Barbara Kump

TECHNOLOGY-ENHANCED WORKPLACE LEARNING: MODELLING COMPETENCE AND PERFORMANCE FOR THE CASE OF REQUIREMENTS ENGINEERING

Diplomarbeit

zur Erlangung des akademischen Grades einer

Magistra

an der Naturwissenschaftlichen Fakultät der

Karl-Franzens-Universität Graz

O. Univ.-Prof. Dipl.-Psych. Dr. Dietrich Albert

Institut für Psychologie

2006

DANKSAGUNG

Ich danke Prof. Albert, dem Hauptbetreuer meiner Diplomarbeit, für seine Unterstützung, für die konstruktiven Beiträge in diversen Phasen meines Arbeitsprozesses und für die wertvollen Hinweise zur Gestaltung dieses Manuskripts.

Mein besonderer Dank gilt Tobias Ley (Projektleiter am Know-Center in Graz), dem externen Betreuer meiner Diplomarbeit, der in einer Reihe von Gesprächen für meine Fragen zur Verfügung stand und der mich während meiner Arbeit immer wieder ermutigt und mit mir gemeinsam Lösungen gefunden hat.

Vielen Dank an Prof. Tochtermann, den Leiter des Know-Centers und Stefanie Lindstaedt, Leiterin des Bereichs Wissensmanagement, die es mir ermöglicht haben, diese Arbeit im Rahmen des APOSDLE-Projekts am Know-Center durchzuführen.

Ich bedanke mich bei Christian Kaernbach, während meiner Arbeit Professor für Psychologische Methodik und Computergestützte Modellierung, für seine Inspiration und Zuversicht.

Schließlich danke ich Armin Ulbrich, Gisela Dösinger und Herbert Kainz für all die fachlichen Ratschläge und aufmunternden Worte.

BESTÄTIGUNG

Die vorgelegte Arbeit „Technology-Enhanced Workplace Learning: Modelling Competence and Performance for the Case of Requirements Engineering“ wird als Manuskript bei einer einschlägigen Fachzeitschrift unter diesem Titel mit Frau Barbara Kump als Erstautorin eingereicht.

Die Arbeit wurde von Frau Barbara Kump selbstständig verfasst. Frau Kump wurde dabei von den beiden Co-Autoren, Prof. Dr. Dietrich Albert (Universität Graz) und Dr. Tobias Ley (Know-Center, Graz), fachlich unterstützt.

Prof. Dr. Dietrich Albert Dr. Tobias Ley

Technology-Enhanced Workplace Learning: Modelling Competence and Performance for the Case of Requirements Engineering

Barbara Kump
University of Graz (Austria)

Tobias Ley
Know-Center Graz (Austria)

Dietrich Albert
University of Graz (Austria)

Contents

Zusammenfassung

Das Ziel dieser Arbeit bestand in der Entwicklung einer Modellierungsmethode zur Aufbereitung von Wissensgebieten für computerunterstütztes arbeitsintegriertes Lernen. Die entwickelte Methode wurde am Beispiel der Lerndomäne Requirements Engineering (RE) erprobt. Die Modellierung erfolgte anhand des Kompetenz-Performanz-Ansatzes, einer mathematisch-psychologischen Theorie über den Zusammenhang zwischen beobachtbarem Verhalten und zugrunde liegenden Kompetenzen, welche eine Erweiterung der Wissensraumtheorie darstellt. Mittels Dokumentanalysen und ExpertInnenbefragungen wurden Kompetenz- und Performanzstrukturen erstellt. Bei eher niedriger Inter-Rater Reliabilität zwischen den beiden ExpertInnen-Modellen erreichten die Koeffizienten der Kreuzvalidierung zufriedenstellende Höhe. Aufgrund dessen erscheinen die Anwendung des Kompetenz-Performanz Ansatzes und die entwickelte Methode zur Modellierung der Lerndomäne (RE) vielversprechend.

Schlüsselwörter: Kompetenz-Performanz Ansatz, Wissensraumtheorie, Lernen am Arbeitsplatz, Adaptivität

Abstract

A modelling method was developed to work up different knowledge domains for technology-enhanced work-integrated learning. The method was tested at the Requirements Engineering (RE) domain. For this purpose, we chose the Competence-Performance Approach, a mathematical-psychological theory on human learning and performance that extended Knowledge Space Theory. In a case study, competence- and performance structures were established by document analyses and expert interviews. With moderate inter-rater reliability between the 2 experts' models, coefficients obtained by cross-validation were satisfying. Hence, the use of competence-performance theory and the developed method for modelling RE were considered promising.

Keywords: competence-performance approach, knowledge space theory, workplace learning, adaptivity

Introduction

Within the scope of Human Resource Development there is broad agreement that knowledge and competencies of employees are important – if not even the most important – competitive factors of organisations (e.g., Van den Berg, 1998; Drucker, 1998). Due to decreasing half-life periods of knowledge (see, e.g., Schüppel, 1997), previous notions of a divided lifetime of acquiring knowledge (in school and universities) and applying knowledge (in working life) do not longer hold (Hockemeyer, Conlan, Wade & Albert, 2003; Schroeder, 2002). Knowledge workers (for definitions see Kelloway & Barling, 2000; Hermann, Becker & Karapidis, 2005, Hermann, 2004) are bound to continuously acquire skills and knowledge in order to cope with the ongoing changes and developments they are facing at their workplaces. Without life-long learning, employees successively will suffer a loss of qualification.

From a learning perspective, knowledge workers constitute the future productivity challenge in the knowledge economy (Ley, 2006). Hence, learning and education have become an integral part of work activities and companies spend a lot of money for training their employees (for a statistics see European Commission, 2003).

In this context, one important concern is on contriving (physical or digital) learning environments that constitute best possible conditions for knowledge workers to overcome competency gaps (i.e. gaps between the competencies required for a task, and competencies the knowledge worker has available). Since workplace learning generally is not an end in itself but rather a means to an end, one central goal of such endeavours has to be the optimisation of knowledge transfer.

Transfer of Knowledge – Obstacles to Overcome

Efforts to attain optimal knowledge transfer by plunging workers into formal trainings (seminars, traditional eLearning courses, etc.) seem to be failed. It has been shown, that only a small amount of knowledge that is actually applied to job activities comes from formal training and that there is sparse transfer of knowledge and competencies to new circumstances (Ley, Lindstaedt & Albert, 2005; Beckett, 1999). According to Farmer, Lindstaedt, Droschl & Luttenberger (2004), this lack of transfer is caused by a disconnection in place, time, and context between the training conditions and the employees' actual working situation. Evidently, formal training is not the most efficient way of enhancing the workers' productivity since it comes along with obstacles impairing both speed and quality of knowledge transfer. These barriers may be overcome by bringing learning and education directly to the workplace and by integrating it into the context of a current task at hand ("training on the job"; workplace learning).

Technology has been seen as a possible solution in addressing the challenges of workplace learning and various tools to support knowledge transfer are available (e.g., Rollett, 2003). Especially, corporate eLearning attempts to transfer learning and knowledge acquisition more closely into the work process. Many times, however, these interventions have been designed with traditional learning and teaching settings in mind and – because of the course structure of traditional eLearning systems – knowledge transfer is still impaired due to a disconnection in context.

These are the shortcomings that are targeted by several new, more informal and adaptive approaches in technology-enhanced workplace learning. Schmidt (2004), e.g., suggests context-directed learning where the learning activity is not determined by a course structure but by the demands of certain tasks within the work process, i.e. by the working context. A similar form of integrating learning into the work practices is proposed by the AD-HOC approach (Lindstaedt, Farmer & Ley, 2004; Farmer et al. 2004; Ley, Lindstaedt & Albert, 2005).

A Process-Oriented Self-Directed Learning Environment (APOSDLE)

In contrast to more traditional learning forms, context-directed learning as well as AD-HOC learning are focussing on unintentional learning. Primarily, workers should be supported in performing a certain task. Additionally, they should acquire competencies to accomplish other tasks or to cope with new situations.

The APOSDLE project[1] was inspired by the central ideas of these approaches: The knowledge workers' productivity should be increased by supporting informal learning and teaching activities in the context of the workers' everyday work processes. Thereby, learning should be self-directed and should happen on demand.

An APOSDLE environment, among other things, should be able to identify discrepancies between the requests of a task at hand and the abilities, knowledge and competencies of a working person. Further, the system should provide the worker with accurate, useful learning content.

In addition to 'classical' learning resources (proper sections in eLearning courses, descriptions of work processes, guidelines), APOSDLE should reuse contents not originally intended for learning, such as previous work results or other knowledge artefacts. Moreover, informal communication between workers (e.g. informal meetings, e-mail correspondence, book recommendations) should be recorded and made available as 'learning material' for other workers facing the same difficulties.

Managing Learning Content in APOSDLE

Within an APOSDLE environment, additional to conventional materials, almost every (side-) product of work could serve as learning content. Without any kind of pre-selection, a worker looking for assistance at a certain task might be facing a vast amount of information that is little help when he or she is being subjected to time pressure. To work, learn and teach efficiently, a knowledge worker should be provided with optimal guidance to manage the large variety of knowledge artefacts available. The question arising at this point is on how to provide a worker with 'ideal' information, i.e. how to pick learning content being the most appropriate for the respective task as well as for the worker's level of expertise.

The issue of adaptivity plays a central role in current eLearning research and development (Albert, Hockemeyer & Wesiak, 2002) and is even more important, when learning, in the first instance, is a means to perform a task at hand. In such situations, learners are seeking information that is neither redundant (i.e. already known) nor incomprehensible. While a human teacher easily, intuitively, and in a flexible manner is able to respond to the learner's (work related) needs, establishing adaptivity constitutes a complex and demanding matter within the construction of a technology-enhanced learning environment (Dösinger & Albert, 2002; Lindstaedt & Ulbrich, 2006).

Modelling Learning and Teaching with APOSDLE – A Psychological View

From a psychological perspective, four components have to be taken into account when building an adaptive computer-based learning and teaching environment: the Knowledge Base, the Student Model, the Teaching Model and the Interactive Human Computer Interface (e.g. Albert, 2001; Albert, Hockemeyer & Wesiak, 2002).

The Knowledge Base contains the structured expert knowledge about a certain domain. The Student Model represents the hypothetical knowledge state and other attributes of the student (e.g., misconceptions, general skills). It constitutes the rationale for individualised pedagogical interventions and has to be adapted to the learning progress. The Teaching Model designates the pedagogical interventions with regard to the Knowledge Base, the Student Model, didactical strategies, the learning context and the learning goal. Finally, the Interactive Human Computer Interfaces are for presenting information to and receiving information from the student. The major concern of the present work is on modelling the Knowledge Base and the Student Model. In the following, the first three components are briefly discussed, the latter, Interactive Human Computer Interfaces, are neglected.

In line with the conception above, after having defined a knowledge domain, the Knowledge Base is to be built. The first step in structuring a domain is to divide all the expert knowledge in small units of information (Albert & Kaluscha, 1997). Usually these are referred to as “items” or “problems”, here – in the context of workplace learning – they are termed “tasks”.

In the past, the use of information technology at the workplace has been primarily concerned with supporting work performance (Ley, Lindstaedt & Albert, 2005). Sole performance support, however, appears unsatisfying with regard to sustainability. The authors claim that, in the sense of a more holistic idea of workplace learning, it would be essential to look at human competencies and their role in the production of performance. The aim should be on the development of competencies that enable workers to perform well not only in the situation at hand but in a broad range of situations. In accordance with this idea, an APOSDLE environment should promote the acquisition of novel competencies that could be applied to other, new tasks (Lindstaedt, Ley & Mayer, 2005). Assigning to each task of a domain these competencies necessary for its accomplishment constitutes one possible second step in structuring the Knowledge Base.

The Student Model of an eLearning system explicitly captures – amongst others – the learner’s knowledge and skills. Thus, the model for every worker must include a profile which contains the worker’s abilities either in terms of (latent) competencies or in terms of (observable) tasks he or she is able to achieve, or in terms of both.

Structuring the Knowledge Base and building the Student Model by the use of competencies has two decisive advantages. Firstly, in the field of workplace learning, “it can be expected that tasks change more or less frequently. Secondly, the set of tasks is possibly very large. In contrast, the set of competencies should be smaller, and also is expected to change less frequently” (Ley, 2006, p.57).

By the Teaching Model of an eLearning system, the pedagogical interventions for every learning situation have to be decided. For a worker seeking assistance at a certain stage of work, an APOSDLE system should identify discrepancies between the worker’s knowledge and competence state (as depicted in the Student Model) and the requirements of the task (as stored in the Knowledge Base). Then, the worker should be provided with learning content to help him or her acquiring the missing competencies.

Aim and Scope of the Present Work

The general scope of the APOSDLE project was, to build a learning- and working environment for knowledge workers (e.g. semi-educated RESCUE experts). This learning- and working environment should allow to systematically (further-) educate knowledge workers during their work (in the concrete example the work as prospective RESCUE expert) and to control the increase of competencies.

Within the present work, a method should be developed to create the Knowledge Base and the Student Model of such an adaptive learning- and working environment for global distributed workplaces. The method should be functional in various fields of knowledge work and it should allow for examining standard psychological quality criteria (reliability, validity). As a first step, the developed modelling method should be applied to parts of the RESCUE-process (Activity Modelling and System Goal Modelling).

A Competence-Performance Approach was chosen to establish the Knowledge Base and the Student Model with the help of actual RESCUE experts (for both, performing and educating RESCUE).

The learning- and working environment to be developed within the APOSDLE project should later be employed for workplace learning (training on the job) of prospective

RESCUE experts. The question of the environment's practical usefulness, i.e. the Knowledge Base's, the Student Model's and the Teaching Model's validity would have to be subject of further investigations (as conducted, e.g., in Albert & Steiner, 2005).

A Competence-Performance Framework

A theoretical framework that addresses the challenges discussed in the previous sections is the <u>Competence-Performance Approach</u> (Korossy, 1993, 1997, 1999a, for similar conceptions see Düntsch & Gediga, 1995, or Doignon, 1994), a mathematical psychological theory that originated from research into the <u>Theory of Knowledge Spaces</u> (see, e.g., Doignon & Falmagne, 1985; Falmagne, Doignon, Koppen, Villano & Johannesen, 1990; Doignon & Falmagne, 1999). Subsequently, key concepts of these approaches will be presented in a simplified manner: Actually, both theories explicitly take into account the case of more than one possible "learning history" (Doignon & Falmagne, 1999, p. 62) for a task. Within the present work, only one such learning history is to be modelled.

