Competence and Performance in Requirements Engineering: Bringing Learning to the Workplace

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Abstract. Challenges for learning in knowledge work are being discussed. These include the challenge to better support self-directed learning while addressing the organizational goals and constraints at the same time, and providing guidance for learning. The use of competencies is introduced as a way to deal with these challenges. Specifically, the competence performance approach offers ways to better leverage organizational context and to support informal learning interventions. A case study illustrates the application of the competence performance approach for the learning domain of requirements engineering. We close with conclusions and an outlook on future work.

Learning in Knowledge Work: The APOSDLE Approach

With the term knowledge worker we refer to an employee of an organisation whose essential operational and value creating tasks consists in the production and distribution of knowledge (Machlup, 1962). Knowledge Workers are predominantly controlled by overall goals and expected results instead of defined procedures. Thus, they have significant autonomy in structuring their activities (such as timing and procedures) (Pyöriä, 2003; Davenport, 2005).

Learning in knowledge work operates in a constant tension between personal goals and organizational constraints. On the one hand, knowledge workers increasingly learn in an informal and self-directed manner (Pinchot & Pinchot, 1996). On the other hand, aligning learning to organizational goals and task requirements is an important factor. This even poses challenges for traditional personnel development instruments and trainings. How this alignment can be addressed within knowledge work, remains an open issue even more (Elkjaer, 2000).

This is also reflected in the differences between eLearning and Knowledge Management (KM) approaches. While eLearning has traditionally focused on providing guidance to learners by structuring content according to pedagogical models, KM has focused more on self-directed aspects of information search and knowledge sharing with a lack of addressing learning issues (Ras, Memmel, &

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Weibelzahl, 2005). While in traditional eLearning the guidance may be too strict to address challenges of knowledge intensive work, KM certainly has neglected that certain structures are needed for learning to take place.

As a result of this discussion, two challenges can be identified when addressing learning in knowledge work: (1) the tension between individual goals and organizational goals and constraints, and (2) the "problem of the amount of guidance" (Ras, Memmel, & Weibelzahl, 2005, p. 158). These challenges are currently being addressed in the APOSDLE project[7]. The goal of APOSDLE is to create a process-oriented learning environment which supports knowledge workers to work and learn at the workplace. The APOSDLE approach to workplace learning addresses the challenges by offering knowledge workers easy access to relevant knowledge artefacts and persons, and thereby giving them considerable freedom to work and learn in a self-directed manner. In order to address organizational issues as well, APOSDLE looks at the organizational context in which the knowledge worker operates (Ulbrich, Scheir, Görtz & Lindstaedt, 2006).

One of the elements of this context is made up of the competencies needed for performing the work the knowledge worker is engaged in. Specifically, our goal is to suggest ways in which a competency gap (i.e. a gap between the competencies required for a task, and competencies the knowledge worker has available) can be (semi-)automatically inferred from a comparison of a person's task performance in the past, and the tasks she is about to tackle in the future.

The purpose of this paper is to suggest a framework which formalizes the connection between knowledge intensive tasks, such as ones performed in a requirements engineering activity, and the competencies needed to perform these tasks. The framework informs an implementation methodology. This is then introduced and illustrated by means of a case study conducted in the domain of requirements engineering.

A Competence Performance Approach for Workplace Learning

The use of competencies has often been advocated as a way to deal with the challenges in workplace learning (Green, 1999; Lucia & Lepsinger, 1999; Erpenbeck & Rosenstiel, 2003). Specifically, competencies are being used to more closely relate learning to organizational requirements (such as goals or task requirements). Ley, Lindstaedt and Albert (2005) have suggested the competence performance approach as a model to formalize competencies and their connection to workplace performance for work-integrated learning.

With the competence performance approach Korossy (1997, 1999) has introduced an extension of knowledge space theory (Falmagne et al., 1990; Doignon & Falmagne, 1999). Knowledge space theory has been developed in the 1980s and 90s as an attempt to model a person's knowledge state as close as possible to observable behavior. It is predominantly concerned with the diagnosis of knowledge and has

[7] APOSDLE is an Integrated Project (IP) partially funded under FP6 of the European Community. For more details, see http://www.aposdle.org.

been applied in adaptive testing and tutoring scenarios and system (e.g. ALEKS Corp., 2003; Hockemeyer, Held & Albert, 1998). The fundamental idea of knowledge space theory is that a person's knowledge state in a certain domain can be understood as the set of problems this person is able to solve. Since solution dependencies exist among the problems, it is possible to present a person only a subset of all problems of a domain in order to diagnose his/her knowledge state. The collection of all possible knowledge states is called a *knowledge space*. A knowledge space is a partial order and is stable under union.

