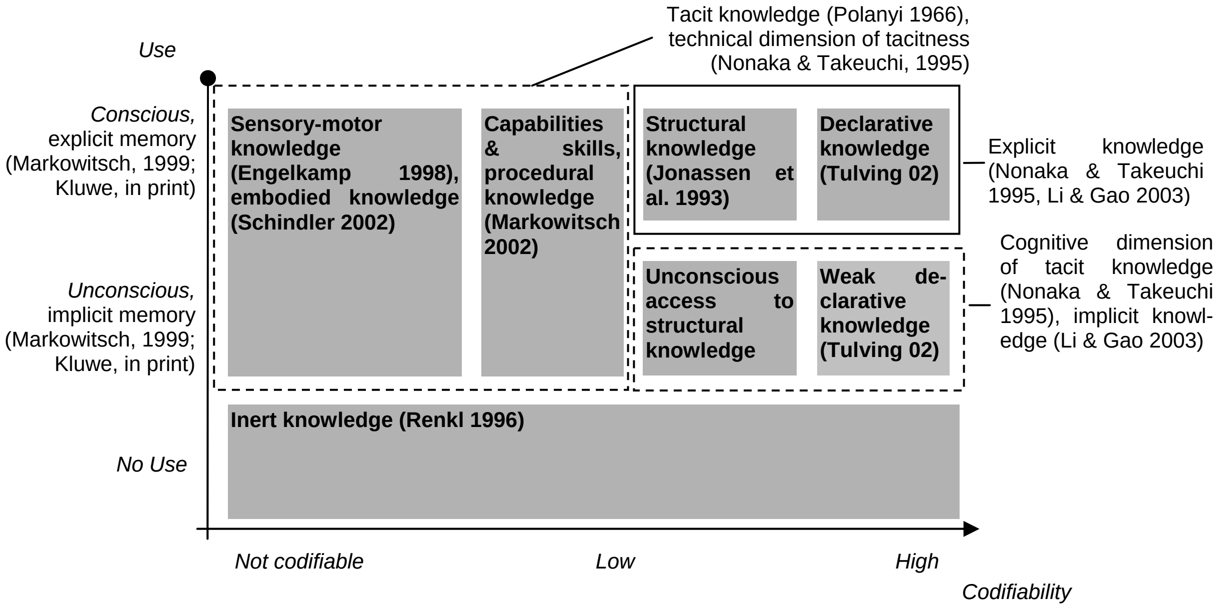

Figure 5: Extended dimensional model of knowledge types

It turns out that constructs from KM literature are not contradictory to findings from memory research and other fields of psychological research. They integrate several constructs in a way that does seem suitable in practice. Both Nonaka and Takeuchi's constructs can be linked to an empirically founded basis.

Empirical support

The potential of the developed framework lies in the fact that it makes a part of non-explicit knowledge, the unconscious access to structural knowledge, available to psychometric assessment. There are a number of empirical studies that try to access, elicitate and measure individual structural knowledge (Davis, Curtis, & Tschetter, 2003; Eckert, 1998a, 1998b; Goldsmith & Johnson, 1990; Goldsmith, Johnson, & Acton, 1991; Jonassen et al., 1993; Lee et al., 2002; Schvaneveldt, 1990; Schvaneveldt, Durso, & Dearholt, 1985; Schvaneveldt, Durso, Goldsmith et al., 1985). The method that is used in all of these studies is the structural assessment technique (SA, compare Jonassen et al., 1993 for a detailed description). The result of SA is a graph representing the semantic structure of individual knowledge within a specified domain. The nodes are knowledge elements, for example important actions for performing a specific task. The edges represent their relation from the subject's viewpoint.
In order to find empirical support for the model's essential assumption that there exists a difference between conscious and unconscious access to structural knowledge, an experiment was conducted.

