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Design of a Performance-Oriented Workplace E-learning System Using Ontology

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Abstract: *E-learning is emerging as a popular learning approach utilized by many organizations. Despite the ever increasing practices of e-learning in the workplace, most e-learning applications fail to meet learners' needs or serve organization's quests for success. Significant gaps exist between organizational interests and individual needs when they come to e-learning, which make e-learning applications less goal-effective. To solve this problem, a performance-oriented approach is presented in this study. Key performance indicators (KPIs) are set up to clarify organizational training needs, and help learners establish rational learning objectives. In addition, ontology is used for constructing formal and machine-understandable conceptualization of the performance-oriented learning environment. Using this approach, a prototype system has been developed and evaluated to demonstrate the effectiveness of the approach.*

Keywords: e-learning system, workplace, performance, ontology

1. Introduction

The development of e-learning offers new possibilities for learning and leads to drastic changes in education practice. Such changes not only affect the educational institutions but also affect the enterprises (Rosenberg, 2001). In this context, e-learning in the workplace is emerging as a popular learning approach which has been utilized by many organizations, especially by small and medium-sized enterprises, due to its flexibility to access, just-in-time delivery, and cost-effectiveness

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(Loots et al., 1998; Sambrook, 2003). Despite the ever increasing practices of e-learning in the workplace, most workplace e-learning applications fail to meet learners' needs and ultimately fail to serve organization's quests for success. Significant gaps exist between organizational interests and individual needs when they come to e-learning (Brink et al., 2002; Servage, 2005), which make e-learning applications less goal-effective.

With a further review on the cause of the problem, it is found that e-learning development tends to focus on technical issues of design and ignores organizational and pedagogical aspects that are necessary for e-learning in the workplace. Information and Communication Technologies (ICTs) have provided people with a wide variety of activities and experiences that support learning. However, most applications are lack of pedagogical underpins on the use of e-learning, and fail to understand learning behavior that takes place in organizational contexts (Moon et al., 2005). The dominance of technology-oriented approach makes e-learning practices less goal-effective, and makes them perceived as being poor in quality and design accordingly.

Moreover, most e-learning studies are focused on formal courses in educational institutions. Learning in the workplace is built on practical tasks and work situations with the aim to serve organizational goals. Learning activities takes place in the context of use and application, and the result often remains implicit and embedded in work practices. In such context, e-learning in the workplace should consider the alignment of individual and organizational needs, the connection between learning and work performance, and the communication between individual learners (Ran et al., 2008). To achieve this, a performance-oriented approach supported by ontology for e-learning development is presented in this study. A set of key performance indicators (KPIs) has been set up to represent a set of measures focusing on different aspects of organizational and individual performance. The KPIs show a clear picture to each individual in the organization as to what is important and what they need to do and learn. In addition, ontology is used to provide a formal and machine-understandable representation of the performance-oriented learning environment to support both organizational and individual needs. Thus, a KPI-model is constructed with ontology representation, where a set of concepts (position, key performance indicator, capability, and knowledge component) and their relationships are specified. The ontology is used to organize learning content and relevant resources (such as learning objects and assessment materials), as well as guide individual learning processes via semantic reasoning. In this study, a prototype system has been developed and evaluated to demonstrate the effectiveness of the proposed approach.

The remainder of the paper is organized as follows: section 2 introduces the background of the study; section 3 describes the design of the proposed performance-oriented learning system by using ontology; section 4 presents the implementation details; section 5 discusses the evaluation of the prototype system; finally, we conclude the study in section 6.

2. Background

2.1. E-learning and Related Work

E-learning may include all types of technology-enhanced learning. In most situations, e-learning refers to “the use of computer network technology, primarily over or through the Internet, to deliver information and instruction to individuals” (Welsh et al., 2003). It is also evolving into systems consisting of a variety of channels and technologies. This study considers e-learning as it applies to the

workplace or organizational environment. Workplace learning is also known as Training and Development, Human Resource Development, Corporate Training, or Work and Learning (Rosenberg, 2001; Driscoll et al., 2005). Practices and studies on workplace learning have received increased attention as a result of the increasingly significant role of professional skills and expertise in organization development. Nowadays e-learning is emerging as a new paradigm of modern education, especially for small and medium-sized enterprises. E-learning in the workplace offers special benefits. *First*, a robust early education and initial occupational preparation will no longer be sufficient for a long working life. Ongoing learning through working life is now a necessity for most workers, and essential for those engaged in transitions across work and occupational boundaries. In this context, e-learning provides an effective approach for ongoing learning by virtue of its flexibility to access, just-in-time delivery, and cost-effectiveness. *Second*, while company product, structure, and policies become more volatile in today's dynamic environment, e-learning enables companies to adjust learning requirement and update knowledge resource in a more efficient way. *Third*, e-learning enables employees to build enduring community of practice when they come together to share knowledge and experience; it is important to improve individual and organizational performance by knowledge sharing and dissemination. Recent research has motivated the integration of e-learning with knowledge management for organizational strategic development (Wang et al., 2009).

E-learning is the use of technologies in learning opportunities, with an aim to automate education and develop self-paced learning. To achieve this, a number of studies have made effort to investigate intelligent tutoring techniques, such as personalized learning assistance (Schiaffino et al., 2008); recommendation of learning objects based on individual preference (Wang et al., 2007); and adaptive learning path guidance (Chen, 2008; Chi, 2009). In doing so, ontology and semantic Web technologies have been applied in e-learning development with the purpose to model, represent, and manage learning resources in a more explicit and effective way. Related work includes ontology mapping for learning object retrieval (Gasevic et al., 2006; Lee et al., 2008; Biletskiy et al., 2009; Neri et al., 2009), ontology-based e-course generation (Kontopoulos et al., 2008; Neri et al., 2009), ontology for knowledge integration and assessment (Fernandez-Breis et al., 2009; Gladun, et al., 2009), and so on. More recently, Internet has become the core platform which places learners at the centre and facilitates informal consumption, creation, communication, and sharing of knowledge. This change has increased the emergence and use of Web 2.0 applications that allow people to create, publish, exchange, share, and cooperate on information and knowledge in a new way of communication and collaboration (O'Reilly, 2005). Web 2.0 technology has been widely applied to e-learning applications to enhance social communication and knowledge transfer in virtual learning environments (Rollett et al., 2007).

However, most existing studies in e-learning have focused on school learning programmes, and ignored the special feature of workplace learning that is built on practical tasks and work situations. Moreover, most applications tend to focus on technical issues. They lack a pedagogical underpins on the use of e-learning, and fail to understand learning behavior that takes place in organizational contexts (Wang et al., 2010b). This makes many workplace e-learning applications fail to align learning with organizational goals and individual needs, and accordingly make e-learning applications perceived being poor in quality and design (Brink et al., 2002; Servage, 2005).