In an attempt to develop Knowledge Space Theory further, Korossy (1997) suggests that in addition to the set of problems, one should look at the set of competencies, that is knowledge, skills and abilities needed to solve the problems. This would generate information on the *reasons* for different levels of performance, and thereby help to suggest learning measures. Similar to the set of problems, competencies are also structured in a competence space which results from a surmise relation on the set of competencies.

The relationship between the two sets (problems and competencies) is formalized by an *interpretation function* which maps each problem to a subset of competence states which are elements of the competence space. This subset of competence states contains all those competence states in each of which the problem is solvable. The interpretation function induces a *representation function* which assigns to each of the competence states all problems which are solvable in that competence state. Which problems are solvable is determined by the interpretation function.

The competence performance approach has been applied in technology enhanced learning applications. For example, Hockemeyer et al. (2003) have assigned "competencies required" and "competencies taught" as metadata to a collection of learning objects. Thereby, prerequisite structures are derived for the eLearning content which allow for adaptive tutoring. New course content could easily be integrated, as metadata was only held locally.

In the current approach, we define *competencies* as personal characteristics of job holders which they bring to bear in different situations. Competencies are hypothetical constructs which determine performance in a job. The term *performance* is understood to encompass all behaviors relevant for the accomplishment of a certain task in a specific situation (Schmitt & Chan, 1998). We will differentiate competencies into more stable characteristics such as personality traits (or temperaments), motives and cognitive abilities, and more variable characteristics, such as skills and knowledge. This differentiation is in line with a large body of research into KSAOs (knowledge, skills, abilities and other characteristics) (Lucia & Lepsinger, 1999; Schmitt & Chan, 1998).

Case Study: Modeling Competencies for Requirements Engineering

This section introduces the methodology we use to model competencies within the competence performance framework. The methodology has already been applied in different settings (i.e. in the automotive industry and in a research based setting) (Ley, Albert & Lindstaedt, in press). We have recently conducted a further case study focused more directly on supporting workplace learning. We briefly introduce this case study here. It will then be used to illustrate the procedure employed for deriving competence performance structures.

The case study is currently being conducted as part of the APOSDLE project where the learning domain for a first prototype is requirements engineering (RE). The learning environment targets persons with various levels of expertise in RE who are working in a requirements engineering project. They may be domain experts with little knowledge of RE who have been made responsible for eliciting requirements for a system to be built, or RE specialists who need only little guidance to conduct RE projects. Specifically, we are using the RESCUE process (Requirements Engineering with Scenarios in User-Centered Environments, see Maiden et al. 2004).

RESCUE is an innovative process developed for the elicitation and specification of requirements for socio-technical systems. RESCUE supports a concurrent engineering process in which different modelling and analysis processes take place in parallel: Human Activity Modeling is done to provide an understanding of how people work in order to baseline possible changes to it. The aim of System Goal Modeling is to model the future system boundaries and dependencies between actors for goals to be achieved. The Goal Modeling is formalized with the i* notation. Use Case Modeling is the process of writing use cases for the future system, exploring it with stakeholders and carrying out impact analyses in order to obtain consistent and valid requirements. These sub processes are aligned at designated synchronization points. During the whole elicitation process, RESCUE provides guidance on requirements management. Furthermore the use of creativity workshops encourages requirements and design ideas to be discovered and elaborated together.

In the following sections, the methodology for modeling competence performance structures will be introduced. According to Ley & Albert (2003a), the methodology entails the following three steps: (1) derive a set of tasks (performance) for the position in question, and for the learning domain to be supported (see 3.1), determine competencies needed to successfully perform the tasks (see 3.2), and relate tasks and competencies in a task competency matrix (see 3.3). These three steps focus on the process "defining competencies" mentioned in the overall organizational competency management process presented by Ley, Albert & Lindstaedt (in press). Section 3.4 then suggest a way to use and validate the resulting structures.

Deriving a Set of Tasks

The tasks can be derived from a detailed analysis of the work to be performed in the chosen domain. It is important that tasks do well reflect the learning domain in question, and that performance in these tasks can be assessed with regard to some quality criteria which are agreed within the organization (i.e. whether a task has been performed well or poorly).

We have previously employed hierarchical task analysis to find tasks employees perform in a certain position (Ley & Albert, 2003b). In Ley & Albert (2003a), we have chosen documents produced by the workforce as a way to reflect the more dynamic nature of the tasks.

In the present case study, the set of tasks is rather easily obtained as there exists extensive documentation for the work to be performed in RESCUE. The set of tasks was derived by means of a detailed content analysis of the RESCUE process document (Maiden & Jones, 2004). We focused on the two streams *Human Activity Modeling (HAM)* and *System Goal Modeling (SGM)*. As a result, a first list of tasks was obtained for these two streams and later reviewed by the authors of the RESCUE process. The final list of tasks was composed of 29 tasks in the *HAM* stream, and 18 tasks in the *SGM* stream.