Hypothesis and method

If structural knowledge can be accessed both consciously and unconsciously, we assume that the quantity of structural knowledge an individual can access consciously and subconsciously is larger than the quantity of structural knowledge that is only available consciously (that is, the subject can name the relation between two knowledge objects). Therefore, we put forward the following hypothesis:

A graph that represents individual knowledge in a certain field that only includes labelled edges (explicit structural knowledge) is smaller (i.e. contains less edges) than a knowledge graph that contains both edges that cannot be labelled and edges that can be labelled by the subject.

We used a two-staged, computer-based process to test this hypothesis. Subjects first had to associate concepts that, to their knowledge, relate to a certain knowledge domain. These associated words were stored in the computer's memory and were then, in a second stage, presented to the subjects as pairs. Subjects had to rate the degree of their relatedness, usually on a five-point scale. The concept x concept matrix of the paired ratings is the raw graph of the knowledge organization for the specified knowledge domain. The measurement error is met by applying the path-finder algorithm on this graph that removes all edges that violate the triangulation criterion (for details on this procedure and its theoretical background, compare Schvaneveldt, 1990). These pathfinder-adjusted graphs are referred to as PFNETs in the literature. PFNETs have proven to be an effective method for differentiating between experts and novices and are recognized as a valid representation of individual structural knowledge (Goldsmith & Johnson, 1990; Goldsmith et al., 1991). PFNETs can be analyzed with methods from graph theory and thus can be represented in a quantitative way.

In our setting, the second rating task of the test came in two different modes. In one mode, subjects were only allowed to make a connection between two concepts if they were able to explicitly state the nature of the connection. This mode was labelled 'explicit' mode. In the other mode, subjects were asked to make quick judgements on the relation between two concepts without having to explicitly state the nature of the connection. This mode was labelled 'implicit' mode. If the aforementioned hypothesis would hold true, subjects in the 'implicit' mode should have significantly more edges in their PFNETS as these would include both edges that could potentially be labelled and edges that could not. The two groups were compared using independent samples T-test as the obtained data is metric.

Subjects

30 graduate students at the department of organizational and social psychology of Humboldt University Berlin participated in the experiment for an extra seminar credit. All of them had previously completed a graduate seminar on organizational knowledge management. The knowledge domain in which subjects had to associate was thus chosen to be 'knowledge management' as all students were expected to have obtained both declarative and non-declarative knowledge in the field. Assignment to the 'implicit' and 'explicit' group was random. All subjects completed the test and associated concepts and edge labels were reviewed by the seminar instructor for face validity.

Results

The results with reference to average individual PFNET degree (number of nodes) and average size (number of edges) are given in Table I.

Table I: Comparison between explicit and implicit group (T-test for independent samples)

	Test mode					
	Implicit (N=15)		Explicit (N=15)			
Item	*M*	*SD*	*M*	*SD*	*p(t)*	d_u [a]
Graph degree (# of associated concepts)	13.40	5.99	10.09	5.66	.244[ns]	0.55
Graph size (# of edges)	53.47	45.35	25.53	15.72	.012*	0.79
Edges per node	3.47	1.40	2.21	1.01	.037*	0.99

Note. [a] Effect size Cohen's d with bias correction for small samples

Table I shows that subjects in the two groups did not associate a significantly different number of concepts in the first part of the test. Therefore a significant difference in the number of edges is not conditioned by the degree of the PFNETs. The average number of edges within the PFNETs does in fact differ significantly between the groups and, with an effect size of almost .80, to a large extent. If the number of edges is adjusted to the number of nodes in subjects' PFNETs, this effect is even stronger and reaches an effect size of almost 1.

Discussion

The above results cannot be seen as comprehensive empirical support for the model as the experiment was too small in scope. However its results support the posited hypothesis and thus these findings are not contrary to the statements of the model. There seems to be a difference between explicit structural knowledge and non-explicit structural knowledge in that subjects see more relations between concepts than they can label. These results correspond to the results of Davis, Curtis und Tschetter (2003), who showed that within the multiple correlation of structural knowledge and declarative knowledge onto a performance-based outside criterion, structural knowledge shows a significant additional explanation of variance. The fact that declarative knowledge and structural knowledge together do not fully explain the variance of a performance-based outside criterion underlines the fact that unconsciously used structural knowledge only captures a fraction of individual non-explicit knowledge.