2.2. Key Performance Indicator

E-learning is the process by which people acquire new skills or knowledge for the purpose of enhancing their performance. In relation to performance, Key Performance Indicators (KPIs), also known as Key Success Indicators (KSIs), are quantifiable measurements, which reflect the critical factors for success at different level such as organizational level, unit level, and position level. KPIs help an organization define and measure its progress toward organizational goals (Chan et al., 2004; Slizyte et al., 2007). KPIs can be used to assess almost any aspect of work performance, whatever financial or non-financial, depending on individual organization's design. For example, a business company may have one of its KPIs as the percentage of its income that comes from return customers; a school may focus its KPI on the graduation rate of its students. Whatever KPIs are selected, they must reflect the organization's goal. An example of KPI is illustrated in Table 1.

Table 1. A KPI example

KPI Title	Project Schedule Achievement Rate (PSAR)
KPI Definition	The project tasks actual completed divided by the portion expected to complete according to the project plan established at the kickoff meeting. For a single employee, his/her PSAR can be calculated as follows: 1) calculate the PSAR of each project that the employee is responsible for during the period of performance review; 2) multiply the results of the first step by corresponding project-weight-numbers; 3) divide the sum of the results obtained from the second step by the number of projects which the employee is responsible for during the period of performance review.
KPI Measure	The project auditor records progresses and details of all projects, and artifacts such as the project plan, kickoff meeting note are well documented. The project-weight-number is assigned to each project considering its scope and difficulty by project committee within the business unit. At the beginning of each performance review, project auditor traces project records and progresses to calculate the PSAR of relevant employees.
KPI Target	Keep "Project Schedule Achievement Rate" at 70% or above.

As a performance measurement approach, KPI has special meaning to workplace learning by considering organizational strategy, structure, and systems (e.g., job system and reward system). KPI bridges the gap between an organization's mission and vision with and its employees' targets. KPIs on the organizational level are defined according to business goals and strategies of the organization. Derived from the organizational KPIs, the unit KPIs for each business unit can be specified. Based on the unit KPIs, the KPIs for each job position within the unit are defined; the KPIs for a position can be further broken down into a set of items that measure the performance of relevant capabilities required for the position. In this way, KPI is able to make organizational goals accomplishable and help employees set up rational learning objectives based on their knowledge gap (Ran et al., 2008). In education, key performance and quality indicators have been raised to guide teaching and learning development to make institutional practice aligned with objectives and strategic plans of high education (Taylor, 2001). However, few studies have investigated the use of key performance and quality indicators into e-learning applications.

2.3. *Ontology and Semantic Web*

The term ontology has its origin in philosophy. It is the study of the nature of being. In computer science and information science, ontology is a formal representation of a set of concepts within a domain and the relationships between those concepts; it is defined as "formal, explicit specification of a shared conceptualization"(Gruber, 1993). Recently, ontologies have become the de-facto standard of

knowledge representation on the Web (Berners-Lee et al., 2001). Ontologies and Semantic Web aim at creating an environment where concepts and contents are defined and linked using formalized representation technologies. They enable machines to interpret and process information on the Web. Ontologies and Semantic Web are the backbone for e-learning. They are applied to e-learning systems by providing mechanisms for semantic annotation of learning resources, reuse and combination of course materials, and computer assisted open question assessment. Moreover, semantic Web-based learning systems may support personalized and context-sensitive learning processes to improve learning efficiency (Gladun et al., 2009).

To represent and exchange ontologies on the Web, the Ontology Web Language (OWL) can be used, which is XML-based and recommended by the World Wide Web Consortium (W3C). OWL allows for defining classes hierarchies, relations between classes and subclasses, properties, associations between classes, properties domain and range, class instances, equivalent classes and properties, and restrictions (<http://www.w3.org/TR/owl-ref/>). OWL includes three increasingly expressive sub-languages for different levels of usability, namely Lite, DL, and Full. Among the three sub-languages, OWL-DL based on Description Logics (DL) is the most popular used version. Although the OWL has considerable expressive power, it does have expressive limitations in reasoning. For example, while defining the ontology “family”, the concept “uncle” and its reasoning algorithm “ $\text{hasParent}(x,y) \wedge \text{hasBrother}(y,z) \rightarrow \text{hasUncle}(x,z)$ ” can not be expressed by the OWL ontology. One solution to this problem is to extend OWL with some form of “rules”. SWRL (Semantic Web Rule Language) is defined to combine OWL sublanguages (OWL DL and Lite) with the Rule Markup Language, which enables rules to be bound with OWL ontology (Horrocks et al., 2005). But it has been proved that the addition of such rules makes the reasoning undecidable, i.e., impossible to construct a reasoning algorithm that always leads the correct result. To solve the problem, a restricted version of rules, namely DL safe rules, can be used. Variables in DL safe rules can be bound only to explicitly named individuals in the ontology. In this study, we use DL safe SWRL to implement rules for learning instructions.

3. KPI-Oriented Workplace Learning

E-learning in the workplace needs management support in order to define a vision and plan for learning and to integrate learning into daily work. To organizations, learning is a means to an end; the end refers to enhanced workplace performance. E-Learning in the workplace requires changes in establishing a culture of “learning in the morning, do in the afternoon”. In this context, learning is the process by which people acquire new skills or knowledge for the purpose of enhancing their performance (Rosenberg, 2001). In order to gain a better understanding of workplace learning, we identify the fundamental elements of a learning environment: learners, learning content, social context, and other learning stakeholders such as organization, society, or parents (Illeris, 2003). An effective workplace learning application should take into consideration the four elements as well as their interactions. *First*, employees are adult learners with distinctive learning characteristics. Even assigned with an identical task, employees would have different learning needs and expectancies as a result of different educational background, work history, and learning performance. *Second*, different from formal learning in educational institutions, learning in the workplace is linked to organizational goals and needs which may refer to organizational systems, structures, policies, and institutional forms of knowledge to link individual and organizational learning. *Third*, learning content in the workplace is more contextual and

dynamic in that knowledge in the workplace is disseminated within an organization and arises from employees' daily activities and interaction with the working environment (Raelin, 1998). Fourth, learning in the workplace can be understood as social networking between learners, which allows the creation and transfer of knowledge among individuals, groups, and organizations (Wang, 2010).

In summary, the development of workplace learning applications should consider the alignment of individual and organizational learning needs, the connection between learning and work performance, and the interaction between individual learners. Learning activities in the workplace should be directed in light of corporate interests, individual needs and work performance. To meet the aforementioned requirements of workplace e-learning, we propose a performance-oriented approach supported by semantic Web ontology for e-learning development. The design of a KPI-oriented and ontology-based workplace e-learning system is presented in the following sections.