Deriving Competencies Needed

When eliciting competencies needed, we rely to a large extent on techniques for eliciting knowledge from domain experts with structured interviews or questionnaires. For instance, Ley & Albert (2003a) have used the Repertory Grid technique to elicit competencies from documents which the experts had written in the past. In the present case study, a first open ended interview was held with the two RESCUE experts mentioned above. We considered the tasks obtained in the previous step and asked the experts to name competencies (knowledge and skills) needed to perform well in these tasks. The interview data obtained was then complemented with data derived from the analysis of existing documented sources from related research, such as van den Berg (1998) and National O*NET Consortium (2005). From these sources, an extensive list of competencies was obtained, cross-checked for consistency and then validated with the RESCUE experts. In total the list consisted of 33 competencies.

Table 1: Tasks in System Goal Modeling Selected for the Example

	Tasks
1_1	Build a first cut Context Model to identify system boundaries
1_2	Carry out an initial stakeholder analysis
1_3	Develop an extended Context Model
1_4	Allocate functions between actors according to boundaries
1_5	Identify intentional strategic actors
1_6	Model dependencies between strategic actors
1_7	Write different forms of dependency descriptions
1_8	Produce an integrated SR Model using dependencies in the SD model
1_9	Check the i* Model for completeness and correctness
1_10	Validate the i* SR Model against the SD model (cross-check)

To exemplify the procedure, we have selected a subset of tasks to be achieved in the sub-process of *System Goal Modeling*. Table 1 shows the lists of tasks, Table 2 shows the list of competencies selected for our example.

Table 2: Competencies in System Goal Modeling Selected for the Example

	Competencies
A	Knowledge about actors, tasks, goals and resources
B	Knowledge of different types of system stakeholders
C	Knowledge of building the Context Model
D	Knowledge about the Strategic Dependency Model (SD-Model)
E	Knowledge about the Strategic Rationale Model (SR-Model)
F	Ability to produce an i* Model
G	Judgement and decision making skills
H	Knowledge of guidelines for validating the SR Model

Constructing Competence Performance Structures

To build the interpretation function, the experts were asked to assign to each task those competencies they regarded as mandatory for successfully accomplishing the respective task. This was done by means of a *task competency matrix* (see Ley & Albert, 2003a). In the present case, the experts were asked to give their assignments independently from each other. This way, agreement can be measured as one way to evaluate the methodology and the resulting structures (see below). In continuing the example from above, Table 3 gives the results of this assignment. The crosses in the matrix indicate the minimal interpretation for each task, i.e. the set of competencies that a person has to have at the minimum to be able to perform the task well.

To obtain the whole competence space, the competence states of the minimal interpretation were closed under union and the empty set was added. Furthermore, for every competence state the representation function was built by assigning to every state the set of tasks a person would be able to accomplish in the respective state, thereby obtaining the competence performance structure.

The competence performance structure derived for the example above, can be seen in Figure 1. In this example, a person who is in the competence state {B, C, D} should perform well in the tasks {1, 2, 7} (the respective performance state). A person who is able to accomplish task 4 (*Allocate functions between actors according to boundaries*) is assumed to be able to also perform task 2 (*Carry out an initial stakeholder analysis*) because any performance state which contains task 4, also contains task 2. In other words task 2 is assumed to be a prerequisite of task 4, since the minimal interpretation of task 2 ({B}) is a subset of the minimal interpretation of task 4 ({A, B, C}).

Table 3: Task Competency Matrix and Minimal Interpretation of tasks in SGM

		Competences								Minimal Interpretation
		A	B	C	D	E	F	G	H	
Tasks	1_1		X	X						{B, C}
	1_2		X							{B}
	1_3		X	X				X		{B, C, G}
	1_4	X	X	X						{A, B, C}
	1_5	X	X	X				X		{A, B, C, G}
	1_6	X	X	X	X		X	X		{A, B, C, D, F, G}
	1_7				X					{D}
	1_8	X	X	X	X	X	X	X		{A, B, C, D, E, F, G, H}
	1_9	X			X	X	X			{A, D, E, F}
	1_10	X			X	X	X		X	{A, D, E, F, H}

The purpose of this procedure is to limit the number of competence states (and performance states) that can be expected to appear in a population as a consequence of the prerequisite relationships. As a result, several adaptive procedures can be applied that can be utilized when the structures are put to use (see next section).