Practical application

The main purpose of the model outlined earlier is the possible psychometric access to parts of non-declarative knowledge. A practical application could thus lie in the use of structural assessment techniques for evaluating KM approaches. However, another application of the model is possible and will be outlined in this section.

Apart from inert knowledge, concrete individual knowledge can be specified for each knowledge type that is specified in the model. It is possible to state what kind of specific declarative knowledge and skills an individual contributed to a project and what kind of weak declarative knowledge manifested itself during the course of a project. If structural knowledge is seen as mediating between declarative and procedural knowledge (see above), it is also possible to draw references to individual structural knowledge from the skilful and articulable application of a capability.

Breaking down project-relevant knowledge of individuals into these categories can add valuable detail to the analysis of project outcomes. At the Japan Advanced Institute of Science and Technology (JAIST), a framework for process analysis of organizational knowledge creation in academic research projects is currently being developed (Sugiyama, 2005). Its intention is to provide tools for precise analysis of small projects in order to discover how project members share contexts, cooperate, obtain, and exchange knowledge. The use of this framework will enable the identification of factors that are essential to a project's outcome.

The framework includes concrete small-scale applications of several Knowledge Creation (KC) theories such as the Equivalent Transformation Theory (Ichikawa, 1970), and the SECI Model (Nonaka & Takeuchi, 1995). The framework also includes an earlier version of the model from Figure 5. The model is used to guide the project leader in post-project evaluation in specifically stating the different knowledge types for each project member that contributed to the project's results. The work guide was developed during the evaluation of a project on abstraction and media conversion. During this project, team members developed strategies to formalize puzzles into abstract models (graphs) which could then be implemented in media that differ from the medium of the original puzzle, e.g. into graphs, blocks, sounds, or robots as shown in Figure 6 (Maeda, Sugiyama, & Mase, 2002; Sugiyama, Maeda, & Mizumoto, 2003; Sugiyama, Maeda, Osawa, & Mizumoto, 2005).

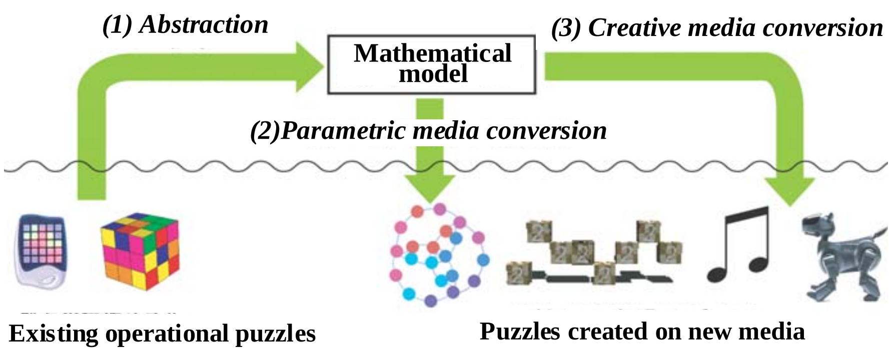

Figure 6: Project overview

Following project completion, the supervisor, based on his knowledge of the progress of the project, intuitively identified an organizational and knowledge network among related persons (see Figure 7) and assembled a list of critical individual knowledge for each member of the research team based on the dimensional model (compare Table II).