3.1. KPI-Oriented Learning Ontology

In this study, KPI is used to interpret organizational mission and vision into clear defined and accomplishable goals and objectives for individual employees. Moreover, the performance of each employee can be measured using KPI. In relation to e-learning, KPI is used as a systemic scheme to direct learning targets and activities, and organize and manage learning resources in line with organizational work context and performance. In brief, KPI helps an employee identify *key performance indicators* required by the organization for his/her *position*; to improve the performance, the employee needs to develop relevant *capabilities*; to develop the capabilities, the employee needs to learn relevant knowledge, which can be represented as a number of *knowledge components* (KCs). To build the domain model of the KPI-oriented learning environment, we list the main concepts (position, key performance indicator, capability, knowledge component) and their relationships in Figure 1 and Table 2. As described in Figure 1, one position is linked with one or more performance indicator; one performance indicator is linked with one or more capabilities; one capability is linked with one or more KCs (Wang et al., 2010a). More illustrations of the relationships are provided in Table 2. For example, one KC can be linked to another KC based on their relations such as prerequisite, composition, and relevance. Moreover, each KPI item consists of two components: rating criterion and KPI value. For each KPI item, *rating criterion* is set up to assess related performance of a KPI item. The proficiency level achieved by an employee is called a *KPI value* for a certain KPI item. An employee's performance measure result is a set of KPI values of his/her job position.

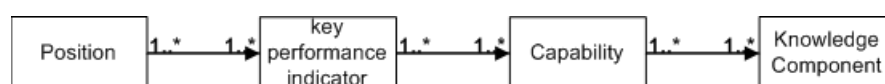


Figure 1. Main concepts with their relationships

Table 2. Relationships between the concepts

Name	Presentation	Description
Prior position	Prp (a,b)	Position a is the prior position of Position b
Has indicator	Hind (a,b)	KPI b is one KPI for position a
Need capability	Cap (a,b)	To improve indicator a , capability b is needed
Relate to KC	Rkc (a,b)	Capability a is directly related to KC b
Is part of	Par (a,b)	KC a is a part of KC b
Sequential	Seq (a,b)	KC a is the prerequisite of KC b
Inhibitor	Inh (a,b)	If KC a is learned, KC b is unnecessary to be learned

To make the KPI-oriented approach operable in a workplace e-learning system, ontology is used for a formal and explicit conceptualization of the learning environment. In a KPI model, a number of positions, key performance indicators, capabilities, and knowledge components are specified. Based on the KPI model, a learning ontology can be constructed to conceptualize these concepts and their relations. In the ontology, a KPI-oriented learning environment is explicitly conceptualized into a set of positions, the positions into key performance indicators (KPIs), the KPIs into required capabilities, and the capabilities into knowledge components (KCs).

In this study, we developed a prototype system for e-learning in PEANUT SOFTWARE, a selected medium-sized company in Mainland China. The development is focused on the Testing Unit, an important and mandatory department of software development. There are four positions in the unit: Junior Tester, Senior Tester, Test Specialist, and Lead Test Specialist. The KPI-based learning ontology constructed for the testing positions is based on the company’s standards as well as IEEE standards for software testing introduced in (Bertolino, 2001). As shown in Figure 2, “Bug Found” and “Bug Returned” are specified as the KPI items for the Junior Tester position. To improve the performance on “Bug Found”, the employees need to develop the capabilities including “Bug Reporting” and others. To develop the “Bug Reporting” capability, the employees need to learn relevant knowledge such as “Test Fundamentals”, “Defect-based Metrics”, and so on.

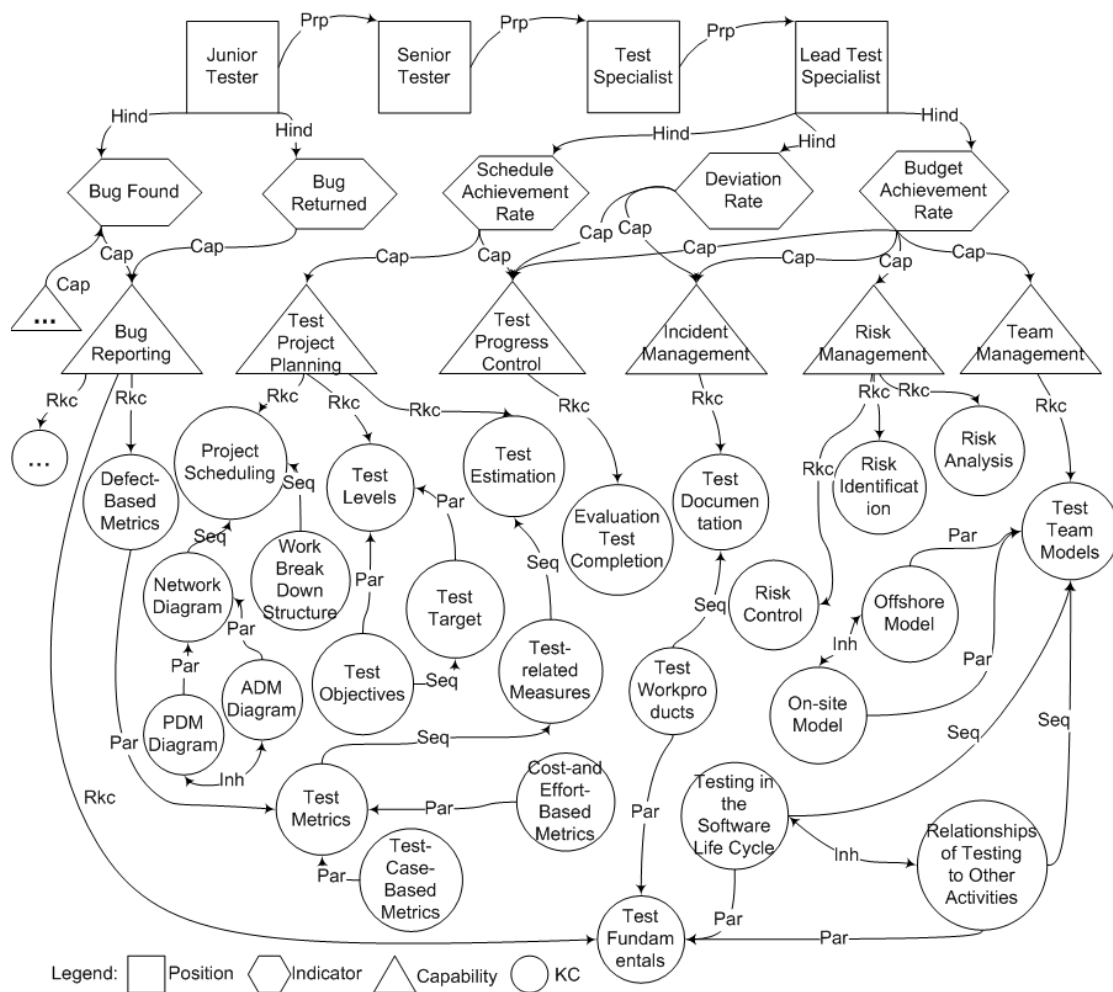


Figure 2. An example of KPI-oriented learning ontology for a Testing Unit

The constructed learning ontology represents a semantically structured knowledge space, which plays an important role in learning content and resource management. Each KC in the ontology can be linked with a number of learning resources, which can be categorized into different types such as articles, books, Web pages, and video files. Meanwhile, the KPI-based learning ontology enables tailor-made query and navigation in the knowledge space, via which individual learning processes can be directed in a personalized and context-sensitive fashion. In doing so, learning instructions are implemented into rules bound with the OWL ontology. More details on how performance-oriented learning activities can be facilitated and directed to meet both organizational and individual learning needs are presented in the following sections.