<u>Knowledge Space Theory</u>

Being aware of the technical improvements and the increasing impact of computers on learning and teaching, Doignon & Falmagne early recognised the necessity for the effective computerised diagnosis of a learner's knowledge. The authors chose a formal, qualitative approach, the <u>Knowledge Space</u> (e.g., Doignon & Falmagne, 1985, 1999).

The Theory of Knowledge Spaces presupposes that a field of knowledge, for instance, <u>algebra</u>, <u>grammar</u>, or <u>chess,</u> can be parsed into a set $\mathcal{A}$ of problems (or tasks) $x \in \mathcal{A}$ each of which has a correct response. $\mathcal{A}$ has to be large enough to give a fine-grained, representative coverage of the field. Instances for tasks from the RE domain are <u>Plan and Prepare Acquisition Sessions</u>, <u>Build a First-Cut Context Model to Identify System Boundaries</u> or <u>Identify a Basic List of Stakeholders</u>.

According to Knowledge Space Theory, every person is able to solve a particular subset $\mathcal{Z}$ of problems of $\mathcal{A}$, he or she is in a particular knowledge state $\mathcal{Z} \subseteq \mathcal{A}$ (later called performance state). This knowledge state is not directly observable but can be inferred from the person's solution pattern. One of the central ideas of Knowledge Space Theory is that there exist solution dependencies among problems of a domain. These solution dependencies are formally denoted by a surmise relation $\prec \subseteq \mathcal{A} \times \mathcal{A}$ that is interpreted by the concept of precedence: When $a \prec b$ holds for two problems $a, b \in \mathcal{A}$, one can say that a is surmisable from b or that a precedes b. An RE example is a surmise relationship between the two tasks (a) Build a First-Cut Context Model to Identify System Boundaries and (b) Develop an Extended Context Model to Refine System Boundaries. The relationship $a \prec b$ means that from a person being able to develop an extended Context Model one could infer the person being able to build a first-cut Context Model. Accordingly, every performance state in that domain that contains task (b) would also contain task (a).

The surmise relation structures the set $\mathcal{A}$ of problems and thus not every subset of $\mathcal{Z}$ constitutes a feasible knowledge state. The set of all feasible knowledge states in a set $\mathcal{A}$ is called knowledge structure (later performance structure) $\mathcal{P}$ on $\mathcal{A}$, denoted by the pair $(\mathcal{A},\mathcal{P})$. If $\emptyset, \mathcal{A} \in \mathcal{P}$ and $\mathcal{P}$ is stable under union, the pair $(\mathcal{A},\mathcal{P})$ is called knowledge space (later performance space) on a domain.

The closure under union is very useful since it allows for the building of a base. The base of a knowledge space is the set of knowledge states that cannot be generated by taking unions of other knowledge states but that allows spanning the whole knowledge space by taking unions. In other words, each knowledge state in $\mathcal{P}$ can be written as union of base elements.

At least three decisive advantages of the Theory of Knowledge Spaces are mentioned: Firstly, coherences that are asserted on a theoretical level are proven mathematically. Secondly, since knowledge states are modelled as empirically expectable solution patterns, a knowledge representation model can be directly exposed to empirical validation. Thirdly, a valid knowledge structure or knowledge space can be utilised as a frame for personalised knowledge diagnosing and adaptive teaching.

Competence-Performance Approach

Korossy (1993, 1997, 1999a) and others supposed to extend Knowledge Space Theory. They proposed to model the knowledge of a person in a twofold manner by regarding his or her competencies and skills on the one hand and his or her performance on the other hand.

In line with Korossy, performance “is conceived as the empirically observable solution behavior on a particular set of problems” (Korossy, 1997, p.58). In contrast, the competencies of a person are latent, i.e. they constitute “theoretical entities for the explanation and prognostication of performance” (Korossy, 1997, p.58).

Korossy took from Doignon & Falmagne’s theory the idea to describe a domain by a set $\mathcal{A}$ of problems $x \in \mathcal{A}$. He also kept the formal structures suggested by the authors, but he changed the notation from “knowledge” into “performance” spaces (or states and structures respectively). What he did was to additionally describe a domain by a set $\mathcal{E}$ of elementary competencies $\varepsilon \in \mathcal{E}$ for each of which can be decided whether a person has this competency or not. Competencies in the RE domain could be, e.g., data-gathering skills, or knowledge about adjacent systems. As for the problem set, a surmise relation is assumed on the set of elementary competencies. The knowledge, ability or skills of a person form his or her competence state K. The set of all feasible competence states can be modelled through a finite, non-empty family of competence states, the competence structure $(\mathcal{E}, \mathcal{K})$. The pair

$(\mathcal{E}, \mathcal{K})$ is a competence space if $\emptyset, \mathcal{E} \in \mathcal{K}$ and $\mathcal{K}$ is stable under union. Analogue to the performance space, the competence space allows for building a base.

The (formal) linkage between competencies and performances happens by defining a function for the relationship between single tasks and sets of elementary competencies. For each problem $x \in \mathcal{A}$ and each competence state $K \in \mathcal{K}$ it is uniquely determined whether or not x can be solved in K. The set of problems $\mathcal{A}$ is interpreted in $\mathcal{K}$ by the mapping $k(\mathcal{A})$ which is called interpretation function. The interpretation function assigns to each problem $x \in \mathcal{A}$ a set k_x that contains all competence states $K \in \mathcal{K}$ the problem can be solved in. To define a competence state $K \in \mathcal{K}$ in which a person has to be at the minimum for mastering a certain problem, Korossy (e.g., 1997) introduced the conception of a minimal interpretation, $Min\ k_x$, of a problem $x \in \mathcal{A}$. For example, a person trying to build a first-cut Context Model might need at least the two competencies knowledge about Context Models and knowledge about adjacent systems. These two competencies thus would form the minimal interpretation of the task.

On the basis of the interpretation function, for each competence state (and each person respectively) a performance state $Z \in \mathcal{P}$ can be identified, i.e. the set of problems a person in the respective competence state is able to solve. The mapping $p(\mathcal{K})$ assigns to each competence state $K \in \mathcal{K}$ the unique (possibly empty) set of all problems solvable in K. This mapping is termed representation function. Note that the representation function is fully determined by the interpretation function.

Within the present work, a model consisting of a competence space, an interpretation and a representation function and a resulting performance structure is referred to as competence-performance structure (compare the concept of a diagnostic in, e.g., Korossy, 1997).

Practical Applications

The practical convenience of knowledge spaces and competence-performance structures has been demonstrated in several areas. The approaches were integrated in environments for adaptive testing and teaching in high-school Mathematics (ALEKS; see ALEKS Corp., 2003) or for a system to learn and teach elementary probability theory (RATH; see, e.g. Hockemeyer & Albert, 2003). The application of Knowledge Space Theory was also suggested for modelling less formalised fields such as workflow-processes (Stefanutti & Albert, 2002), educational and cross-cultural values (Albert, Pivec, Spörk-Fasching, & Maurer, 2003) or child philosophy (Pilgerstorfer, Albert & Camhy, 2006). Ley & Albert (2003a) proposed for using Competence Performance Theory in Knowledge Management to establish worker profiles in order to derive individual education needs. Ley (2006) examined the approach's applicability in four case studies and obtained promising results in terms of construct validity.

Building a Competence-Performance Model

Korossy (e.g., 1997, 1999b, see also Korossy & Held, 2001) describes the milestones and key deliverables in the process of a competence-performance structure's development:

A particular domain with typical problems or tasks and corresponding solution ways has to be defined. A set of elementary competencies has to be established and it has to be structured with regard to "diagnostically relevant" prerequisite relationships (Korossy, 1999). For each competence state of the thus obtained competence space, suitable problems are to be selected and the resulting performance space has to be designed.

Knowledge Space Theory and Competence Performance Approach are principally applicable in every domain that can be structured. Naturally, there are several domains, e.g., the field of school Mathematics, that are structured more easily than others, e.g., work domains such as RESCUE. For the latter, establishing a surmise relation on the set of elementary competencies constitutes the main challenge: One can easily imagine, that experts may be overstrained when they are asked to decide whether, e.g., analytical skills are prerequisites for the ability of abstraction, whether it is right the other way round or whether the two are independent from each other.

In order to overcome the difficulty of directly establishing a surmise relation on the set of elementary competencies, Ley & Albert (2003a, 2003b, see also Ley, 2006) introduced the simplified method of a task-competency matrix. The idea is, to identify feasible competence states by means of competence-requirements of single tasks and of sets of tasks: If a person is able to perform a certain task, he or she has to have all required competencies. Hence, building the minimal interpretation of a task leads to a feasible competence state. By closing the set of minimal interpretations under union, the set of all feasible competence states in a domain, i.e. the whole competence space, is obtained.

To apply the task-competency matrix in a certain domain, a set of tasks has to be identified and a set of competencies potentially necessary for performing all tasks in the domain has to be generated. The two sets are linked by means of the task-competency matrix, a table where to each task is assigned the set of competencies necessary for performing the task (the task's minimal interpretation). These competence states are closed under union to build a competence space on the set of elementary competencies. The corresponding performance structure is spanned by assigning to each competence state the set of tasks that are solvable in the respective state.

Note that the resulting performance structure is not necessarily union-stable (For conditions to create union stable performance structures and union-preserving representation functions respectively see, e.g., Korossy, 1997).

Evaluating the Reliability of the Competence-Performance Model

Evaluating the reliability of competence-performance models means to examine the degree to which the process of the models' establishment is independent to accidental circumstances, e.g. to guessing of the developer(s). In psychological diagnostic and test-theory, three aspects of reliability are mentioned: test-retest reliability, split-half reliability and internal consistency (see, e.g., Bortz & Döring, 2002).

For the present work, because of building models with the help of experts, inter-rater agreement (e.g., Wirtz & Caspar, 2002) was considered the most interesting to examine: If two experts are building similar models independently from each other, this would constitute a strong indicator for the models' reliability. If the experts would not arrive at similar models, this would imply that, on the one hand, they have different views on the domain and, on the other hand, at least one of the models is inadequate (i.e., its validity is impaired).

Evaluating the Validity of the Competence-Performance Model

The validity of a competence-performance model concerns the model's usefulness for accurately prognosticating performance in the context of the model's application.

An empirical validation in this context means to prove, whether predicted performance states coincide with observed solution patterns. This has been carried out for several domains, e.g., Chess, Word Problems and Mathematics (e.g., Albert & Lukas, 1999; Doignon & Falmagne, 1999).

For competence-performance models in Knowledge Management, only several of the common aspects of psychological validity – content validity, criterion validity, construct validity (see, e.g., Bortz & Döring, 2002) – have been explored (see Ley, 2006; Ley & Albert, 2003b).

In work domains such as RESCUE, a direct validation by comparing predicted performance states with observed solution patterns is difficult for several reasons. A sufficient amount of workers is required, who are neither able to achieve every task nor failing at every task. And, probably even more problematic, in order to obtain accurate solution patterns, every person under consideration must have tried to perform every task of the domain. Both may be hard to find in knowledge work. Hence, alternative validation methods have to be found.

One possibility to overcome the problem of a missing (external) validation sample by re-sampling the modelling sample is the Leave One Out method suggested by Lachenbruch (compare Bortz, 1999; see also Schröder & Reineking, 2004). The Leave One Out method is a special cross-validation technique. For this method, one incident (e.g. a person's performance at a certain task) is predicted on the basis of the model from all other (n-1) incidents. This is repeated n times, until each incident has been predicted. Conclusions can then be drawn from a comparison of the left out incidents (e.g. the person actually is able to perform the task) and the respective predictions.

The application of Leave One Out in the context of a competence-performance model's validation requires the complete solution pattern of at least one person.

The Learning Domain: Requirements Engineering with RESCUE

The domain selected for modelling technology enhanced workplace learning was requirements engineering, more concrete, the RESCUE process. RESCUE constitutes a typical example for knowledge work as should be supported by an APOSDLE environment: Requirements engineering with RESCUE has a (more ore less) fixed structure, it is rather complicated, and it requires extensive education and training.

Requirements engineering is "the branch of software engineering concerned with the real-world goals for functions of and constraints on software systems." (Zave, 1997, p. 315).

The aim of any requirements engineering activity is, to identify a number of critical requirements for a future system which is essential to the success of a software product. In order to standardise the course of requirements engineering, the RESCUE process (Requirements Engineering with Scenarios in User-Centered Environments, Maiden & Jones, 2004a) was developed. The outcome of RESCUE is a standardised Requirements Specification that consists of correct, consistent and valid requirements for a future system. Throughout the RESCUE process, different modelling and analysis activity, i.e. different so-called streams, are running in parallel. These sub processes strongly inform each other and are aligned at designated synchronization points.

Activity Modeling is done to provide an understanding of how people work in order to baseline possible changes to it. Data on human activities are gathered by the use of different acquisition techniques. These data are structured into activity descriptions and the Activity Model is built. The aim of the second stream, System Goal Modeling, is to model the future system boundaries and to identify dependencies between actors for goals to be achieved. This is done by building a Context Model that is refined stepwise. The result is a graphical Strategic Rationale Model that depicts what actors can achieve on their own and what they are depending on others for. System Goal Modeling is formalised with i* notation, a graphical syntax and semantics to support the modelling of organisation goals and the relationships of these goals with respect to tasks, resources and requirements, as well as other goals. Use Case Modeling is the process of writing use cases, exploring it with stakeholders and carrying out impact analyses. During the whole elicitation process, RESCUE provides guidance on Requirements Management, which is the fourth stream.

The domain chosen for the case study were only RESCUE’s first two streams, Activity Modelling and System Goal Modelling.