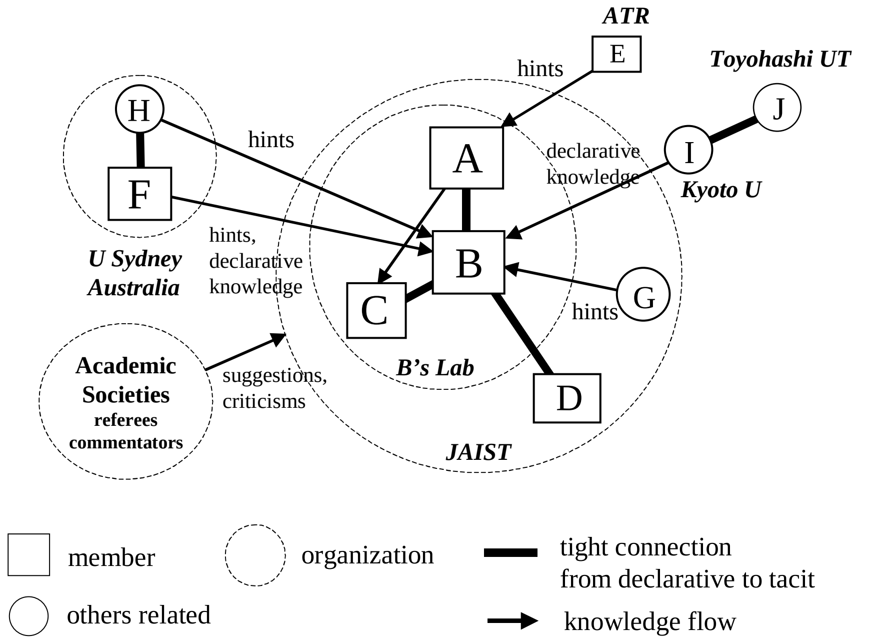

Figure 7: Individual knowledge exchange over different organizations during the project

Table II: Individual project-relevant knowledge in a small-scale research project as seen from the project's supervisor point of view after the project's completion (Sugiyama, 2005).

	Explicit Knowledge		*Non-Explicit Knowledge*			
Person	*Declarative Knowledge*	*Conscious access to structural Knowledge*	*Weak declarative knowledge*	*Unconscious access to structural knowledge*	*Acquired skills / procedural knowledge*	*Embodied knowledge*
A	Spring algorithm	How to utilize spring algorithm	Logic of puzzles	Equivalent transformation thinking	Programming skills for developing generators	Artistic senses
B	Graph drawing algorithm, Geometry, Graph theory	Mathematical formalizations	Logic of puzzles	Systems integration and analysis	Mathematical derivations	System thinking
C	Tutte algorithm				Programming skills	
D	AIBO control				Integration of IT tools, Programming	

The empty cells in the table indicate that the project supervisor assumes that these individual knowledge types did not contribute substantially to the project's outcome.

The use of such fine granular analysis is threefold. Firstly, the project supervisor realizes that it is more than knowledge of facts that contributes to the outcome of a project. Secondly, combined with cross-tables for inter-individual knowledge exchange that is based on the analysis of knowledge flows (compare Figure 7), knowledge flows within the project can be analyzed at a deeper level. Thirdly, this analysis can reveal potential areas for future improvements. For example if a project fails and the post-project analysis reveals a lack of individual non-explicit knowledge use or exchange, this could be an indicator for areas of improvement for future projects.

Sugiyama (2005) concludes that the work flow model which is in part based on this model was successfully employed in the analysis of a scientific research project and that he recognized evidence of the concepts. It is also stated that further research in the form of analysis of further cases is desirable. However in this concrete application, the model has proven to be of practical use in KM practice in addition to structural assessment.

Conclusion and outlook

In this paper, we have introduced memory models for individual knowledge representation and linked them to KM concepts such as Polanyi and Nonaka's concepts of tacit knowledge. In this way, we arrived at a dimensional model of knowledge types that proved to be of concrete use for application in a KM project. Some empirical support for the model's assumptions was also found.

Future studies that capture structural knowledge in a valid way and are able to demonstrate an additional explication of variance of a performance-based outside criterion through the inclusion of structural knowledge will have to be conducted. These will show whether the proposed dimensional conceptual framework for knowledge receives further empirical support. This includes the empirical evaluation of the hypothesis that access to structural knowledge can be unconscious.