3.2. KPI-Oriented Learning Process

The KPI-based learning ontology helps employees make sense of their work context and required expertise, and accordingly help them set up rational learning objectives; access relevant knowledge artifacts; navigate learning processes; and finally improve their work performance. To facilitate the KPI-oriented e-learning experiences, employees need to go through a number of learning activities described as follows.

- An employee's job performance is evaluated and recorded as a set of KPI values. If one or more KPI values of the employee do not reach the required level, an improvement is suggested.
- Based on the learning ontology and KPI values, a customized exam paper will be generated to assess the employee's knowledge relevant to the KPI items to be improved.
- If the exam result is consistent with the KPI values, a personalized learning syllabus (a set of KCs and their relations) will be generated to guide the employee's learning process. Otherwise, the employee will be recommended to consult a domain expert.
- According to the learning syllabus, a number of related learning objects will be recommended to the employee. During the learning process, quizzes are provided for the employee to assess their understanding of the subject matter.
- If the employee is not able to pass the quiz within a specified time frame, additional learning objects or suggestion will be provided, such as supplement materials and prerequisite knowledge that the learner should have mastered before he/she was promoted to the current position, and advice from domain experts.
- The employee may continue to learn until he/she quits the learning process.

Figure 3 shows the flow chart of the KPI-oriented learning process. In addition to individual learning activities, social communication and networking are also facilitated in the proposed learning system. Learners are able to share and evaluate learning resources, discuss their learning problems or experiences at forums, and conduct peer evaluation of work performance. Each employee is provided with a KPI identification, i.e., a set of KPI values that indicates his/her expertise and proficiency level, stored in the learner's profile. The efficiency of social learning can be improved by using KPI to reflect individual background, reputation, altruism, and reward, which underlie the motivation and commitment to co-create and share knowledge. In detail, learners are able to share, access, and aggregate knowledge assets in a more systemic way by using KPI to link the knowledge assets with work context; learners are able to know about and interact with each other based on their work context

and expertise represented in their KPI profiles; discussion and social communication in the learning community can be directed by linking their topic to relevant position or skill, which makes the social networking more effective and goal-oriented.

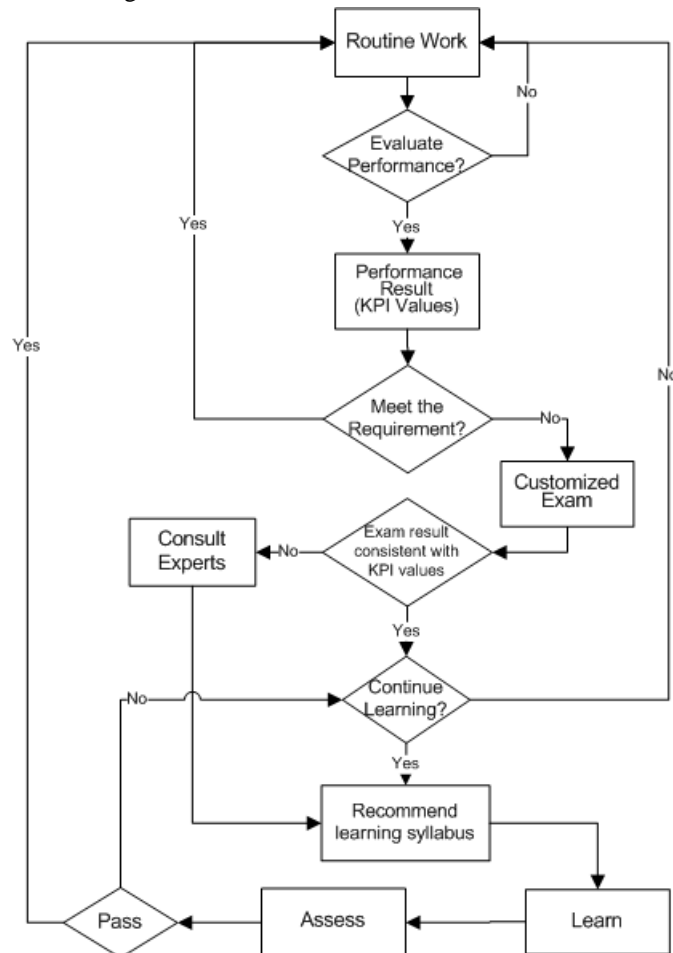


Figure 3. A flow chart of KPI-oriented learning process

3.3. Reasoning Mechanism

The details on how the system helps employees set up rational learning objectives, access relevant knowledge artifacts, and direct individual learning processes through appropriate reasoning services with the ontology are illustrated as follows.

- Identify the knowledge components required for the position – KCP

Given the position P_i , the KPI items of the position can be found through the “Has indicator” relation. In the same way, a set of capabilities associated the KPI items, and a set of KCs linked to the capabilities can be found. In this way, the set of KCs that are directly linked to the position P_i can be identified, denoted as $KCP(P_i)$. Following the example in Figure 2, KCP for the position “Lead Test Specialist” (P_3) can be reasoned out as follows.

$KCP(P_3) = \{\text{Project Scheduling, Test Levels, Test Estimation, Evaluation Test Completion, Test Team Models, Test Documentation, Risk Analysis, Risk Identification, Risk Control}\}$

- Identify the knowledge components required for the employee to improve his/her work performance – KCE

Given the employee’s work performance recorded as KPI values, the KPI items to be improved can be highlighted as outstanding KPI items for the employee. Based on the relationships between the KPI items, capabilities, and KCs, a set of KCs that are *directly* linked to the capabilities under the outstanding KPI items can be reasoned out, denoted as DKCE for the employee. In the example shown in Figure 2, if the employee’s performance in “Schedule Achievement Rate” and “Deviation Rate” does not meet the requirement of his/her position Lead Test Specialist (P_3), the DKCE for this employee E_1 is reasoned out as follows.

$$DKCE(P_3, E_1) = \{\text{Project Scheduling, Test Levels, Test Estimation, Evaluation Test Completion, Test Documentation}\}$$

In addition to DKCE, the KCs that are indirectly linked to the capabilities under the KPI items are also necessary for the position, such as Test Target, Test Metrics, and Test Objectives in the example. We denote *all* the KCs required for an employee E_j at a position P_i as $AKCE(P_i, E_j)$. DKCE is a subset of AKCE. With the following rules, AKCE can be reasoned out from DKCE.

$$DReq(a) \rightarrow AReq(a)$$

$$AReq(a) \wedge Seq(a, b) \rightarrow AReq(b)$$

$$AReq(a) \wedge Par(b, a) \rightarrow AReq(b)$$

$$AReq(a) \wedge Inh(a, b) \rightarrow AReq(b)$$

where $DReq(a)$ means that KC a is in DKCE, and $AReq(b)$ means that KC b is in AKCE.