Research Questions and Targets of the Case Study

The present case study was pursuing the following targets:

Firstly, an efficient and economic modelling method should be developed in order to tackle the challenges in establishing competence-performance structures for a knowledge work domain such as RESCUE. In a next step, competence-performance models for the RESCUE domain should be built with the help of RESCUE experts. Task-competency matrices should be used to link tasks and competencies and to identify surmise relationships on the set of competencies and the set of tasks respectively.

The second research question was, if the developed way of modelling competence-performance structures would lead to reliable results in terms of inter-rater agreement. In the concrete case, inter-rater agreement should be examined by reviewing contingency for two domain experts' task-competency assignments. Would two experts who had applied the modelling method independently from each other arrive at similar results?

Thirdly, the validity of the two experts' models should be explored by means of the Leave One Out technique. Would the models' predictions allow for accurately prognosticating the performance of workers at certain tasks?

Finally, the question should be answered, whether the modelling method was convenient or whether it was inappropriate at certain stages. In this context, another endeavour of the case study was on exploring the effort coming along with the construction of competence-performance structures.

Method

In the following, we firstly present the method that was developed to establish and evaluate competence-performance structures for knowledge intensive work domains, specifically the RESCUE domain. Subsequently, involved experts, materials and the procedure of the case study are described in more detail.

Overview Over the Developed Modelling Method

The aim was on developing a realistic, useful method for modelling global distributed work-processes such as RESCUE. As much information as possible should be gathered by document analyses, and by reusing existing sources (e.g. competency catalogues). At critical stages of the modelling process (e.g., the review of task lists, or the task-competency assignment), two RESCUE experts in England were consulted, who consented to participate in the case study. One important concern of the modelling method was to minimise the RESCUE experts' efforts.

The developed modelling method was including techniques focussing on divergent thinking (e.g. brainstormings) so that input from experts in related fields was considered fruitful. Hence, three more experts were asked to participate in the case study.

Gathering Tasks and Elementary Competencies

First of all, sets of tasks to be achieved in the Activity Modelling and System Goal Modelling streams had to be detected. Since a number of existing documents and tutorials were giving a detailed description of the RESCUE process, a content analytical approach was chosen. In order to maximise completeness and correctness of the tasks lists, the results of the content analysis was reviewed by domain experts. In a next step, a set of possible elementary competencies was compiled. Again, it was decided to draw upon existing sources, both RESCUE specific and non-specific (e.g. existing competence catalogues). In addition, domain experts and experts from related fields were asked to brainstorm competencies necessary for the accomplishment of certain tasks. In doing so, an extensive list of candidate elementary competencies should be produced. The list was reduced by bundling and categorising competencies. A competence catalogue was compiled by adding descriptions and examples to each competency. As the lists of tasks, also the competence catalogue was reviewed by RESCUE experts.

Linking Tasks and Competencies

Because of their practical convenience, it was decided to use task-competency matrices for having domain experts defining each task's minimal interpretation.

Within a task-competency matrix, each expert got the possibility to assign to each task competencies considered 'mandatory' (value 2) and competencies considered 'somehow important' (value 1) for its accomplishment. All other task-competency combinations in the matrix were regarded as 'not important' (value 0). For the effective building of competence-performance structures, only competencies considered mandatory were taken into account. This procedure was suggested by Ley (2006), in order to avoid experts assigning too many competencies to one single task.

Evaluating the Reliability of Competence-Performance Structures

To assess reliability in terms of inter-rater agreement between two experts' task-competency assignments, contingency-tables were produced and a contingency coefficient, τ_b, (see Kendall, 1962, derived from τ, Kendall, 1938; for an overview of according measures see e.g., Agresti, 1984; or Liebetrau, 1985) was computed. The range of τ_b is between +1 (only concordant values in the assignment) and –1 (only discordant values) with 0 indicating two uncorrelated samples. The coefficient's significance is established by testing it against the z-distribution (see, e.g., Agresti, 1984).

Inter-rater agreement was examined for the whole task-competency assignment as well as for parts of it, e.g., for single tasks or single competencies.

Consistency-coefficients of single tasks were used to compare the assigned competencies. This was done to see whether there were tasks of particularly high or low agreement. Furthermore, τ_b was computed for each competency separately to compare the assigned tasks. The purpose at this was to identify competencies of exceptionally high or low agreement. Regarding the results of both, contingency across tasks and across competencies, enabled assumptions on what – inadequate descriptions of tasks or poorly defined competencies – might have been the reason for eventually low agreement.

Spanning Competence-Performance Structures

Competence-performance structures were built separately for the two experts and the two streams. Structures were directly derived from task-competency matrices. The sets of competencies associated to a particular task with value 2 were regarded as minimal interpretations for the respective tasks. The set of elementary competencies for each structure was determined by uniting the minimal interpretations of all tasks in the respective assignment. The bases of the competence spaces were built by removing minimal interpretations that were equal to the union of two or more other minimal interpretations. For each expert, a surmise relation on the set of competencies was derived. A pair (a, b) of competencies was element of the surmise relation $a \prec b$ if every competence state that contained b also contained a. By closing the base states under union and by adding $\emptyset$, the whole competence space was spanned. The representation functions were defined by assigning to each competence state the associated performance state, i.e. the set of tasks that could be achieved by a person being in that particular competence state: The performance state that represents a competence state contains exactly these tasks with a minimal interpretation that is a subset of the competence state. Consequently, a performance structure is established on the set of tasks.

Merging Assignments

In the case of high agreement between the RESCUE experts’ minimal interpretations, it was intended to aggregate their assignments and to that way establish a common competence-performance structure.

To integrate two (or more) knowledge spaces, Dowling (1994; see also Dowling & Hockemeyer, 1996; Baumunk & Dowling, 1997) argued for taking the union of both spaces.

While the authors built knowledge spaces by querying experts directly about surmise relationships between problems, for the present case study, the indirect method of a task-competency matrix was chosen. Hence, it was decided to integrate the two experts' task-competency assignments not by uniting whole competence spaces but by uniting each task's minimal interpretations. In other words, each competency at least one of the experts had considered 'mandatory' for the accomplishment of a certain task was also considered 'mandatory' in the merged assignment.

Evaluating the Validity of Competence-Performance Structures

Lacking the needed amount of empirically observed solution patterns that could be compared with predicted performance states, a re-sampling approach, the Leave One Out cross-validation technique, was chosen.

As mentioned above, the Leave One Out method requires the solution pattern of at least one person who has tried to accomplish every task and who was neither performing well in every task nor failing at each one. Unfortunately, such persons (and solution patterns respectively) were not available. In order to obtain best possible estimations of real solution patterns, the experts were asked to generate notional solution patterns of five Requirements Engineers with various degrees of expertise they both knew well (the procedure is described below). These five persons' solution patterns built the basis for the cross-validation.

For Leave One Out, one competence-performance model is looked at. The solution pattern of one person is reviewed and the person's performance in one of the tasks is left out. His or her competence state is inferred from the solution pattern in the remaining tasks by taking the union of all mastered tasks' minimal interpretations. From the thus obtained competence state, the person's performance in the left-out task is predicted: If the left-out task's minimal interpretation is a subset of the competence state, the person should perform the task well. Otherwise, the person should not be able to perform the task. This procedure is repeated for each task and each person under consideration.

Contingency can be examined for a competence-performance model's predictions and the assessed performance in the original solution patterns.

Experts

In modelling the RESCUE domain both, RESCUE experts (in England) and experts from related fields of knowledge (in Austria) were involved.

One RESCUE expert (in the following referred to as Expert 1) was Professor of Systems Engineering who was principal investigator on numerous projects in the fields of RE, and socio-technical systems design. The other RESCUE expert (Expert 2), a Research Assistant of Expert 1, did a lot of work on human-computer interaction and RE. She also taught various courses and published a large amount of papers in related areas. Both domain experts had a huge expertise in RESCUE's second stream, System Goal Modelling, and a lot of knowledge about, but less practical experience with the first one, Activity Modelling.

Three more experts were concerned with the acquisition of competencies. Expert 3 was a project manager in the field of Knowledge Management. He has a PhD in Psychology and had already applied the Competence Performance framework in Competency Management. Expert 4, female, was the department head of a Knowledge Management organisation with a PhD in Computer Science. Expert 5, male, was a computer scientist who wrote a thesis on a computer support system for RESCUE.

Document Analyses – Identification of Tasks and Elementary Competencies

The identification of tasks and competencies was largely based on existing documents and previous work.

Documents

The main part of tasks were elicited from the extensive RESCUE process documentation (Maiden & Jones, 2004a), a very detailed description of the four streams that includes theory as well as worked examples and practical guidance. Other documents used were a collection of illustrating examples of performing RESCUE (Maiden & Jones, 2004b), and a short description of the method (Maiden, Jones & Flynn, 2003).

Moreover, existing competency catalogues, e.g., from Van den Berg (1998) or the Occupational Information Network ("O*NET", National O*NET Consortium, 2005), were used for the compilation of the set of competencies. The latter, "O*NET", is a database of worker attributes that was created to support, e.g., the development of job descriptions.

Content Analysis

In order to identify the tasks to be accomplished by a person conducting Activity Modelling and System Goal Modelling and to accumulate elementary competencies, a Summarising Qualitative Content Analysis (Mayring, 2003) was applied on the RESCUE process documentation by pursuing the following steps:

1. Phrase-by phrase analysis of the whole document

Throughout the document, all relevant phrases that described activity (i.e. no explanations, no theory) were collected for the Activity Modelling and System Goal Modelling streams.

2. Analysis and paraphrasing of the material for Activity Modelling and System Goal Modelling (see external appendix [EA], pp.7)

Within the amassed material, for each stream, relevant text passages were paraphrased, i.e. they were reworded in a simple grammatical form without elaborations. To give an example, the text passage "The analysis of the activity should identify constraints of the domain in order for the design to support practitioners in complying with them" was transformed into “Identify constraints of the domain”. By paraphrasing the whole material, a first, preliminary list of tasks was obtained.

3. Cross-check of the list of tasks with the respective chapter of the original document

The cross-check was done to ensure completeness and correctness of the identified tasks. Simultaneously, competencies that were described in the RESCUE documentation or that could be inferred from the text were gathered. For instance, from the hint that a person would have to “undertake creative thinking to investigate […] boundaries” was inferred the competency “knowledge of creativity techniques”. The outcomes of this were a complete and correct but still disorganised list of tasks and a first collection of competencies. Bottom-up categorisation of similar tasks

The preliminary list of tasks was further reduced by removing too specific and too general tasks and by eliminating inadequate ones. Similar tasks were bundled into one task until there were two lists (one for each stream) containing meaningful tasks. As an example, the phrases “Identify external resources” and “Identify resources available to achieve goals (observable)” were aggregated into “Identify external resources that are available for practitioners to achieve their goals”. In contrast, the phrases “Identify the system’s goals and high level functional goals” and “Identify local goals” were not merged, since they were assumed to be performed in a different manner (and thus to require different sets of competencies).

4.Top-down categorisation of tasks into the RESCUE Process-Steps

Subsequent to the bundling, tasks were categorised into the coarse process steps as described in the RESCUE document. This was only done to sort tasks and consequently to facilitate the RESCUE experts’ review activity. The top-down categorisation did not lead to a reduction of the collected material.

5.Top-down categorisation of tasks into hierarchical categories (only for the first process step in Activity Modelling)

Particularly the first process step in Activity Modelling, Gathering Data on Human Activity, was consisting of a huge number of tasks. Thus it was decided to grade the tasks of that process step into five theoretically assumed hierarchical categories of Work Analysis (Vicente, 1999) as suggested in the RESCUE process documentation. This was only done to facilitate the experts' review and did not lead to a reduction of tasks.

Accumulation of Competencies

The preliminary set of elementary competencies was compiled from several sources. Some competencies were gathered from the RESCUE process documentation. Simultaneously, a brainstorming of competencies was carried out together with Experts 3, 4, and 5. The experts went through a preliminary list of tasks and named competencies they considered necessary for the accomplishment of the corresponding tasks. These were logged by the modeller. Moreover, existing competence catalogues were scanned for additional competencies meaningful in the scope of RESCUE.

Material

The development and refinement of the material happened iteratively throughout the whole modelling process. The material's evolution was strongly embedded into the single steps of the case study's implementation and is thus described in the respective sections. Subsequently, the final material is presented.

Task Lists

All in all, by means of content analysis, 85 tasks were identified, 60 for Activity Modelling and 25 for System Goal Modelling. In the following, these lists are referred to as first lists of tasks.

For the review, the RESCUE experts were provided with Microsoft Word files of these first lists of tasks. During the interviews, print versions were used.

After the experts' review of the task lists, in total 47 tasks remained, thereof 29 tasks belonged to Activity Modelling and 18 were pertaining to the System Goal Modelling stream (reviewed lists of tasks, see Appendix A and B). Some of the remaining tasks were slightly modified, no tasks were added by the experts

Competence Catalogue

In all, 134 competencies had been accumulated. Having merged similar competencies and removed inadequate ones, a list of 34 competencies remained. Thereof, 20 rather referred to knowledge (e.g., domain knowledge, knowledge about acquisition techniques available) and 14 rather constituted skills (e.g., communication skills, inference skills). Competencies in the list were specified by some characteristics and examples in order to clarify their meanings. In the following, this list is called the first competence catalogue.

After the experts' review, Competency 14 was included into Competency 13 and some of the competencies were slightly reworded. The reviewed competence catalogue consisted of 33 competencies (20 knowledge, 13 skills, Appendix C).

Task-Competency Matrix

The task-competency matrix, a digital Microsoft Excel sheet with all 47 tasks in the rows and all 33 competencies in the columns, was used to link the set of tasks with the set of competencies. The first task-competency matrix still included Competency 14, which was removed in the reviewed task-competency matrix (for an example of a filled-out task-competency matrix see Appendix D).

Validation Questionnaire

The questionnaire, a digital Microsoft Excel sheet, was used to create notional solution patterns that could be checked against predicted performance states. Therefore, the experts together (orally) had generated descriptions of five requirements engineers with different degrees of expertise they both had worked with in at least one project (first description of persons). The descriptions of the five requirements engineers were transcribed and reviewed afterwards (reviewed description of persons).