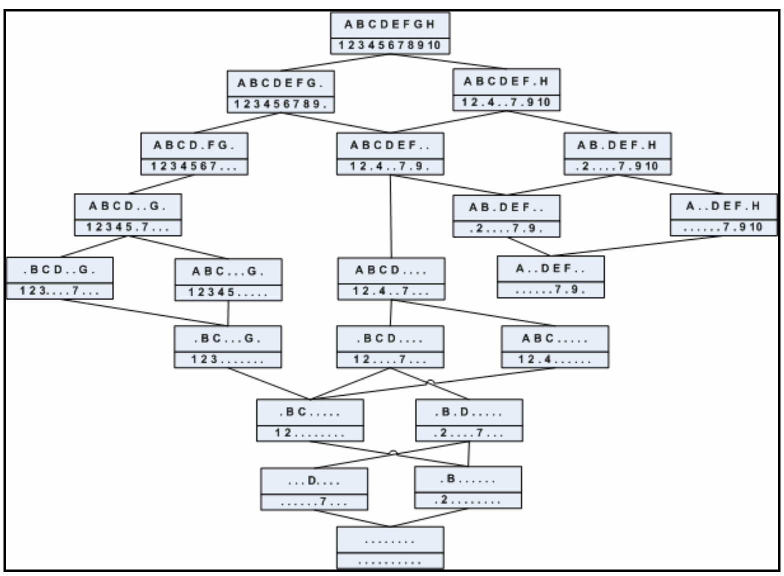

Fig. 1. Competence Space and Representation Function for the Example

Using and Validating the Structures

Given a valid structure of the domain, one can diagnose the competence state of a person by evaluating his/her performance in the tasks being performed, and thereby derive competency gap. Given certain tasks that were performed well, and others that were not performed well, it is relatively easy to find the likely competence state this person is in. If a person consistently performs well in tasks 1, 2 and 7 in the above example, but fails to perform well in task 4, this would mean that competency A (*Knowledge about actors, tasks, goals and resources*) would be a relevant learning goal. In case of such discrepancies one could provide the person with tailored learning contents.

This competency diagnosis can make use of the adaptive potential mentioned previously. From knowing that a person can perform well in certain tasks, it can be inferred with some certainty that this person also performs well in other tasks. This seems to be especially relevant for structures that encompass a large number of tasks where it is unlikely that performance information about all tasks is available for each and every employee.

Judgments of whether a certain task has been performed well or not (performance appraisal) can be obtained in a number of different ways. Standard procedures of self- and supervisor rating known from competency management and other Human Resource instruments (such as assessment centers or performance appraisal schemes) can be obtained. An important advantage when compared to many of the standard practices is that appraisal can be based on task performance which is relevant for the job that is being performed. This avoids several biases known from the appraisal of competencies (Schmitt & Chan, 1998).

The procedure of diagnosing competence states from past performance, and especially the adaptive procedures, require that the structures are valid. This is not an exclusive requirement for our approach, but in fact is essential for any appraisal system that is being put to use (see e.g. Schmitt & Chan, 1998). A special benefit offered by the competence performance approach is that it makes validating easier and offers the opportunity to integrate validation directly into the modeling or assessment process (Ley & Albert, 2004). Criteria for validating competence performance structures are discussed in Ley, Albert & Lindstaedt (in press). In the present case study, an initial comparison of the assignments done by the two experts resulted in an agreement coefficient (inter-rater reliability) of $r=0.26$ for the *HAM* stream and $r=0.53$ for the *SGM* stream.

Conclusions and Outlook

The above structures map the learning domain in terms of learning goals and the related tasks directly derived from relevant working tasks. This means that learning is specifically tailored to the requirements of working tasks and processes. We are currently also examining other elements of the user context that can be of use when providing process learning support, namely the process context and the application domain (see Ulbrich et al., 2006). We expect that by integrating competence performance structures (as well as other elements of the user context) into a user profile component, the retrieval component of the APOSDLE system will be able to better tailor the retrieval of existing resources to current available and missing competencies of the user.

In terms of structuring available content, competence performance structures provide an overall map of the learning content. Moreover, the use of competencies makes it possible to structure single learning resources according to the underlying knowledge need. We are currently researching ways to construct learning material automatically from available content that is structured by a “learning template” (de Jong, van Joolingen, Veermans, & van der Meij, 2005). The structure of the template and content of the material is dependent on the learning goals of the user (derived from the missing competencies), as well as the type of missing knowledge. For example, competency A (“Knowledge about actors, tasks, goals and resources” in Table 1) is mainly based on conceptual knowledge, whereas competency C (“Knowledge of building the Context Model”) is mainly based on procedural knowledge. As a consequence, the structure of the template will be different for learning something about competency A (e.g. learning definitions, background of terms etc.) than for competency B (learning procedures using how-tos and worked out examples).

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