If the position P_i has one or more prior positions (P_0, P_1, \dots, P_{i-1}), we assume that the employee has already mastered the knowledge for the prior positions before he/she takes the current position P_i . Thus, the necessary KCs for the employee E_j at the position P_i , denoted as $KCE(P_i, E_j)$, can be reasoned out of $AKCE(P_i, E_j)$ by removing those KCs related to the prior positions.

$$KCE(P_i, E_j) = AKCE(P_i, E_j) - \sum KCP(P_m), \text{ where } m=0, 1, \dots, i-1$$

The reasoning result of the example is presented in Figure 4, which shows a number of knowledge components to be learnt by the employee as well as the relations between the knowledge components.

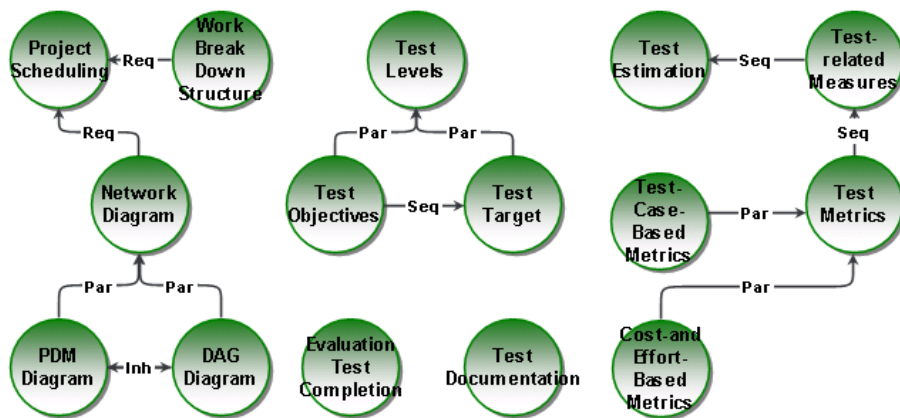


Figure 4. Reasoning result for the “Lead Test Specialist”

- Generate the customized exam papers

Based on KCE (the knowledge components required for the employee to improve his/her work performance), customized exam papers will be generated to test the employee’s knowledge status.

- Identify the knowledge components that have not been mastered by the employee – RKCE

According to the test results, the KCE can be further refined into RKCE by removing the KCs that have been mastered by the employee. Moreover, if KC a has an alternate or inhibitor KC b , there is no need to learn both KC a and KC b at the same time. The rules for refinement are specified as follows.

$$Req(a) \wedge \neg Mas(a) \wedge \neg \exists b Inh(a,b) \rightarrow Req_{ref}(a)$$

$$Req(a) \wedge \neg Mas(a) \wedge \forall b (Inh(a,b) \wedge \neg Mas(b) \wedge Hsc(a,b)) \rightarrow Req_{ref}(a)$$

Where $Req(a)$ means that KC a is covered in KCE; $Req_{ref}(a)$ means that KC a is in RKCE; $Mas(a)$ means that KC a has been mastered by the user; and $Hsc(a, b)$ means that the test score of KC a is higher than that of KC b .

In the example, the test exam results show that the learner has mastered the KCs “Evaluation Test Completion” and “Test-Case-based Metrics”; and the score for “ADM Diagram” is higher than that of “PDM Diagram”. Based on the reasoning rules, the KC “Evaluation Test Completion”, “Test-Case-based Metrics”, and “PDM Diagram” are removed from the employee’s learning scope.

- Generate the personalized learning syllabus

After the RKCE is reasoned out for an employee, a personalized syllabus can be generated. The syllabus is a *strict partial order* (Schröder, 2002) of KCs in RKCE. The notation “ $>$ ” is used to indicate the partial order; $a > b$ means that KC a should be learnt before KC b . The syllabus is determined by the following rules.

$$Seq(a,b) \rightarrow b > a; \quad Par(a,b) \rightarrow a > b$$

Based on the example discussed above, a learning syllabus is reasoned out for the employee, in which a number of knowledge components together with one or more learning paths are figured out. The knowledge components are listed as follows; the learning paths are outlined in Figure 5.

RKCE(P_3, E_1) = {Test documentation, Test Objectives, Test Target, Test Levels, ADM Diagram, Network Diagram, Project Scheduling, Work Break down Structure, Cost-and Effort-Based Metrics, Test Metrics , Test-related Measures, Test Estimation}

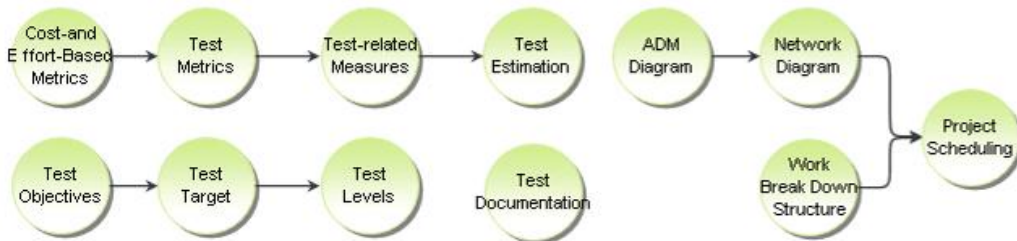


Figure 5. A personalized syllabus for the “Lead Test Specialist”

4. System Design and Implementation

4.1. System Architecture

A Web-based e-learning prototype system has been developed, with the system architecture outlined in Figure 6. In the prototype, three interfaces are provided for learner, training manager, and domain expert respectively. The interfaces enable different roles of users to access relevant functions of the learning system. The *Learner Interface* enables the learner to access learning resources, share and evaluate learning materials, assess learning performance, and maintain personal information. The *Expert Interface* enables the expert to process and maintain learning materials, generate and update learning objects based on learning materials, participate in and coordinate discussions with learners, and maintain the KPI framework. The *Manager Interface* enables the training manager to manage learners' profiles, learning instructions, and assessment base, as well as maintain the KPI framework with the domain experts.

The system can be viewed in two layers. The "Learning Layer" provides basic learning management functions in relation to learner profiles, learning objects and materials, and discussion forum. The "Reasoning Layer" extends the basic functions by implementing the KPI-based learning ontology and executing semantic reasoning to provide customized learning instructions to the learners. The reasoning layer is constructed to facilitate individual learning experiences by adapting individual learning processes to both job requirements and the learner's background and performance. The mechanism how the system facilitates and guides e-learning activities in the workplace is elaborated in section 3.2.3.