By an instruction on the top of the validation questionnaire, the experts were informed that they would receive descriptions of five persons. They were requested to go through the task list below the description of a person and decide for each task, whether the person would be able to accomplish the task. If they thought that the person would be able to accomplish the task successfully without assistance, they should type 2 in the respective cell of the questionnaire. If the experts thought, the person would only be able to perform the task with assistance, they should note 1. Else, 0 should be noted. Below the instruction, the experts found the description of the first person and the complete list of tasks to be achieved in the first two streams of RESCUE. Next to each task was an empty cell where the appraisal of the respective person should be noted.

The task lists for the assessment of the remaining four persons and the descriptions of these persons were presented in the same manner.

Procedure

The actual investigation was conducted between March and June 2006. The modelling of the competence-performance structures and the interviews with Experts 3, 4, and 5 happened in Austria, the RESCUE experts were in England. Hence, interviews with the RESCUE experts were conducted at the phone, and questionnaires were sent via e-mail.

The single segments of the modelling process are described in the following.

Questioning RESCUE Experts 1: Quality-Check and Brainstorming of Competencies

In order to validate the first lists of tasks obtained by means of Qualitative Content Analysis, on the 21st of March 2006, these were e-mailed to the RESCUE experts together with a short description of the process of task identification. Both experts were asked to run through the task lists. They were requested to merge tasks that were the same thing, to remove tasks that were dispensable and to add missing tasks. In a conference phone-call on the 30th of March 2006 at 2:00 p.m, the lists should be discussed and reviewed. For the call was planned a duration of 60 minutes, the RESCUE experts had ongoing time limits.

During the call, both RESCUE experts were together in one office in England. Expert 3 and the modeller of the competence-performance structures were together in one office in Austria. Expert 3 was asked to join the conference call because of his experience in modelling competence-performance structures for workplace settings. In both offices hands-free kits were used. In the modeller's room, the call was recorded with a tape recorder. Each participant had the first task lists lying in front of him or her. Both RESCUE experts stated that they had been thinking about the lists before the call but had not talked about it with each other. For the interview, a compend with keywords was used by the modeller.

After the salutation and an overview of what should be done during the call, one RESCUE expert (Expert 2 in Activity Modelling, Expert 1 in System Goal Modelling) went through the first lists of tasks and decided for each task whether it was correct or had to be reworded, sorted into another process step, or removed. The other RESCUE expert was completing these comments. Both, the modeller and Expert 3, minuted changes on the task lists. At the end, the RESCUE experts were asked if they wanted to add tasks. No tasks were added by the domain experts.

Then, the meanings of ambiguous tasks should be clarified. Therefore, the modeller had marked tasks with ambiguous meanings in the first lists. These tasks – if not removed – were discussed together.

In a next step, the experts were asked to generate descriptions of five persons with various degrees of expertise that would be candidates to do RE with RESCUE (first descriptions of persons). These five requirements engineers should be persons they both had worked with in at least one project. The experts were told that these descriptions would be used to produce notional solution patterns at a later date.

After that, possible elementary competencies were brainstormed. On that account, the RESCUE experts were asked to think of concrete situations and to name competencies necessary for the performance of the respective task.

At the end, the RESCUE experts were informed about the content and the goal of the second phone call.

Further development of the Material

The lists of tasks for Activity Modelling and System Goal Modelling were edited as suggested by the RESCUE experts (reviewed task lists). In addition to the notes taken during the interview, the record was taken into account. From the collection of competencies, the first competence catalogue was compiled. Moreover, the first descriptions of persons from the first phone call were transcribed.

Questioning RESCUE Experts 2: Quality-Check and Task-Competency Assignment

The reviewed task lists, the first competency catalogue and the first descriptions of persons were e-mailed to the two RESCUE experts on the 4th of April with the request to check it. They were asked to immediately inform the modeller via e-mail about indispensable changes in the competency catalogue. No changes were suggested by the RESCUE experts.

Expert 2 was called on the 6th of April 2006 at 11:15 am. For the second interview, 90 minutes were planned. Expert 2 was alone in her office, the modeller and Expert 3 were together in another office and used a hands-free kit. Again, a tape recorder was availed to record the call. For the interview, the modeller had a compend with keywords. All interlocutors had the reviewed lists of tasks, the first competence catalogue and the first descriptions of persons lying in front of them. The modeller had a print version of the first task-competency matrix of format DIN A3. In the case of rigorous changes on the material it was intended to interrupt the call.

After the salutation, Expert 2 stated that she had read through the material obtained via e-mail. That followed a short repetition of what had been achieved up until that point. Expert 2 was asked to go through the reviewed lists of tasks and the first competency catalogue and to make comments on the first descriptions of persons. The modifications she made were taken into account in the subsequent procedure.

To build the minimal interpretations of each task, Expert 2 was instructed orally to start with the first task in the reviewed list and to select every competency in the reviewed competence catalogue that she regarded necessary for performing the task well. Every competency she regarded as ‘indispensable, absolutely necessary, mandatory’, she should (orally) assign the value 2. Every competency she regarded as ‘somehow important, nice to have’, she should give the value 1. Finally, every competency she regarded as ‘not necessary’ or competencies she didn’t mention should be assigned the value 0.

Actually, the assignment was intended to be done on the phone. Values should be noted in the task-competency matrix by the modeller. After the completion of several tasks, however, Expert 2 suggested to do the assignment alone and to e-mail the results.

At the end of the phone call, Expert 2 was informed that after the completion of the task-competency assignment, she would receive a validation questionnaire. The spreadsheet for the reviewed task-competency matrix and the reviewed competency catalogue were sent to her after the call.

The competency catalogue and the descriptions of persons as modified by Expert 2 were e-mailed to Expert 1 who was phoned on the 7th of April 2006 at 10:00 am. The setting of the interview with Expert 1 was the same as in the interview with Expert 2. All had the reviewed descriptions of persons and the reviewed competence catalogue lying in front of them. The modeller used the reviewed task-competency matrix (print version, DIN A3).

Changes on the competency catalogue and on the descriptions of persons made by Expert 2 were discussed with Expert 1. Then, the same instruction as had got it Expert 2 was told to Expert 1. Unaware the suggestion of Expert 2, also Expert 1 proposed to fill out the task-competency matrix on his own. He also was informed about the remaining validation questionnaire and was provided with the reviewed task-competency matrix.

Both experts were invited to note assumptions on how they thought the respective tasks had to be performed, if they arrived at task descriptions that were unclear or ambiguous. None of them made assumptions when filling out the questionnaire.

The completed assignment of Expert 2 was obtained on the 11th of April 2006 and that of Expert 1 on the 2nd of May 2006. Instead of filling out the Matrix, Expert 2 returned a text file with a list of competencies she assigned to each task with value 2 and value 1 respectively. This list was transcribed into a task-competency matrix.

<u>Completion of the Validation Questionnaire</u>

For evaluation purposes, the RESCUE experts were requested to fill in the validation questionnaire they obtained via e-mail on the 30th of May 2006 (Expert 1) and on the 6th of June 2006 (Expert 2). They were instructed not to look at their task-competency assignments when completing the questionnaire.

The experts returned the validation questionnaire on the 1st of June (Expert 1) and on the 10th of June (Expert 2) respectively.

Results

<u>Contingency of Task-Competency Assignments</u>

Descriptive results are reported for the domain experts' complete task-competency assignments as well as broken down into streams. The two streams are regarded separately for two reasons: Firstly, there are qualitative differences between the corresponding tasks, e.g., performing System Goal Modelling is more structured by a sequence of events than is Activity Modelling. Secondly, both RESCUE experts had performed Activity Modelling less frequently than System Goal Modelling.

In total, the task-competency matrix was consisting of 1551 cells (47 tasks by 33 competencies). Expert 1 chose value 2 for 191 cells (12.31%) and value 1 for 427 cells (27.53%). Expert 2 assigned value 2 to 275 task-competency pairs (17.73%) and value 1 to only 48 pairs (3.09%).

For Activity Modelling, 957 task-competency pairs (29 tasks by 33 competencies) had to be assessed. Expert 1 assigned value 2 to 128 cells (13.38%) and value 1 to 316 cells (33.02%). Expert 2 used value 2 for 195 cells (20.38%) and value 1 for 48 cells (5.02%) of the matrix.

The task-competency matrix of the System Goal Modelling stream was consisting of 594 cells (18 tasks by 33 competencies). Expert 1 allocated value 2 to 63 pairs (10.61%) and value 1 to 111 task-competency pairs (18.70%). Expert 2 assigned value 2 to 80 cells (13.47%) of the matrix. She never assigned a competency with value 1 to any task in System Goal Modelling.

The fact that Expert 2 never assigned value 1 in System Goal Modelling may be due to several reasons. It might reflect Expert 2's opinion, that a competency either is mandatory or is not important for performing a task in System Goal Modelling, and that there is nothing in between. It might also indicate a response bias (compare, e.g., Bortz & Döring, 2002; Esser, 1977), which, however, is doubtable since Expert 2 had assigned value 1 in Activity Modelling. Eventually, it might also constitute an artefact of Expert 2's method to assign competencies and tasks by means of a list that later was transcribed into a task-competency matrix.

Inter-Rater Reliability of Task-Competency Assignments

Table 1 shows the contingency of the RESCUE experts' assignments for both streams. As scheduled, cells in the task-competency assignments with value 1 ('somehow important') were recoded into value 0 ('not important'). Measures of contingency were established for the total assignment as well as for each stream separately. Significance was tested two-tailed on a 5%-level.

The contingency of the raters' assignments was moderately positive (τ_b = .32, z = 8.60, $p < .01$) across both streams. The contingency coefficient was .25 for Activity Modelling (z = 5.90, $p < .01$) and .45 for System Goal Modelling (z = 6.13, $p <.01$).

Subsequently, at first, inter-rater agreement was regarded for each single task in the matrix and results are reported for the two streams. Then, consistency between the experts' assignments was examined for each single competency. Computations were made for each stream separately.

Agreement of Task-Competency Assignments Across Tasks

A contingency coefficient, τ_b, was computed to assess the RESCUE experts' agreement in the minimal interpretation of every single task[2]. This was done to see whether the experts' agreement was rather homogeneous across all tasks or if there were tasks of comparatively high or low agreement.

Values for the 29 tasks of Activity Modelling were ranging between -.15 and 1. Within the Activity Modelling stream, 5 of 29 tasks had slightly negative coefficients. Positive coefficients of 14 tasks were higher than .30, 1 of them was higher than .70.

Tasks in the System Goal Modelling stream were correlated with values between -.11 and .80. In System Goal Modelling, 3 of 18 tasks had negative coefficients. Of the positive coefficients 14 were higher than .30, and 4 of them had coefficients equal to or higher than .70.

In Activity Modelling, τ_b reached low to moderate values for single tasks. The experts' agreement for System Goal Modelling, in general, was moderate to rather high with only some low coefficients.

Agreement of Task-Competency Assignments Across Competencies

Inter-rater agreement of task-competency assignments was also regarded for each of the 33 competencies using τ_b.[2] Similar as for the tasks, if any, competencies of particularly high or low agreement should be identified. Contingency of the tasks that were assigned to each competency was reviewed for each stream separately. Coefficients could only be computed for competencies that were assigned by both RESCUE experts at least once (with value 2) to any of the tasks since else the coefficient was undefined.

Inter-rater agreement could be regarded for 19 competencies in Activity Modelling. Coefficients were ranging between -.27 and 1. Besides the notably negative correlation of Competency 30 (τ_b = -.27), 3 of 19 competencies under consideration had slightly negative coefficients. The disagreement on Competency 30 seemed to have been lower in System Goal Modelling: The competency was never assigned by one expert – hence the correlation coefficient is undefined – and only once by the other: Both experts "agreed" in regarding Competency 30 rather unimportant for System Goal Modelling. Of the positive coefficients in Activity Modelling, 5 were higher than .30, for 1 of them, the RESCUE experts' assignments were correlated higher than .70.

In System Goal Modelling, τ_b could only be established for 12 competencies. Regarding cell frequencies for competencies that were assigned by one expert but not by the other, two results were standing out: Competency 4 was assigned to 8 of 18 tasks by Expert 2 and to no task by Expert 1, Competency 31 was assigned to 10 tasks by Expert 2 but was never assigned by Expert 1. These two competencies' rank correlation coefficients were also low in Activity Modelling (τ_b = .14, and τ_b = .07 respectively). The 12 competencies' coefficients were ranging between -.06, and 1 with the former being the only negative value. Of the positive correlations, 10 were higher than .30, 2 of them were higher than .70.

Inter-rater agreement for single competencies seemed to be higher for System Goal Modelling than for Activity Modelling. In Activity Modelling, most correlation coefficients were low whereas in System Goal Modelling, except for some competencies, the experts' agreement was moderate to high.

Competence-Performance Structures

Five competence-performance structures were built on the basis of the two experts' assignments (value 2): From each RESCUE expert's task-competency assignment, separate structures were derived for Activity Modelling and System Goal Modelling. In order to establish a common competence-performance structure for the two experts, their assignments for System Goal Modelling were aggregated. The experts' assignments for Activity Modelling were not merged because of low inter-rater agreement,.

In the following, the establishment of competence-performance structures will be exemplarily demonstrated for a small subset of tasks and the according set of elementary competencies. Then, results for the five expert structures will be presented.

An Illustrative Example

The tasks and competencies of the example (see Table 2) stem from Expert 1's task-competency assignment for System Goal Modelling. In order to improve the clearness of the exemplary results and to keep the number of competence states low, it was decided to consider only knowledge competencies, i.e. Competencies 1 to 20.

From Expert 1's assignment, ten tasks were selected. By uniting the tasks' minimal interpretations, the set of elementary competencies was obtained.

To build the base of the competence space, some minimal interpretations were removed. Table 3 shows the relationship between task-competency assignments (crosses indicate assignments with value 2), minimal interpretations and competence states that belong to the base of a competence space. For instance, the minimal interpretation of Task 5_3 is not an element of the competence space's base, since it is obtained, amongst others, by uniting the minimal interpretations of Tasks 4_2 and 5_1. Consequently, the base of the competence space in the example comprises seven competence states.

From the task-competency assignments, a surmise relation on the set of competencies was derived (see Figure 1). According to the surmise relation from the example, for instance, a person who has Competency 16 is assumed to also have Competencies 13 and 15. In other words, Competencies 13 and 15 are prerequisites for Competency 16.