As indicated above, current empirical and practical support are still very limited. The experiment's small sample size and its homogenous structure (30 HU students) do not allow generalization of findings. Further experiments that aim at replicating the findings outside the academic field using larger samples are currently under way, as well as validation experiments that deal with the test's predictive validity. At the same time, the outlined computer-based structural knowledge elicitation test is turned into a modular web-based application. If the validation experiments prove to be successful, the described test will be published under the name AST* (Association Structure Test) and will be available for organizational use. It will then allow an exact quantification of individual knowledge increase over time through pre-post-analyses. In this way, the test can be used for assessment of organizational knowledge management initiatives. If they are successful, employees should have more structural knowledge after the initiative than before. This assumption could be tested with the AST*.

Because of the small project size and possible social and cultural issues, the preliminary application of the model at JAIST is also difficult to generalize. Possible cultural issues include a higher demand for conformity and a strong awareness for hierarchy in Japanese project teams. In the presented case, the project leader intuitively assembled the list of team members' relevant contributed knowledge and project members may have refrained from correcting his assessment.

In order to tackle the limitations of the empirical findings, new experiments are being conducted at Humboldt University Berlin, focusing on the predictive validity of structural knowledge elicitation and on measuring knowledge increase over time. Therefore, attempts at predicting students' grades in future exams by features of their structural knowledge are being made. Furthermore, the changes of individual implicit and explicit knowledge graphs after face-to-face interaction are measured with the AST*. In this way, insights on constraints and enablers of successful knowledge sharing are gained and our understanding of the importance of shared educational backgrounds is broadened. In further studies, we seek to find empirical answers to questions such as: 'Do similar or dissimilar educational backgrounds lead to higher knowledge increases through interaction?'.

Despite the challenges that lie ahead in the course of empirically supporting the dimensional model, it has the advantage that knowledge management activities targeting non-explicit knowledge can be narrowed in their target focus, e.g. with the aim of targeting either motor skills or cognitive components. However the actual promise of the outlined dimensional framework lies in its inherent possibility to empirically evaluate knowledge-based activities that target individual non-explicit knowledge through structural assessment, as an increase in non-explicit knowledge should also lead to an increase in structural knowledge. This possibility justifies further investigations based on the proposed framework.

References

Amelingmeyer, J. (2004). *Wissensmanagement : Analyse und Gestaltung der Wissensbasis von Unternehmen* (3rd ed.) (in German). Wiesbaden: Dt. Univ.-Verl.

Argyris, C., & Schön, D. A. (1999). *Die Lernende Organisation : Grundlagen, Methode, Praxis* (in German). Stuttgart: Klett.

Busch, P. A., Richards, D., & Dampney, C. N. G. (2001). Visual mapping of articulable tacit knowledge. In P. Eades & T. Pattison (Eds.), *Australian Symposiumon Information Visualization, December 2001. Conferences in Research and Practice in Information Technology* (Vol. 9, pp. 37-47). Sydney.

Damerow, P., & Lefèvre, W. (1998). Wissenssysteme im geschichtlichen Wandel (in German). In F. Klix & H. Spada (Eds.), *Enzyklopädie der Psychologie* (Vol. 6: Kognition, pp. 77 - 114). Göttingen: Hogrefe.

Davenport, T. H., & Prusak, L. (1998). *Working Knowledge: How Organizations Manage What They Know*. Cambridge, MA: Harvard Business School Press.

Davis, M. A., Curtis, M. B., & Tschetter, J. D. (2003). Evaluating cognitive training outcomes: validity and utility of structural knowledge assessment. *Journal of Business and Psychology, 18*(2), 191-206.

Despres, C., & Chauvel, D. (2000). A thematic analysis of the thinking in knowledge management. In C. Despres & D. Chauval (Eds.), *Knowledge Horizons. The Present and the Promise of Knowledge Management* (pp. 55-86). Boston: Butterworth-Heinemann.