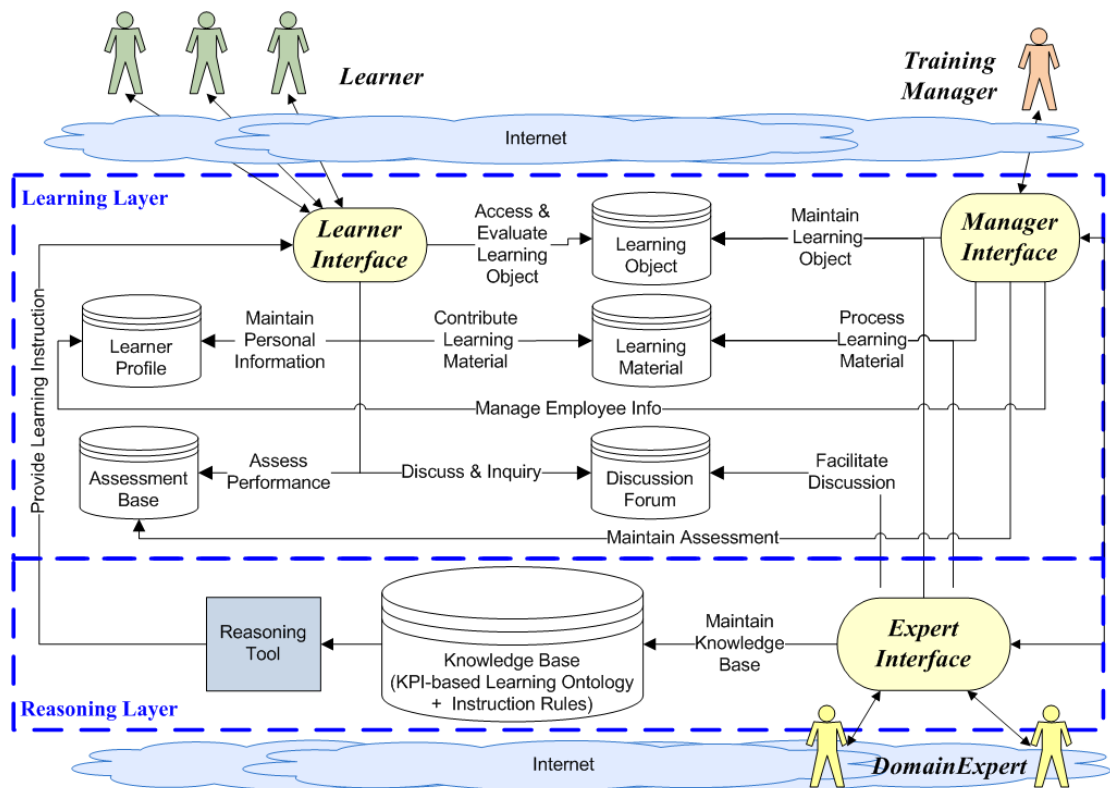


Figure 6. Architecture of the proposed workplace e-learning system

The system was built using Java programming tools together with Java Struts Hibernate, Protégé, JGraph, and OWL SWRL. A set of screenshots of the system are presented in Figure 7. In addition to the KPI-based learning ontology, customized learning syllabus and learning paths are also visualized in graphs for easy human-computer interaction. In the system, learners are able to locate learning objects related to a specific knowledge component by clicking it in the graph. Learning objects are created by the training manager or domain experts based on remixing or syndication of learning materials. Discussion messages can be treated as a special type of learning material in the repository. Moreover, learners are able to share and evaluate learning objects as well as participate in discussion and communication to share knowledge and experiences. During discussion and communication, learners are able to locate peers or experts in relation to their background, expertise, or their contribution to the learning community.

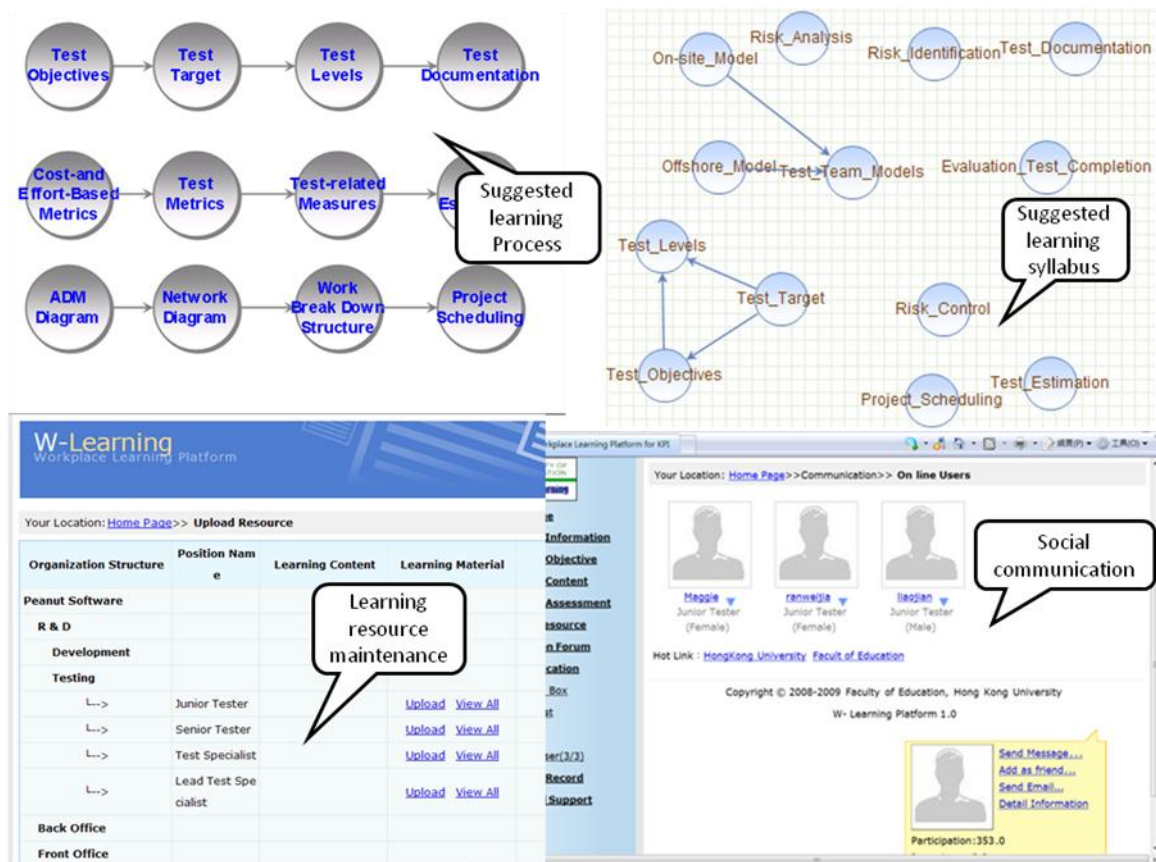
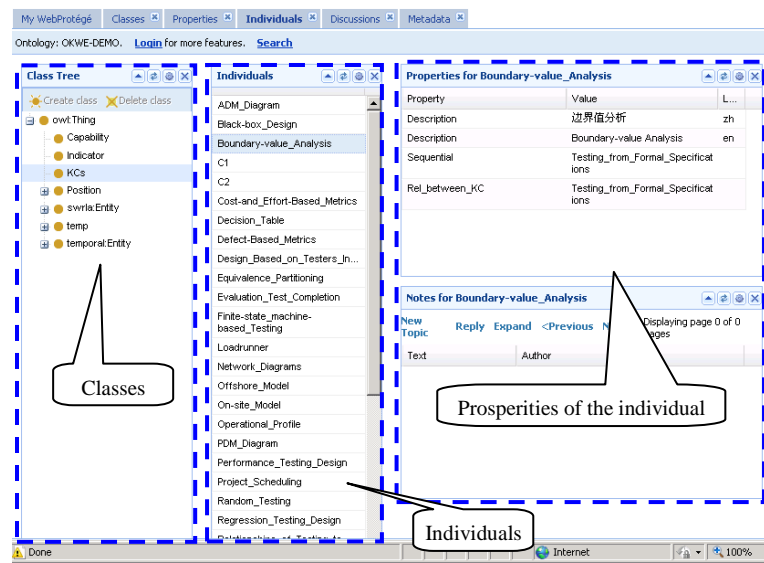