Comparing the Hasse-diagram in Figure 1 and the base states from Table 3, one will recognise that the competence states {20} and {3, 13} are missing in the base of the competence space. This is due to the application of task-competency matrices: According to the task-competency assignments, none of the tasks can be performed by a person being in the competence states {20} or {3, 13} respectively. Hence, these competence states are not regarded feasible in the model, although they are feasible according to the surmise relation. A competence space that is established by means of a task-competency matrix does not contain competence states of which the performance representation is an empty set.

The whole competence space was spanned by closing the base states under union. In the example structure, there are 64 (2^n, where n is the number of competencies) possible combinations of competencies but only 18 are feasible competence states. Figure 2 shows the Hasse-diagram of the competence space and the performance representation from the example. Performance states were generated by assigning to each competence state the set of tasks that can be performed by a person being in the respective state.

Figure 2 depicts several properties of the resulting competence-performance structure. Firstly, surmise relations on the set of tasks are due to relations on the set of competencies.

This is illustrated by the following example: A person who is able to accomplish Task 4_3 is assumed to be able to perform well Task 4_6. In other words, Task 4_6 is considered as a prerequisite of Task 4_3 since the minimal interpretation of Task 4_6 ({13, 20}) is a subset of the minimal interpretation of Task 4_3 ({3, 13, 20}).

Secondly, the performance structure is not a performance space since it is not stable under union. For example, {5_1, 5_2} and {4_2, 5_2} both constitute feasible performance states but their union, {4_2, 5_1, 5_2}, is no feasible performance state: Uniting the corresponding competence states ({13, 15} and {15, 20}), one arrives at the (feasible) competence state {13, 15, 20} which is represented by the performance state {4_2, 4_5, 4_6, 5_1, 5_2, 5_3, 5_4, 5_5}.

Summary of the Experts' Competence Spaces

The sets of 29 and 18 tasks to be achieved in Activity Modelling and System Goal Modelling respectively were regarded as problem sets for the experts' structures. The sets of elementary competencies were subsets of the 33 competencies in the catalogue since they contained only these competencies considered mandatory for any of the tasks in a particular problem set.

Table 4 summarises the most important characteristics of the five structures derived from the RESCUE experts' task-competency assignments. The second column shows the numbers of competencies considered mandatory in the respective assignment, i.e. the cardinalities of the sets of elementary competencies. In the third column, the numbers of all possible combinations of competencies, i.e. the cardinalities of the power sets on the sets of elementary competencies, are registered. The cardinalities of the bases and the competence spaces are noted in column four and five.

In both streams, Expert 1 assigned more competencies than Expert 2. Moreover, the cardinalities of Expert 1's bases for both streams were higher than Expert 2's and also the cardinalities of Expert 1's competence spaces were much higher than Expert 2's. This is interesting since Expert 2 in both streams had used value 2 more often than Expert 1.

Validity of Competence-Performance Structures

For validating the competence-performance structures, notional solution patterns of five persons were looked at. The RESCUE experts had appraised the performance of these persons by means of a validation questionnaire. Only tasks that the experts had allocated value 2 in the questionnaire were regarded as mastered by a person under consideration.

First, the agreement between the two RESCUE experts' assessments of persons is viewed. Then, the results of the Leave One Out cross-validation are reported for each of the five competence-performance structures. Significance was tested two-tailed on a 5%-level.

Inter-Rater Agreement on the Assessment of Persons

There was a positive correlation between the assessments of Expert 1 and Expert 2 across all five persons and both streams (with an overall contingency of τ_b = .57, z = 9.15, p < .01). The experts' assessments for Activity Modelling were positively associated (τ_b = .59, z = 6.01, p < .01). In System Goal Modelling, the coefficient was a little lower but still highly significant (τ_b = .49, z = 5.39, p < .01).

The agreement between the experts' assessment of persons was quite good.

Leave One Out Cross-Validation

For the Leave One Out method, the solution pattern of one the five persons from the validation questionnaire is reviewed. One competence-performance structure is regarded.

The person's performance in one of the tasks is left out. From the person's performance in all other tasks, his or her minimal competence state is inferred by means of the competence-performance structure under consideration. Then, the person's performance (mastery or failure) in the left-out task is predicted by taking into account the task's minimal interpretation: If the person has all competencies required for performing the task, he or she should perform it well, else he or she should not be able to perform it. By conducting this procedure for every task (and each of the five persons), the agreement between obtained solution patterns and predicted performance can be assessed.

In the present case study, contingency was examined for each of the five model's predictions and the assessed performance in the original solution patterns.

For Activity Modelling, one person's assessment had to be excluded, since both experts didn't assume the person to be able to accomplish any task without help (i.e. no task got value 2). In System Goal Modelling, the validation with Expert 1's assessments is based on only four solution patterns because of the same reason.

Table 5 shows contingency coefficients for solution patterns as assessed by the experts and the persons' solution behaviours as predicted by the five different structures[3]. The values of all coefficients were significantly positive.

In 3 of 4 cases, predictions of Expert 2's model were more consistent with both experts' appraisals than Expert 1's and the merged structure's predictions. The highest agreement, τ_b = .77 (z = 7.72, p < .01) was between Expert 2's assessment of the persons' performances and the predictions for System Goal Modelling derived from her own assignment. The lowest agreement, τ_b = .26 (z = 3.01, p < .01), was between Expert 2's predictions for Activity Modelling and the assessment of the persons' performances by Expert 1.

In Activity Modelling, the solution patterns generated by both experts were higher correlated with the predictions of their own models than with these of the other expert. In System Goal Modelling, the notional solution patterns of both experts were higher correlated with the predictions of Expert 2's structure. Predictions from the merged structure were nearly equally consistent with the solution patterns as predictions from each expert's own structure.

The assessed solution patterns of Expert 1 were higher correlated with all structures' predictions in System Goal Modelling than in Activity Modelling, with Expert 2's solution patterns it was the other way round. On a task-level, Expert 1 produced more valid descriptions of persons performing System Goal Modelling, and Expert 2 of persons performing Activity Modelling.

The fact that Expert 2's model for System Goal Modelling predicted best not only her own assessments but also these of Expert 1 is considered as an evidence for her model being the most valid of the three structures.

Discussion

The case study was conducted to answer the questions whether the developed modelling method, firstly, would be workable and, secondly, would lead to competence-performance structures that are meeting standard quality criteria. In the following, results are being discussed with regard to reliability and validity. Further, the modelling method is reviewed and practical issues on its implementation are drawn upon. Finally, the usefulness of competence-performance structures in the context of an APOSDLE environment is discussed.

Reliability

The overall inter-rater reliability between the two RESCUE experts' task-competency assignments was quite low. Computing the coefficients separately for the two streams, the assignments of System Goal Modelling turned out to be somewhat more reliable than those of Activity Modelling.

These results are in line with Ley (2006), who found rather high agreement within (retest reliability), but low agreement between raters for task-competency matrices in knowledge-work domains. Also, e.g., Baumunk & Dowling (1997), who established surmise relations by querying six experts in Mathematics, obtained low to moderate (pairwise) inter-rater agreement.

So what are possible reasons for the rather low inter-rater reliability in the present case study? Firstly, corresponding to the interpretation of Baumuk & Dowling (1997), we are confronted with the problem that different experts have different experiences, and therefore yield different minimal interpretations (and different competence-performance structures respectively). Obviously, the two RESCUE experts were having different views about what competencies were required for performing certain tasks. Secondly, for some tasks and for some competencies, the descriptions might have been interpreted in a different manner by the two experts. To examine this assumption, a closer look is taken at the contingency coefficients for single tasks and single competencies:

Reviewing the sets of tasks, consistently, the inter-rater agreements of the tasks' minimal interpretations in Activity Modelling were rather low. In System Goal Modelling, a good portion of the minimal interpretations were correlated satisfying with several negative outliers, i.e. several tasks where the experts' assignments were differing more strongly (e.g. Task 4_2 Model the system's hard and soft goals, or 4_4 Identify the intentional strategic actors).

The same set of competencies were considered for the assignments in both streams. The experts' assignments of single competencies were correlated rather low in Activity Modelling. In System Goal Modelling, there was comparatively high inter-rater agreement on the bigger part of the competencies.

These findings indicate that the description of competencies in the catalogue was rather clear except for these competencies with poor agreement in both streams (e.g., Competencies 4 Knowledge about actors, tasks, goals and resources and 31 Ability of structuring data and organising information in contrast to, e.g., 33 Analytical skills).

Consequently, the rather low inter-rater agreement in Activity Modelling may be due to different understandings of particular tasks (e.g., 1_12 Identify information needs for the new tool or 1_15 Identify resources available to achieve goals). To a certain extent, this may be caused by the fact that the experts had performed Activity Modelling rather seldom in comparison with, e.g., System Goal Modelling.

Low inter-rater agreement, however, does not mean that both models under consideration are useless. Actually, it implies that the two experts have different views of the domain that can be valid or less valid.

Validity

There is strong evidence for the practical effects of Competence Performance Theory in the RESCUE domain. The correlations between all structures' predictions and the Experts' respective assessments obtained by the Leave One Out method were significantly positive.

A closer look is taken at the notional solution patterns that built the base of the Leave One Out cross-validation: In fact, the five persons to be appraised in the validation questionnaire had not tried to perform every task. Hence, the experts' appraisals, to a certain extent, were based on their practical experience and on inferences on the persons' performance. The reliability of these appraisals is influenced by at least two factors: Firstly, a common understanding of tasks is needed, and secondly, a common understanding of persons and their abilities respectively is required. Quite good inter-rater agreement between the appraisals of persons indicates a common understanding of the persons' abilities in terms of tasks they are able to achieve. Nevertheless, validity is impaired due to a low inter-rater reliability of task-competency assignments, i.e. a low agreement on what competencies are necessary for performing each task.

The two domain experts' solution patterns in Activity Modelling were better predicted by their own model than by the other one's. This is consistent with the assumption, that the experts had different ideas of the tasks to be achieved in the first RESCUE stream.

In System Goal Modelling, the solution patterns of both experts were best predicted by Expert 2's competence-performance structures. Hence, Expert 2's model seems to be the most valid of the three structures for System Goal Modelling.

One possible explanation may be provided by the different modes of task-competency assignments used by the RESCUE experts: Expert 1 assigned competencies with values 1 and 2 by means of the matrix, Expert 2, in System Goal Modelling, just listed competencies with value 2. Possibly, merely assigning competencies regarded 'mandatory' leads to more meaningful relationships between competencies (and between tasks respectively) than the distinction into 'somehow important' and 'mandatory'.

Merging competence-performance structures by uniting each task's minimal interpretation did not enhance validity. For System Goal Modelling, both experts' models were equally consistent ore more consistent with the solution patterns than the merged model's predictions. Consequently, other ways to improve validity by integrating competence-performance models should be thought of (see, e.g., Baumunk & Dowling, 1997).

Remarks on the Modelling Process and Implications

Querying domain experts on the phone and e-mailing materials (task lists, questionnaires, etc.) had worked quite well, but turned out to be rather inconvenient. The main problem at this seemed to be the time passing by between the oral instruction given at the phone and the actual completion of spreadsheets and questionnaires. In addition, the RESCUE experts had obtained written instructions via e-mail, but emerging queries, if any, could not be answered that easily.

Identifying tasks by means of content analysis came along with huge efforts. For future competence-performance modelling in working domains, in the case of no existing task list, it is strongly recommended to develop such a list together with experts in a workshop setting. In addition, assumptions should be added on what is meant by each task and maybe also solution ways should be defined.

For the completion of the task-competency matrix, because Expert 2's assignment method was leading to a more valid model, it should be reconsidered to assign competencies with values 0, 1 and 2.

Using Competence-Performance Structures for APOSDLE

In the context of technology-enhanced workplace learning within an APOSDLE environment, a valid competence-performance structure may be useful in a twofold manner:

On the one hand, it maps the learning domain in terms of learning goals and the related tasks. That way, learning is specifically tailored to the requirements of working tasks and processes. Together with other elements of the user context (see Ulbrich, Scheir, Götz & Lindstaedt, 2006), competence-performance structures are expected to enhance the APOSDLE system's ability to better tailor the retrieval of existing resources to current available and missing competencies of the user.

On the other hand, competence-performance structures provide an overall map of the learning content. By the use of competencies, single learning resources can be structured according to underlying knowledge needs.

Conclusions and Future Outlook

The first attempt in modelling the RESCUE domain by means of competence-performance structures led to promising results. Nevertheless, in the scope of APOSDLE (and any other practical field of application) the aim is not only on building a competence model and testing its fit but on iteratively developing a valid structure of practical convenience. The vision in this context is a distributed modelling method that allows for repetitive refinement. Hence, in a next step, procedures and techniques to identify and overcome a model's deficits should be developed. As a first indicator for a model's insufficiencies may, e.g., serve single tasks or competencies with low inter-rater agreement.

Moreover, it should be thought about methods and measures to empirically evaluate a model once established in a work setting, i.e. to explore its fit on real data instead of notional solution patterns. This may be achieved with analysing documents produced by workers or by questioning superiors about their employees.

References

Albert, D. (2001). E-learning Future – The Contribution of Psychology. (Keynote). In R. Roth, L. Lowenstein & D. Trent (Eds.), Catching the Future: Women and Men in Global Psychology – Proceedings of the 59 th Annual Convention, International Council of Psychologists, July 8-12, 2001, Winchester, England (pp. 30-53). Lengerich, Germany: Pabst Science Publishers.

Albert, D., Hockemeyer, C., & Wesiak, G. (2002). Current Trends in eLearning based on Knowledge Space Theory and Cognitive Psychology. Psychologische Beiträge, 44 (4), 478–494.

Albert, D., & Kaluscha, R. (1997). Adapting Knowledge Structures in Dynamic Domains. In C. Herzog (Ed.), Beiträge zum Achten Arbeitstreffen der GI–Fachgruppe 1.1.5/7.0.1 "Intelligente Lehr–/Lernsysteme", September 1997, Duisburg, Germany [Contributions of the 8th Workshop of the GI SIG ``Intelligent Tutoring Systems''] (pp. 89–100). TU München.