Dick, M., & Wehner, T. (2002). Wissensmanagement zur Einführung: Bedeutung, Definition, Konzepte (in German). In W. Lüthy, E. Voit & T. Wehner (Eds.), *Wissensmanagement - Praxis* (pp. 7-27). Zürich: vdf Hochschulverl. an der ETH.

Drucker, P. (1993). *Post-capitalist Society*. New York: Econ.

Eckert, A. (1998a). Die “Netzwerk Elaborierungs Technik (NET)” - Ein computerunterstütztes wissensdiagnostisches Instrumentarium (in German). *Diagnostica, 44*(4), 220-224.

Eckert, A. (1998b). *Kognition und Wissensdiagnose : die Entwicklung und empirische Überprüfung des computerunterstützten wissensdiagnostischen Instrumentariums Netzwerk-Elaborierungs-Technik (NET)* (in German). Lengerich: Pabst Science Publ.

Eigler, G. (Ed.). (1990). *Plato: Werke in acht Bänden. Bd. 6: Theaitetos, Der Sophist, Der Staatsmann, griech./dt., bearb. von P. Staudacher* (Vol. 6) (in German). Darmstadt: Wiss. Buchges.

Engelkamp, J. (1991). *Das menschliche Gedächtnis : das Erinnern von Sprache, Bildern und Handlungen* (2nd ed.) (in German). Göttingen: Verl. für Psychologie Hogrefe.

Engelkamp, J. (1998). *Memory for actions*. Hove: Psychology Press.

Engelkamp, J., & Pechmann, T. (Eds.). (1993). *Mentale Repräsentation* (in German). Bern: Huber.

Engelkamp, J., & Zimmer, H. D. (1994). *Human memory : a multimodal approach*. Seattle: Hogrefe & Huber.

European Council. (2000). *Lisbon European Council 23 and 24 March 2000: Presidency Conclusions*. Retrieved 09/24/2003 from http://www.europarl.eu.int/summits/lis1_en.htm

European Foundation for the Improvement of Living and Working Conditions. (2004). *Advancement of the knowledge society*. Retrieved 06/04/2004 from http://www.eurofound.eu.int/publications/files/EF0409EN.pdf

Fitts, P. M., & Posner, M. I. (1979). *Human performance*. Westport, Conn: Greenwood.

Forschungsinstitut für anwendungsorientierte Wissensverarbeitung (FAW). (2001). *Management von nicht-explizitem Wissen: noch mehr von der Natur lernen* (in German). Retrieved 05/20/2004 from http://www.faw.uni-ulm.de/deutsch/publikationen/bmbf-studie/BMBF_Studie_Teil_1.pdf

Goldsmith, T. E., & Johnson, P. J. (1990). A structural assessment of classroom learning. In R. W. Schvaneveldt (Ed.), *Pathfinder associative networks : studies in knowledge organization* (pp. 241-254). Norwood, NJ: Ablex Publ. Corp.

Goldsmith, T. E., Johnson, P. J., & Acton, W. H. (1991). Assessing Structural Knowledge. *Journal of Educational Psychology, 83*(1), 88-96.

Güldenberg, S. (1999). *Wissensmanagement und Wissenscontrolling in lernenden Organisationen* (in German). Wiesbaden: Gabler / Dt. Univ. Verl.

Ichikawa, K. (1970). *The science of creativity*. Tokyo: Japan Broadcast Publishing.

Jonassen, D. H., Beissner, K., & Yacci, M. (1993). *Structural knowledge : techniques for representing, conveying, and acquiring structural knowledge*. Hillsdale, NJ: LEA. Lawrence Erlbaum Associates.

Klimecki, R., & Thomae, M. (2000). *Zur Bedeutung von Strukturmodellen für das Wissensmanagement* (in German). Paper presented at the Workshop der Kommission Organisation 3 and 4 March 2000, Zurich.

Klix, F. (1984). *Gedaechtnis, Wissen, Wissensnutzung* (in German). Berlin: VEB Deutscher Verlag der Wissenschaften.