Figure 7. Screenshots of the developed system

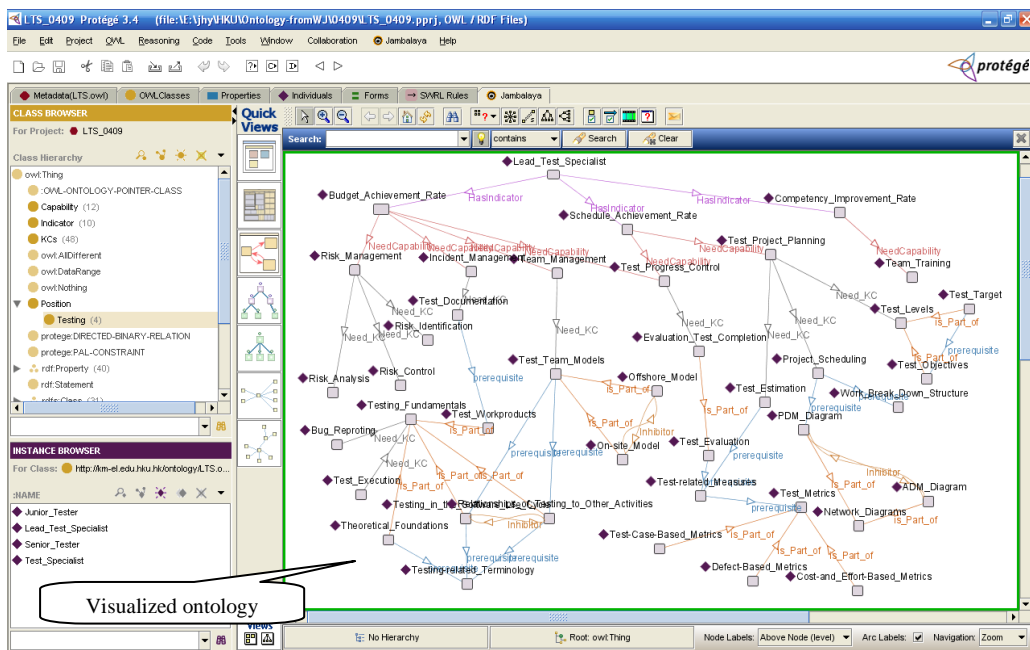
4.2. Ontology Implementation

To implement the ontology in the e-learning system, computational languages and tools are the essentials. This study employs OWL-DL to build the learning ontology. To support the reasoning services, instruction rules are bound with the ontology using DL safe SWRL. To implement both OWL ontology and SWRL rules, a number of semantic reasoning tools can be used such as Pellet, KAON2, and Hoolet. We use OWL-API to access Pellet (Sirin et al., 2007) in this system. Technical details about the OWL-API and Pellet can be found at owlapi.sourceforge.net and clarkparsia.com/pellet/.

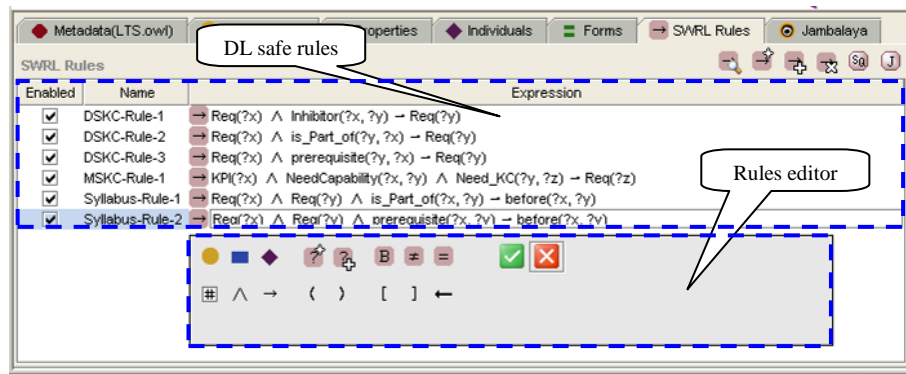
Moreover, to enable domain experts and training manager to construct and maintain the ontology, tools for ontology editing and visualization are necessary. In this study, Protégé together with “SWRL tab” and “Jambalaya tab” plug-in are employed. Protégé is a free open-source ontology editor developed the Stanford Medical Informatics (SMI) at Stanford University (Rubin et al., 2007), which is an integrated software environment used by system developers and domain experts to develop knowledge-based systems. The core of this environment is the ontology editor; moreover, it holds a library of plug-ins that adds more functionality to the environment. “SWRL tab” is a plug-in for protégé, which provide a SWRL Editor that supports the editing of SWRL rules. It can be used to create SWRL rules, edit existing SWRL rules, and read and write SWRL rules. To visualize the OWL ontology, “Jambalaya tab” is another plug-in for Protégé. Figure 8 shows a set of screenshots about using Protégé, “Jambalaya tab”, and “SWRL tab” to build the ontology and rules of the system. More details about protégé and the plug-ins can be found at protege.stanford.edu and protege.cim3.net/cgi-bin/wiki.pl?SWRLTab.



(a) Protégé for editing the OWL ontology



(b) “Jambalaya tab” plug-in for visualizing the ontology



(c) “SWRL tab” for editing the rules

Figure 8. Screenshots of the Protégé and the plug-ins

5. Evaluation and Discussion

The evaluation considers two parts: the KPI-based learning ontology and the learning system. The need of evaluation methodologies in the field of ontology development and reuse showed up in 1994, and has been growing ever since (Gangemi et al., 2006; Sure, 2004). Although there is no comprehensive and global approach to this problem, a number of principles are suggested as structured descriptions of the quality of ontology (Gangemi et al., 2006; Uschold et al., 1996). According to these principles, we evaluate the quality of the proposed KPI-based learning ontology in the following aspects.