Albert, & J. Lukas (1999), Knowledge Spaces: Theories, Empirical Research, and Applications. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Albert, D., Pivec, M., Spörk-Fasching, T., & Maurer, H. (2003). Adaptive intercultural competence testing: A computerized approach based on knowledge space theory. Proceedings of the UNESCO Conference on Intercultural Education, Jyväskylä, Finland. June 15-18, 2003.

Albert, D., & Steiner, C. M. (2005). Representing Domain Knowledge by Concept Maps: How to Validate Them?. In T. Okamoto, D. Albert, T. Honda & F. W. Hesse (Eds.), The 2nd Joint Workshop of Cognition and Learning through Media-Communication for Advanced e-Learning (pp. 169-174).

Agresti, A. (1984). Analysis of Ordinal Categorical Data. New York: Wiley.

ALEKS Corp. (2003). ALEKS - A Better State of Knowledge. Retrieved October 13, 2003, at http://www.aleks.com

Baumunk, K., & Dowling, C. E. (1997). Validity of Spaces for Assessing Knowledge about Fractions. Journal of Mathematical Psychology, 41, 99-105.

Beckett, D. (1999). Past the guru and up the garden path: the new organic management learning. In D. Boud & J. Garrick (Eds.), Understanding Learning at Work.(pp. 83-97). London: Routledge.

Bortz, J. (1999). Statistik für Sozialwissenschaftler. 5th rev. ed. Berlin: Springer.

Bortz J., & Döring, N. (2002). Forschungsmethoden und Evaluation für Human- und Sozialwissenschaftler. 3rd ed. Berlin: Springer.

Doignon, J. (1994) Knowledge Spaces and Skill Assignments. In G. H. Fischer & D. Laming (Eds.), Contributions to Mathematical Psychology, Psychometrics and Methodology (pp. 111–121). New York: Springer.

Doignon, J.-P. & Falmagne, J-C. (1985). Spaces for the assessment of knowledge. International Journal of Man-Machine Studies, 23, 175-196.

Doignon, J., & Falmagne, J. (1999). Knowledge Spaces. Heidelberg: Springer.

Dösinger, G., & Albert, D. (2002). Adaptive Competence Testing in eLearning. In M. Auer & U. Auer (Eds.), Interactive computer aided learning (ICL) 2002. International Workshop. Kassel: University Press.

Dowling, C. E. (1994). Integrating different knowledge spaces. In G. H. Fischer & D. Laming (Eds.), Contributions to mathematical psychology (pp. 149-158). New York: Springer.

Dowling, C. E. & Hockemeyer, C. (1996). Computing the intersection of knowledge spaces using only their basis. In C. E. Dowling, F. S. Roberts & P. Theuns (Eds.), Recent progress in mathematical psychology (pp. 133-141). Hillsdale, New Jersey: Erlbaum.

Drucker, P. F. (1998). Peter Drucker on the profession of management. Boston: A Harvard Business Review Book.

Düntsch, I., and Gediga, G. (1995) Skills and knowledge structures. British Journal of Mathematical and Statistical Psychology, 48, 9-27.

Esser, H. (1977). Response Set- Methodische Problematik und soziologische Interpretation. Zeitschrift für Soziologie, 6, 253-263.

European Commission (Ed.): Continuing training enterprises in Europe - Results of the second European Continuing Vocational Training Survey in enterprises, 2003 (published under http://europa.eu.int/comm/education/programmes/leonardo/new/leonardo2/cvts/cvts_en.pdf).

Falmagne, J., Doignon, J., Koppen, M., Villano, M., & Johannesen, L. (1990). Introduction to Knowledge Spaces: How to Build, Test, and Search Them. Psychological Review, 97 (2), 201-224.

Farmer, J., Lindstaedt, S. N., Droschl, G. & Luttenberger, P. (2004). AD-HOC – Work-integrated Technology-supported Teaching and Learning. Proceedings of the 5th

European Conference on Organisational Knowledge, Learning and Capabilities, Innsbruck, Austria, April 2-3, 2005. Innsbruck: University of Innsbruck.

Hermann, S. (2004). Produktive Wissensarbeit: Eine Herausforderung. In S. Hermann (Eds.), Ressourcen strategisch nutzen - Wissen als Basis für den Dienstleistungserfolg (pp. 207-228). Stuttgart: Fraunhofer IRB-Verlag.

Hermann, S., Becker, T. & Karapidis, A. (2005). Knowlege Work Management: Wissensarbeit gestalten. In Spath, D.; Ganz, W.; Becker, T. (Eds.): e3World: Work, learning, performance - Lernen für die Arbeit von morgen (pp. 54-64). Stuttgart: Fraunhofer IRB-Verlag.

Hockemeyer, C., & Albert, D. (1999). The Adaptive Tutoring System RATH. In M. E. Auer & U. Ressler (Eds.), ICL99 Workshop Interactive Computer aided Learning: Tools and Applications. Villach, Austria: Carinthia Tech Institute.

Hockemeyer, C., Conlan, O., Wade, V., & Albert, D. (2003). Applying Competence Prerequisite Structures for eLearning and Skill Management. Journal of Universal Computer Science, 9, 1428–1436.

Kelloway, E. K. & Barling, J. (2000). Knowledge work as organizational behavior. International Journal of Management Reviews, 2 (3), 287-304.

Kendall, M. G. (1938). A New Measure of Rank Correlation. Biometrika, 30, 81-93.

Kendall, M. G. (1962). Rank Correlation Methods. 3rd edition. London: Griffin.

Korossy, K. (1993). Modellierung von Wissen als Kompetenz und Performanz. Eine Erweiterung der Wissensstruktur-Theorie von Doignon & Falmagne. Universität Heidelberg: Dissertation.

Korossy, K. (1997). Extending the theory of knowledge spaces: A competence-performance approach. Zeitschrift für Psychologie, 205, 53-82.

Korossy, K. (1999a). Modeling Knowledge as Competence and Performance. In D. Albert, & J. Lukas (Eds.), Knowledge Spaces: Theories, Empirical Research, and Applications (pp. 103-132). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Korossy, K. (1999b). Qualitativ-strukturelle Wissensmodellierung in der elementaren Teilbarkeitslehre. Zeitschrift für experimentelle Psychologie, 46 (1), 28-52.

Korossy, K. & Held, T. (2001). Theory-based knowledge modeling in a subdomain of elementary algebra. Zeitschrift für Psychologie., 209 (3), 277-315.

Ley, T. (2006). Organizational Competency Management – A Competence Performance Approach. Methods, Empirical Findings & Practical Implications (Grazer Schriftenreihe Knowledge Management, 4). Aachen: Shaker.

Ley, T. & Albert, D. (2003a). Kompetenzmanagement als formalisierbare Abbildung von Wissen und Handeln für das Personalwesen. Wirtschaftspsychologie, 3, 86-93.

Ley, T. & Albert, D. (2003b). Identifying Employee Competencies in Dynamic Work Domains: Methodological Considerations and a Case Study. Journal of Universal Computer Science, 9 (12), 1500-1518.

Ley, T., Lindstaedt, S. N., & Albert, D. (2005). Supporting Competency Development in Informal Workplace Learning. In K.-D. Althoff, A. Dengel, R. Bergmann, M. Nick, T. Roth-Berghofer (Eds.), Professional Knowledge Management (LNAI 3782, pp. 189-202). Berlin: Springer.

Liebetrau, A. M. (1985). Measures of Association (Quantitative Applications in the Social Sciences 32). Beverly Hills, London & New Delhi: Sage Publications.

Lindstaedt, S. N., Farmer, J., & Ley, T. (2004). Betriebliche Weiterbildung. In J. Haake, G. Schwabe, & M. Wessner (Eds.), CSCL-Kompendium - Lehr- und Handbuch zum computerunterstützten kooperativen Lernen (pp. 423-434). München: Oldenbourg.

Lindstaedt, S. N., Ley, T., & Mayer, H. (2005). Integrating Working and Learning in APOSDLE. Proceedings of the 11th Business Meeting of the Forum Neue Medien, November 10-11, 2005, University of Vienna, Austria. Graz/Austria: Forum Neue Medien.

Lindstaedt, S. N. & Ulbrich, A. (2006). Integration von Arbeit und Lernen – Kompetenzentwicklung in Arbeitsprozessen. In T. Pellegrini & A. Blumauer (Hrsg.), Semantic Web – Wege zur vernetzten Wissensgesellschaft. Heidelberg: Springer.

Maiden, N.A.M., & Jones, S.V. (2004a). The RESCUE Requirements Engineering Process – An Integrated User-centered Requirements Engineering Process, Version 4.1. Unpublished Manuscript, Centre for HCI Design, The City University, London.

Maiden, N.A.M., & Jones, S.V. (2004b). RESCUE Process: Examples. Version 2. Unpublished Manuscript, Centre for HCI Design, The City University, London.

Maiden, N.A.M., Jones, S.V. & Flynn, M. (2003). Innovative Requirements Engineering Applied to ATM. Proceedings ATM (Air Traffic Management) 2003, Budapest, June 23-27 2003.

Mayring, Philipp (2003). Qualitative Inhaltsanalyse. Grundlagen und Techniken, 8th edition. Weinheim: Beltz.

National O*NET Consortium (2005). O*NET OnLine. Retrieved March 20, 2006, at http://online.onetcenter.org.

Pilgerstorfer, M., Albert, D., & Camhy, D. G. (2006). Considerations on Personalized Training in Philosophy for Children. In D. G. Camhy & R. Born (Eds.), Encouraging Philosophical Thinking: Proceedings of the International Conference on Philosophy for Children in Graz, Austria (Vol. 17, pp. 85-89). Academia Verlag.

Rollett, H. (2003). Knowledge Management: Processes and Technologies. Boston: Kluwer Academic Publishers.

Schmidt, A. (2004). Kontextgesteuertes Lernen in Unternehmensumgebungen: Der „Learning in Process“-Ansatz. Beitrag präsentiert auf der Deutschen e-Learning – Fachtagung der Gesellschaft für Informatik 2004 (Delfi 04), Paderborn.

Schroeder, U. (2002). Meta-Learning Functionality in eLearning Systems, International Conference on Advances in Infrastructure for Electronic Business, Education, Science, and Medicine on the Internet 2002, L'Aquila, Italy.

Schröder, B. & Reineking, B. (2004). Validierung von Habitatmodellen. In C.F. Dormann, T. Blaschke, A. Lausch, B. Schröder & D. Söndgerath (Eds.), Habitatmodelle-Methodik, Anwendung, Nutzen. Tagungsband zum Workshop vom 8.-10. Oktober 2003 am UFZ Leipzig (pp. 47-56). UFZ-Berichte 9/2004.

Schüppel, J. (1997). Wissensmanagement: organisatorisches Lernen im Spannungsfeld von Wissens- und Lernbarrieren. Wiesbaden: Dt. Univ.-Verl.

Stefanutti, L. & Albert, D. (2002). Efficient assessment of organizational action based on knowledge space theory, In K. Tochtermann & H. Maurer (Eds.), Proceedings of I-KNOW ’02, 2nd International Conference on Knowledge Management, Graz/Austria, Juli 11-12 (pp. 183-190). Graz: Know-Center.

Ulbrich, A., Scheir, P., Görtz, M. & Lindstaedt, S. N. (2006). A Context-Model for Supporting Work-Integrated Learning. In W. Nejdl & K. Tochtermann (Eds.), Proceedings of 1st European Conference on Technology-enhanced Learning (LNCS, Vol. 4227). Heidelberg: Springer.

Van den Berg, P. T. (1998). Competencies for Work Domains in Business Computer Science. European Journal of Work and Organisational Psychology, 7(4), 517-531.

Vicente, K. (1999). Cognitive work analysis. Toward Safe, Productive, and Healthy Computer-Based Work. Mahwah, N.J.: Lawrence Erlbaum Associates.

Wirtz, M. & Caspar, F. (2002). Beurteilerübereinstimmung und Beurteilerreliabilität. Methoden zur Bestimmung und Verbesserung der Zuverlässigkeit von Einschätzungen mittels Kategoriesystemen und Ratingskalen. Göttingen: Hogrefe.

Zave, P. (1997). Classification of Research Efforts in Requirements Engineering. ACM Computing Surveys, 29 (4), 315-321.