Kluwe, R. (in print). Informationsaufnahme und Informationsverarbeitung (in German). In B. Zimolong & U. Konradt (Eds.), *Enzyklopädie der Psychologie: Ingenieurpsychologie* (Vol. 2). Göttingen: Hogrefe.

Kogut, B., & Zander, U. (1992). Knowledge of the firm, combinative capabilities and the replication of technology. *Organization Science, 3*(3), 383-397.

Lee, S., Choi, K. S., & Choe, I.-S. (2002). *Representation of tacit knowledge in organizations*. Retrieved 04/06/2004, from http://www.alba.edu.gr/OKLC2002/Proceedings/pdf_files/ID121.pdf

Li, M., & Gao, F. (2003). Why Nonaka highlights tacit knowledge: a critical review. *Journal of Knowledge Management, 7*(4), 6-14.

Maeda, A., Sugiyama, K., & Mase, K. (2002). Media conversion of cyclic puzzles and development of cyclic puzzle generators. *IPSJ SIG Notes Human Interface, 101*, 40-47.

Markowitsch, H.-J. (1992). *Neuropsychologie des Gedächtnis* (in German). Göttingen: Hogrefe.

Markowitsch, H.-J. (1999). *Gedächtnisstörungen* (in German). Stuttgart: Kohlhammer.

Markowitsch, H.-J. (2002). *Dem Gedächtnis auf der Spur : vom Erinnern und Vergessen* (in German). Darmstadt: Wiss. Buch-Ges.

Nonaka, I., & Konno, N. (1998). The concept of “ba”: building a foundation for knowledge creation. *California Management Review, 40*(3), 40-54.

Nonaka, I., & Takeuchi, H. (1995). *The knowledge-creating company : how Japanese companies create the dynamics of innovation*. New York [u.a.]: Oxford Univ. Press.

Opwis, K., & Lüer, G. (1996). Modelle der Repräsentation von Wissen (in German). In D. Albert & K.-H. Stapf (Eds.), *Enzyklopädie der Psychologie* (Vol. 5: Gedächtnis, pp. 337-432). Göttingen: Hogrefe.

Polanyi, M. (1958). *Personal Knowledge*. London: Routledge & Kegan Paul.

Polanyi, M. (1966). *The Tacit Dimension*. Garden City, NY: Doubleday.

Polanyi, M. (1985). *Implizites Wissen* (in German). Frankfurt am Main: Suhrkamp.