Appendix A

Reviewed List of Tasks (Activity Modelling)

ACTIVITY MODELLING

Gather Data on Human Activity

1_1 Plan and prepare acquisition sessions, decide on acquisition methods

Analyse the functional structure on the work domain

1_2 Analyse the scope/validity domain of the new tool

1_3 Identify properties of the domain and the environment that constrain current and future performance

1_4 Identify properties of the system that constrain performance

1_5 Identify degrees of freedom allowing for that variability that makes the system flexible

1_6 Identify the system's goals and high level functional goals

1_7 Identify external resources that are available for practitioners to achieve their goals

Identify tasks/goals to be achieved (independently of how they are to be achieved or by whom they are to be achieved)

1_8 Identify the workers' prescribed goals as defined by norms and regulations

1_9 Identify the prescribed tasks to be executed to achieve the prescribed goals

Identify strategies how tasks can be achieved independently of who is executing them

1_10 Identify non-prescribed goals set up by the practitioners to achieve prescribed goals

1_11 Identify non-prescribed tasks that operators put in place to achieve goals while coping with internal and external constraints

1_12 Identify different strategies of the workers to acquire and process information

1_13 Identify information needs for the new tool

1_14 Identify inefficiencies of the existing system experienced by the users

1_15 Identify resources available to achieve goals

1_16 Analyse the different action sequences envisaged in certain situations

1_17 Identify and record inter- and intra- subjective variability to highlight work processes

1_18 Analyse contextual features that are sources of variability

1_19 Analyse the relevance of an aiding tool in relation to certain actions

Identify social organisation and co-operation between actors (both human and artificial)

1_20 Identify prescribed goals that are to be achieved by a team of workers

1_21 Identify prescribed tasks that are to be achieved by a team of workers

1_22 Identify different forms of communication and the exchange of information among workers

1_23 Analyse the mutual knowledge of teams or team members

Identify worker competencies such as knowledge, rules or skills that workers need to effectively accomplish their tasks

1_24 Identify semantic knowledge the workers need for effectively accomplishing the task

Appendix A (Continued)

Model Human Activity

2_1 Identify the major types of activity in the current system the automation will affect

2_2 Model activities in a functional matter with respect to a purpose they serve

2_3 Break down actions in the normal course into their physical, cognitive and communicative components

2_4 Structure the particular activities into activity descriptions by using the Activity Modelling templates

2_5 Review the Activity Model

Appendix B

Reviewed List of Tasks (System Goal Modelling)

SYSTEM GOAL MODELLING

Determine System Boundaries

3_1 Use the findings of the Activity Model to identify system boundaries
3_2 Build a first cut Context Model to identify system boundaries
3_3 Identify a basic list of stakeholders
3_4 Carry out an initial stakeholder analysis to determine the major categories of system stakeholder
3_5 Consider for each stakeholder whether he corresponds to an adjacent actor
3_6 Develop an extended Context Model to refine the first cut model of system boundaries

Determine system dependencies, goals and rationale

4_1 Allocate functions between actors according to boundaries
4_2 Model the system's hard and soft goals
4_3 Interpret the Activity Model and integrate the identified actors and goals into the SD-Model
4_4 Identify the intentional strategic actors
4_5 Model dependencies between strategic actors for goals to be achieved and tasks to be performed
4_6 Model dependencies between strategic actors for availability or entity of resources
4_7 Write different forms of dependency descriptions

Refine system dependencies, goals and rationale

5_1 Refine the Strategic Dependency Model
5_2 Refine the Strategic Rationale Models
5_3 Produce a single, integrated SR model using dependencies in the SD model
5_4 Check that each individual SD model is complete and correct with stakeholder goals, soft-goals, tasks and resources
5_5 Validate the i* SR model against the SD model by cross-checking the two models

Appendix C

Reviewed Competence Catalogue

KNOWLEDGE

1. **Knowledge about acquisition techniques available**
   Knowledge about strengths and weaknesses of every technique
   Knowledge about limits on use of each method
   Knowledge about minimum conditions for method use
   Knowledge about method interdependencies

2. **Knowledge about how to organise an acquisition programme**
   Knowledge about guidelines for selecting from a broad range of different methods
   Knowledge about practical constraints on each session

3. **Knowledge about the Activity Model and the activity descriptions**
   Knowledge about the content of activity descriptions
   Knowledge about the properties and the content of an Activity-Model

4. **Knowledge about actors, tasks, goals and resources**
   Knowledge about what is an actor, what is an 'intentional strategic actor'
   Knowledge about different kinds of goals (prescribed, non prescribed, local, soft-g., …)
   Knowledge about what is a task
   Knowledge about resources (means available to achieve goals and sub-goals)
   Knowledge about the connection between actors, tasks and goals
   Knowledge about the differentiation between these concepts

5. **Knowledge about possible physical/environmental factors influencing human activity**
   Knowledge about preconditions of actions,
   Knowledge about contextual features (distinctive features of the working context)
   Knowledge about constraints (properties of the environment that need to be taken into account when deciding about an action)
   Knowledge about the differentiation between these concepts

6. **Basic understanding of human cognition, background in cognitive psychology**
   Knowledge about different types of knowledge (tacit, semi-tacit, non-tacit)
   Knowledge about properties of non-tacit, semi-tacit and tacit knowledge
   Basic understanding of selection and evaluation of information
   Knowledge about individual and collective information processing strategies
   Knowledge about individual and collective problem solving strategies

7. **Basic understanding of social and organisational behaviour**
   Basic knowledge of social psychology or sociology
   Knowledge about the appreciation of social networks
   Knowledge about different forms of team cooperation

8. **Knowledge about the domain and the environment of the system**
   Domain knowledge
   Knowledge of the environment

9. **Knowledge of different types of system stakeholders**
   Knowledge about the responsibilities and roles of different types of system stakeholders (USTM)

10. **Basic technical understanding**
    Knowledge about automation available
    Knowledge about possible technical solutions
    Knowledge about technical possibilities

Appendix C (Continued)

11. Knowledge about different types of adjacent systems
Knowledge about the taxonomy of adjacent system types to consider
Knowledge about the properties of different types of adjacent systems

12. Knowledge about the Context Model
Ability to read and understand a Context Model
Knowledge about the properties and the content of a Context model
Knowledge about guidelines to develop an extended Context model

13. Knowledge about the Strategic Dependency Model (SD-Model)
Ability to read and understand an SD model
Knowledge about the properties and the content of an SD-Model
Knowledge of different types of the dependency link
Knowledge about guidelines for the different possibilities of wording for links between elements of the SD-Model

14. Removed: Knowledge about the different possibilities of notation of the elements of the SD-Model

15. Knowledge about the Strategic Rationale Model (SR-Model)
Ability to read and understand an SR model
Knowledge about the properties and the content of an SR-Model
Knowledge about different types of the dependency links
Knowledge about different types of the task decomposition link
Knowledge about different types of the means end link ?
Knowledge about different types of the contribute to soft-goal link
Knowledge about what dependencies between what concepts are allowed

16. Knowledge of validating the SR Model
Knowledge of guidelines and techniques to cross-check the SD- and SR-Model

17. Knowledge of brainstorming techniques

18. Knowledge of creativity techniques

19. Ability to produce a Context Model

20. Ability to produce an i* Model

Appendix C (Continued)

SKILLS

21. Standard project management skills

Ability of creating and maintaining an environment that guides a project to its successful completion

Understanding the procedures and methods that define a project while confronting and overcoming the problems encountered over the project lifespan.

22. Listening Skills

Ability to carefully listen in a way that you don't prejudge information

Ability to clearly understand spoken, partly expressed, and unspoken messages from others (workers, stakeholders)

Understand the message being conveyed and identify the key ideas the speaker is sending by paying close attention to what is being communicated both verbally and non-verbally

Ability of giving full attention to what other people are saying, taking time to understand the points being made, asking questions as appropriate, and not interrupting at inappropriate times

23. Communication skills

Ability of sending clear and convincing messages

Ability to clearly articulate your ideas

24. Collaboration skills and Empathy

Ability to balance a focus on tasks with attention to relationships

Ability of sensing others' feelings and perspective and taking an active interest in their concerns

25. Writing skills

Ability to write well

Ability of non-biased writing

Ability to relay a message or represent one's thoughts in written format with clarity and accuracy

26. Learning skills

Ability to acquire and integrate new information by gathering data

Ability to understand the implications of new information for both current and future problem solving and decision making

27. On-line data gathering skills

Skills of collecting data while practitioners are working with the system

Ability to make non-biased observations

Knowledge of on-line data gathering techniques such as Protocol Analysis, Ethnography, …

28. Off-line data-gathering skills

Skills of eliciting information from practitioners while they are not involved in any activity

Structured and unstructured interviewing skills, non-prejudging interviewing, asking the right questions

Knowledge of direct elicitation techniques, off-line data gathering techniques such as Card sorting, Laddering, …

Appendix C (Continued)

29. Judgement and decision making
Ability to consider the relative costs and benefits of potential actions to choose the most appropriate one
Ability of using logic and reasoning to identify the strengths and weaknesses of alternative solutions, conclusions or approaches to problems
Ability to make effective decisions quickly, based on a careful and balanced consideration of all available facts
Ability to identify complex problems and review related information to develop and evaluate options and implement solutions

30. Ability of thinking in processes and analysing processes
Ability to regard a particular course of action as intended to achieve a goal or result
Ability of analysing actors and concepts with regard to their mutual dependencies

31. Ability of structuring data and organising information
Ability to arrange things or actions in a certain order or pattern according to a specific rule or set of rules
Ability to organise the material you collect

32. Ability of functional decomposition
Ability to break down concepts (goals, tasks, …) into sub-elements
Ability to decompose processes into sub-elements

33. Analytical skills
Ability to provide a logical, in-depth analysis of a problem or situation
Ability to decompose and structure the problem space
Ability to examine the situation in a systematic way
Ability of filtering out the important information
Ability to extract the most important thing of what somebody says
Ability to select and understand the most important facets of some peace of work

34. Ability of abstraction
Ability to abstract from literal objects or instances and to extract concepts such as actors, goals, etc. from them
Ability to understand a general rule of examples people are telling you

Appendix D

Task-competency matrix of Expert 1 (Extract)

Phase	No.	Task	1. Knowledge about acquisition techniques available	2. Knowledge about how to organise an acquisition programme	3. Knowledge about the Activity Model and the activity descriptions	4. Knowledge about actors, tasks, goals and resources	5. Knowledge about possible physical factors influencing human activity	6. Basic understanding of hum. cognition, background in cogn. psychology	7. Basic understanding of social and organisational behaviour	8. Knowledge about the domain and the environment of the system	9. Knowledge of different types of system stakeholders	10. Basic technical understanding	11. Knowledge about different types of adjacent systems	12. Knowledge about the Context Model	13. Knowledge about the Strategic Dependency Model (SD-Model)	15. Knowledge about the Strategic Rationale Model (SR-Model)	16. Knowledge of validating the SR Model	17. Knowledge of brainstorming techniques
1. Gather Data on Human Activity	1_1	Plan and prepare acquisition sessions, decide on acquisition methods	2	2	0	0	0	1	1	1	1	0	0	0	0	0	0	1
	1_2	Analyse the scope/validity domain of the new tool	1	0	1	0	1	0	1	2	1	0	1	0	0	0	0	0
	1_3	Identify properties of the domain and the environment that constrain current and future performance	0	0	1	2	2	0	1	2	1	0	1	0	0	0	0	0
	1_4	Identify properties of the system that constrain performance	0	0	1	2	2	0	1	2	1	0	1	0	0	0	0	0
	1_5	Identify degrees of freedom allowing for that variability that makes the system flexible	0	0	1	0	1	1	1	2	1	0	1	0	0	0	0	0
	1_6	Identify the system's goals and high level functional goals	1	0	0	1	0	0	0	0	1	0	0	0	0	1	0	1
	1_7	Identify external resources that are available for practitioners to achieve their goals	1	0	0	2	0	1	0	1	0	1	0	0	0	1	0	0
	1_8	Identify the workers' prescribed goals as defined by norms and regulations	0	0	1	1	0	1	1	1	1	0	0	0	0	0	0	0
	1_9	Identify the prescribed tasks to be executed to achieve the prescribed goals	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0
	1_10	Identify non-prescribed goals set up by the practitioners to achieve prescribed goals	1	0	1	1	2	1	2	1	1	0	0	0	0	0	0	0
	1_11	Identify non-prescribed tasks that operators put in place to achieve goals while coping with constraints	1	0	1	1	2	1	2	1	1	0	0	0	0	0	0	0
	1_12	Identify different strategies of the workers to acquire and process information	1	0	1	1	0	1	1	1	0	0	0	0	0	1	0	0
	1_13	Identify information needs for the new tool	1	0	1	1	0	1	1	1	1	1	0	1	0	0	0	0
	1_14	Identify inefficiencies of the existing system experienced by the users	2	0	1	0	1	1	1	1	2	0	0	0	0	0	0	0
	1_15	Identify resources available to achieve goals	1	0	1	1	1	0	0	1	2	1	1	0	0	0	0	0
	1_16	Analyse the different action sequences envisaged in certain situations	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0
	1_17	Identify and record inter- and intra- subjective variability to highlight work processes	2	0	2	1	1	2	2	2	2	0	0	0	0	0	0	0
	1_18	Analyse contextual features that are sources of variability	2	0	2	1	1	2	2	2	2	0	0	0	0	0	0	0
	1_19	Analyse the relevance of an aiding tool in relation to certain actions	0	0	1	0	1	1	1	0	1	1	0	0	0	0	1	0
	1_20	Identify prescribed goals that are to be achieved by a team of workers	1	0	1	1	0	0	0	0	1	0	0	0	1	1	0	0
	1_21	Identify prescribed tasks that are to be achieved by a team of workers	1	0	1	1	1	0	1	0	1	0	0	0	0	1	0	0
	1_22	Identify different forms of communication and the exchange of information among workers	1	0	2	1	2	1	1	1	1	0	0	1	1	0	0	0
	1_23	Analyse the mutual knowledge of teams or team members	2	0	2	1	0	2	2	2	2	1	0	1	0	0	0	0
	1_24	Identify semantic knowledge the workers need for effectively accomplishing the task	1	0	1	1	0	1	1	1	1	0	0	0	0	1	0	0
2. Model Human Activity	2_1	Identify the major types of activity in the current system the automation will affect	0	0	2	0	0	0	0	1	0	2	1	1	1	1	0	0
	2_2	Model activities in a functional matter with respect to a purpose they serve	0	0	1	2	0	0	0	2	2	2	2	1	1	1	0	0
	2_3	Break down actions in the normal course into their physical, cognitive and communicative components	0	0	1	1	2	0	0	1	0	0	0	0	0	1	0	0
	2_4	Structure the particular activities into activity descriptions by using the Activity Modelling templates	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
	2_5	Review the Activity Model	0	0	2	2	1	1	1	1	0	0	0	0	0	0	0	0
3. Determine System Boundaries	3_1	Use the findings of the Activity Model to identify system boundaries	0	0	2	1	0	0	0	0	0	0	1	2	2	0	0	0
	3_2	Build a first cut Context Model to identify system boundaries	1	1	0	1	0	0	1	0	1	1	1	2	0	0	0	1
	3_3	Identify a basic list of stakeholders	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0
	3_4	Carry out an initial stakeholder analysis to determine the major categories of system stakeholder	0	0	0	0	0	0	0	0	2	0	1	1	1	0	0	0
	3_5	Consider for each stakeholder whether he corresponds to an adjacent actor	0	0	0	0	0	0	0	0	2	0	2	2	2	0	0	0
	3_6	Develop an extended Context Model to refine the first cut model of system boundaries	0	0	0	0	0	0	0	2	1	2	2	2	1	0	0	0
4. Determine System Dependencies	4_1	Allocate functions between actors according to boundaries	0	0	1	0	0	0	2	1	0	0	1	1	1	0	0	0
	4_2	Model the system's hard and soft goals	0	0	0	1	0	0	0	0	0	0	0	0	0	2	1	0
	4_3	Interpret the Activity Model and integrate the identified actors and goals into the SD-Model	0	0	2	1	0	0	0	0	0	0	1	0	2	1	0	0
	4_4	Identify the intentional strategic actors	0	0	0	0	0	0	0	0	2	0	1	0	2	0	0	0
	4_5	Model dependencies between strategic actors for goals to be achieved and tasks to be performed	0	0	0	1	0	0	0	0	1	0	1	0	2	1	0	0
	4_6	Model dependencies between strategic actors for availability or entity of resources	0	0	0	1	0	0	0	0	1	0	1	0	2	1	0	0
	4_7	Write different forms of dependency descriptions	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
5. Refine System Depend.	5_1	Refine the Strategic Dependency Model	0	0	0	0	0	0	0	0	0	0	1	0	2	1	0	0
	5_2	Refine the Strategic Rationale Models	0	0	0	0	0	0	0	0	0	0	1	0	1	2	0	0
	5_3	Produce a single, integrated SR model using dependencies in the SD model	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0
	5_4	Check that each individual SD model is complete and correct	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0
	5_5	Validate the i* SR model against the SD model by cross-checking the two models	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	0

Footnotes

1. “Advanced Process Oriented Self-directed Learning Environment” (see Lindstaedt, Ley & Mayer, 2005). APOSDLE is partially funded under the FP 6 of the European Commission within the IST Workprogramme 2004 (FP6-IST-2004-027023).