Preece, P. F. W. (1976). Mapping cognitive structure: A comparison of methods. *Journal of Educational Psychology, 68*, 1-8.
Quillian, M. R. (1968). Semantic Memory. In M. Minsky (Ed.), *Semantic information processing* (pp. 227-270). Cambridge, MA: MIT Press.
Rehäuser, J., & Krcmar, H. (1996). Wissensmanagement im Unternehmen (in German). In G. Schreyögg & P. Conrad (Eds.), *Managementforschung 6: Wissensmanagement* (pp. 1-40). Berlin: de Gruyter.
Renkl, A. (1996). Träges Wissen: Wenn Erlerntes nicht genutzt wird (in German). *Psychologische Rundschau, 47*, 78-92.
Rothe, H.-J., & Warning, J. (1991). Zur Identifikation von semantischen Relationen im fachspezifischen Gedächtnisbesitz von Experten vermittels Analogiebildung (in German). *Zeitschrift für Psychologie, Supplement 11*, 375-384.
Scheele, B., & Groeben, N. (1984). *Die Heidelberger Struktur-Lege-Technik (SLT)* (in German). Weinheim: Beltz.
Schindler, R. (2002). *Knowledge sharing by means of lessons learned repositories: How to assist understanding, reflection and transfer.* Paper presented at the International Conference on the Future of Knowledge Management, 8-10.03.2002, Berlin.
Schnotz, W. (1994). *Aufbau von Wissensstrukturen : Untersuchungen zur Kohärenzbildung beim Wissenserwerb mit Texten* (in German). Weinheim: Beltz.
Scholl, W. (2004). *Innovation und Information. Wie in Unternehmen neues Wissen produziert wird* (in German). Göttingen: Hogrefe.
Schreyögg, G., & Geiger, D. (2003). Kann die Wissensspirale Grundlage des Wissensmanagements sein? (in German). *Diskussionsbeiträge des Instituts für Managements, 20*, 2-31.
Schütt, P. (2003). *Die dritte Generation des Wissensmanagements* (in German). Retrieved 04/11/2004 from http://www.km-a.net/file_upload/km-journal_1-03_schuett.pdf
Schvaneveldt, R. W. (Ed.). (1990). *Pathfinder associative networks: studies in knowledge organization*. Norwood, NJ: Ablex Publ. Corp.
Schvaneveldt, R. W., Durso, F. T., & Dearholt, D. (1985). *Pathfinder : Scaling with network structures*.
Schvaneveldt, R. W., Durso, F. T., Goldsmith, T. E., Breen, T. J., Cooke, N. M., Tucker, R. G., et al. (1985). Measuring the structure of expertise. *International Journal of Man-Machine Studies, 23*, 699-728.
Shavelson, R. J. (1972). Some aspects of the corrspondance between content structure and cognitive structure in physics instruction. *Journal of Educational Psychology, 63*, 225-234.
Sinz, R. (1979). *Neurobiologie und Gedächtnis: Neuronennetzwerke und Informationsspeicherung im menschlichen Gehirn* (in German). Stuttgart: Fischer.
Spender, J. C. (1996). Making knowledge the basis of a dynamic theory of the firm. *Strategic Management Journal, 17*, 45-62.
Squire, L. R., & Frambach, M. (1990). Cognitive skill learning in amnesia. *Journal of Psychobiology, 18*, 109-117.
Squire, L. R., Knowlton, B., & Musen, G. (1993). The Structure and Organization of Memory. *Annual Review of Psychology, 44*(1), 453-495.
Stehr, N. (1994). *Knowledge societies*. London: Sage.
Strube, G., & Schlieder, C. (1998). Wissensrepräsentation im Symbolverarbeitungsansatz (in German). In F. Klix & H. Spada (Eds.), *Enzyklopädie der Psychologie* (Vol. 6: Kognition, pp. 501-530). Götingen: Hogrefe.

Sugiyama, K. (2005). Framework Development and Process Analyses of Organizational Knowledge Creation in Academic Research Projects. Paper presented at the First World Congress of the International Federation for Systems Research IFSR2005, Nov 14-17, Kobe, Japan.

Sugiyama, K., Maeda, A., & Mizumoto, A. (2003). *Divergence via Abstraction: Practices for inventing new puzzles.* Paper presented at the 4th International Conference on Systems Science and Systems Engineering.

Sugiyama, K., Maeda, A., Osawa, R., & Mizumoto, A. (2005). Creating new puzzles: Practices of “abstraction and conversion” strategy. *Journal of the Japan Creativity Society, 8*, 1-20.

Tulving, E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson (Eds.), *Organization of memory* (pp. 381-403). New York: Academic Press.

Tulving, E. (1995). Organization of Memory: Quo vadis. In M. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 839-847). Camebridge, MA: MIT Press.

Tulving, E. (2002). Episodic Memory: From Mind to Brain. *Annual Review of Psychology, 1*(53), 1-25.

Vogel, E. K., Woodman, G. F., & Luck, S. J. (2001). Storage of features, conjunctions, and objects in visual working memory. *Journal of Experimental Psychology: Human Perception & Performance, 27*(1), 92-114.

von Glasersfeld, E. (1997). *Wege des Wissens : konstruktivistische Erkundungen durch unser Denken* (in German). Heidelberg: Carl-Auer-Systeme.

von Glasersfeld, E. (1996). *Radikaler Konstruktivismus : Ideen, Ergebnisse, Probleme* (in German). Frankfurt a. M.: Suhrkamp.

Whitehead, A. N. (1929). *The aims of education*. New York, NY: Macmillan.