2. Here, τ_b is employed primarily as a descriptive measure. A meaningful testing for significance requires larger samples and adequate cell frequencies.

3. In Table 3, there is no merged structure for Activity Modelling because of low inter-rater agreement between the RESCUE experts’ task-competency assignments.

Table 1

Contingency table of task-competency assignments

	Expert 2			
Expert 1	0	1	2	Expert 1 total
0	847	16	70	933
	(54.61%)	(1.03%)	(4.51%)	(60.15%)
1	292	26	109	427
	(18.83%)	(1.68%)	(7.03%)	(27.53%)
2	89	6	96	191
	(5.74%)	(0.39%)	(6.19%)	(12.31%)
Expert 2 total	1228	48	275	1551
	(79.17%)	(3.09%)	(17.73%)	(100%)

Table 2

<u>Set of tasks and set of elementary competencies (example)</u>

Tasks and Elementary Competencies	
<u>Tasks</u>	
3_1	Use the findings of the Activity Model (AM) to identify system boundaries
4_2	Model the system's hard and soft goals
4_3	Interpret the AM and integrate the identified actors and goals into the Strategic Dependency (SD) Model
4_5	Model dependencies between strategic actors for goals to be achieved and tasks to be performed
4_6	Model dependencies between strategic actors for availability of resources
5_1	Refine the Strategic Dependency Model
5_2	Refine the Strategic Rationale (SR) Models
5_3	Produce an integrated SR Model using dependencies in the SD Model
5_4	Check that each individual SD Model is complete and correct with stakeholder goals, soft goals, tasks and resources
5_5	Validate the i* SR Model against the SD Model (cross-check)
<u>Competencies</u>	
3	Knowledge about the Activity Model and the activity descriptions
12	Knowledge about the Context Model
13	Knowledge about the Strategic Dependency Model (SD-Model)
15	Knowledge about the Strategic Rationale Model (SR-Model)
16	Knowledge of validating the SR Model
20	Ability to produce an i* Model

Table 3

Task-competency assignment, minimal interpretation and base states (example)

Task-Competency Assignment

	Competencies						Minimal Interpretations
Tasks	3	12	13	15	16	20	and Base States
3_1	X	X	X				{3, 12, 13}*
4_2				X		X	{15, 20}*
4_3	X		X			X	{3, 13, 20}*
4_5			X			X	{13, 20}*
4_6			X			X	{13, 20}*
5_1			X				{13}*
5_2				X			{15}*
5_3			X	X		X	{13, 15, 20}
5_4			X	X	X		{13, 15, 16}*
5_5			X	X	X		{13, 15, 16}*

* Base State

Table 4

Number of elementary competencies (N_{Comp}), cardinality of power set (Power Set), cardinality of bases (Base) and cardinality of competence spaces (C. Space) obtained by task-competency assignments

Competence Spaces				
Assignment	N_{Comp}	Power Set [a]	Base	C. Space
Activity Modelling				
Expert 1	22	4194304	25	3338
Expert 2	21	2097152	23	849
System Goal Modelling				
Expert 1	19	524288	15	756
Expert 2	15	32768	12	166
Merged Structure	22	4194304	14	420

[a] Cardinality of the power set was calculated as 2^n where n is the number of competencies

Table 5

Rank correlation between assessed and predicted performance of persons, Leave One Out method

Notional Solution Patterns (Assessment) [b]	Competence-Performance Structure (Prediction) [a] Expert 1	Expert 2	Merged Structure
Activity Modelling [c]			
Expert 1	.33**	.26**	
Expert 2	.45**	.77**	
System Goal Modelling			
Expert 1 [c]	.54**	.76**	.54**
Expert 2	.32**	.42**	.41**

[a] Competence-performance structure used for the prediction of task performance by means of Leave One Out

[b] Notional solution patterns obtained by the validation questionnaire Appraisal of Persons

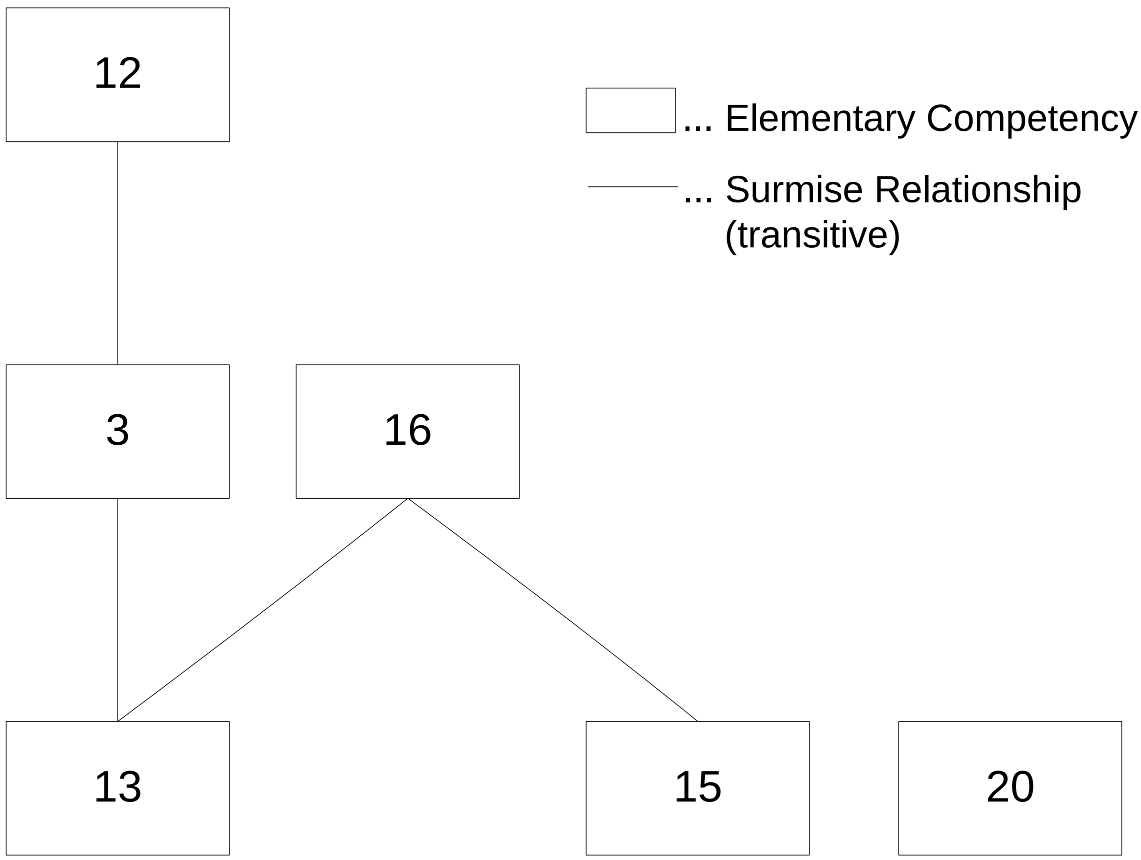
[c] Only four solution patterns were considered

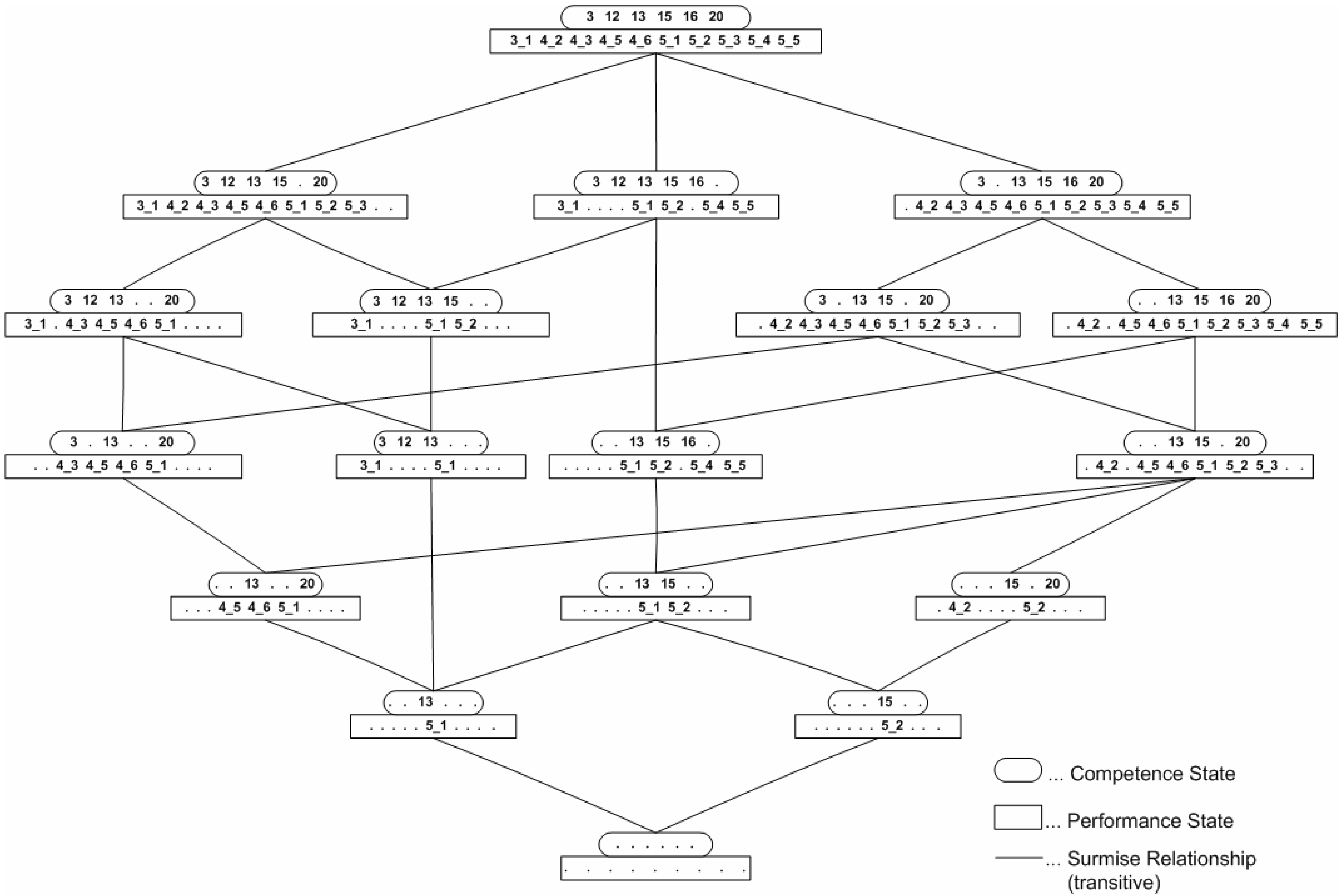
** $p<.01$

Figure Captions

Figure 1 : Hasse-diagram of the surmise relation on the set of elementary competencies. (Example). Upwardly lines indicate transitive prerequisite relationships between competencies.

Figure 2 : Hasse-diagram of competence space and performance representation (Example). Upwardly lines indicate transitive prerequisite relationships between competence states and performance states respectively.


12
... Elementary Competency
... Surmise Relationship (transitive)
3
16
13
15
20



3 12 13 15 16 20
3_1 4_2 4_3 4_5 4_6 5_1 5_2 5_3 5_4 5_5
3 12 13 15 . 20
3_1 4_2 4_3 4_5 4_6 5_1 5_2 5_3 . .
3 12 13 15 16 .
3_1 . . . . 5_1 5_2 . 5_4 5_5
3 . 13 15 16 20
. 4_2 4_3 4_5 4_6 5_1 5_2 5_3 5_4 5_5
3 12 13 . . 20
3_1 . 4_3 4_5 4_6 5_1 . . . .
3 12 13 15 . .
3_1 . . . . 5_1 5_2 . . .
3 . 13 15 . 20
. 4_2 4_3 4_5 4_6 5_1 5_2 5_3 . .
. . 13 15 16 20
. 4_2 . 4_5 4_6 5_1 5_2 5_3 5_4 5_5
3 . 13 . . 20
. . 4_3 4_5 4_6 5_1 . . . .
3 12 13 . . .
3_1 . . . . 5_1 . . . .
. . 13 15 16 .
. . . . . 5_1 5_2 . 5_4 5_5
. . 13 15 . 20
. 4_2 . 4_5 4_6 5_1 5_2 5_3 . .
. . 13 . . 20
. . . 4_5 4_6 5_1 . . . .
. . 13 15 . .
. . . . . 5_1 5_2 . . .
. . . 15 . 20
. 4_2 . . . . 5_2 . . .
. . 13 . . .
. . . . . 5_1 . . . .
. . . 15 . .
. . . . . . 5_2 . . .
. . . . . .
. . . .
... Competence State
... Performance State
... Surmise Relationship (transitive)