- **Cognitive ergonomics:** The KPI-based learning ontology is designed based on an organization’s mission and vision, organizational structure, and job system, which can be easily understood by employees and managers. Once KPIs are understood and accepted by the people from different units and at different levels of position, the KPI model and ontology can be easily exploited and manipulated via tight cooperation between managers and employees.
- **Modularity and flexibility:** Modularity and transparency refer to building blocks for the design of an ontology. To design a complex system, one powerful technique is to decompose it into a number of interrelated components, which in turn have their own components in (Simon, 2003; Baldwin et al., 1997). In the KPI-based ontology, a complex learning environment is conceptualized into a set of positions, the positions into KPIs, the KPIs into required capabilities, and the capabilities into knowledge components. By explicitly presenting these concepts and their relationships, the ontology provides a rich conceptualization of the performance-oriented learning environment. The ontology can be easily adapted to multiple views by selecting appropriate concepts in the context.
- **Compliance to procedures for extension, reuse, and adaptation:** The proposed KPI-based learning ontology is easy to be understood and manipulated for reuse, extension, or adaptation by adjusting positions, performance indicators, required capabilities, or knowledge components. The adjustment should consider the work context and job system of the selected organization.
- **Meta-level integrity:** The proposed ontology is specified based on Description Logics, a family of knowledge representation languages that can be used to represent the concept definitions of an application domain. The underlying knowledge model allows representing classes, partitions, relations, attributes, instances, and axioms. It also provides flexible modeling components like meta-classes. These features ensure the meta-level integrity of the ontology.

- **Computational integrity and efficiency:** The ontology can be easily processed by computational languages and tools. Before selecting a tool for developing an ontology, it is also important to know the inference services attached to the tool such as constraint and consistency checking mechanisms, type of inheritance, etc. In this study, Protégé is used to edit the ontology in OWL, and check any inconsistency within the ontology. “Jambalaya tab”, a plug-in for Protégé is used to visualize the ontology. “SWRL tab”, another plug-in of protégé, is used to support the editing of SWRL rules bound with the ontology. To implement the ontology and SWRL rules, a number of semantic reasoning tools can be used such as Pellet, KAON2, and Hoolet. We use OWL-API to access Pellet in this system.
- **Compliance to expertise:** The KPI-based learning ontology is constructed based on the knowledge of human resource manager, domain expert, and training manager. The proposed ontology for software testing in this study is constructed based on a KPI model designed by the domain experts in the field as well as the IEEE standards for software testing introduced in (Bertolino, 2001).
- **Organizational fitness:** The KPI-based learning ontology is designed based on the KPI framework that represents an organization’s mission and vision, quantifiable measurements, organizational structure, and job system. This ensures the organizational fitness of the ontology. The ontology constructed in this study is easy to be applied in the e-learning system development for the selected company. The fitness of the ontology has also been recognized from the users.

For evaluation of the learning system, a pilot test was conducted. In the pilot test, we invited 24 employees who currently work or previously worked with the Testing Unit of the company to participate in the experiments. Two parallel prototypes are used for evaluation, the prototype system developed by using the KPI-oriented approach, and another one developed based on a traditional approach without KPI support. The participants are divided into two groups, 12 for KPI Group and 12 for Reference Group, using the two different e-learning prototypes respectively. The data collected includes learning-outcome related data obtained through pre-tests and post-tests, and participants’ perception data obtained through questionnaires and interviews. The evaluation was conducted based on Donald Kirkpatrick’s model (Kirkpatrick et al., 2006), which includes four levels: reaction (how participants react to the learning system), learning (knowledge learning or skill development by using the application), behavior (transfer of learning into change of behavior by using the system), and result (organizational and individual outcome as a result of the training programme).

The results obtained from the questionnaires are presented in Table 3. It was found that the KPI-oriented system was perceived to be more effective in terms of meeting individual learning requirement and functional support for learning (Reaction); the KPI-oriented system was perceived to be more helpful to learners in obtaining knowledge and skill (Learning); the KPI-oriented system was perceived to be more helpful in enabling learners to integrate learning into practice and transform individual learning into collaborative learning (Behavior); and the KPI-oriented system was perceived to lead to better outcomes in improving work performance (Result). On the other hand, the results of the pre-test and post-test scores indicated that there was no significant difference between the two groups in the pre-test or post-test scores. The results are understandable, as other factors associated with the learners (e.g., their learning capability and effort) as well as their learning environment (e.g., Internet accessibility, speed and cost) may have affected the results. As a supplement to the 1st round evaluation, the 2nd round evaluation was conducted by swapping the learning systems between the two

groups. 20 out of 24 participants completed the 2nd round evaluation. The results show that a majority of the participants preferred the KPI-oriented learning system concerning all the aspects of the system.

Table 3. Evaluation result of the proposed KPI-oriented e-learning system

Level	Item	KPI Group	Reference Group
Reaction	The system is able to Meeting individual learning requirement.	5.5	5.1
	I am satisfied with the functions of the system.	5.5	5.2
Learning	Pre-test score	7.3	6.9
	Post-test score	8.4	8.0
	I feel my knowledge is increased by using this system	5.5	4.9
Behavior	The system helps me integrating learning with work practice.	4.9	3.9
	The system helps me engaged in social learning with peers.	5.3	4.8
Result	My learning from the system helps me improve my work performance.	5.8	5.3
	The organization may get benefits from using this system for employee training.	5.3	6.2

Qualitative feedback from the interviews has shown positive evaluation of the KPI-oriented system, especially in terms of providing a clear picture of what needs to be learnt in order to develop specific skills. The learners also gave positive comments about the KPI-oriented system concerning its facilities for effective communications, knowledge sharing, and discussion. Moreover, the experts stressed the importance of providing convenient and instant help for learners to solve their learning problems. As for the training managers, their major concern was cost, which may refer to setting up the KPI framework and developing the KPI-based learning system. As a result, the developed e-learning system may not necessarily bring significant benefits to the company in the short term. However, the training managers gave positive comments on the KPI-oriented learning system since they felt that it provided flexible ways of learning and assessment. They also felt that the knowledge contributed by employees is harnessed and well organized around the KPI model; this may enhance further reuse, aggregation, and sharing of the knowledge asset of the company.

6. Conclusion and Future Research

Technologies have been enhancing education all the time, especially with the emergence of computer and network related information technologies. Most existing studies in e-learning have focused on school learning programmes, and ignored the special features of workplace learning that is built on practical tasks and work situations. This study claims that workplace e-learning development should consider the alignment of individual needs and organizational interests, the connection between learning and work performance, and the communication between individuals. To achieve this, we proposed a

performance-oriented approach to enhance e-learning systems development in the workplace. KPIs are used for assisting organizations to clarify their training objectives, helping individuals make sense of work context and performance requirement, and accordingly helping individuals set up rational learning objectives, access relevant knowledge resource, and communicate with relevant peers and experts (according to their KPI profiles) to enhance their learning process. In addition, ontology is used for formal and machine-understandable conceptualization of the performance-oriented learning environment. Using the proposed KPI- and ontology-based approach, a prototype system has been developed for a selected software company. The evaluation results have demonstrated the effectiveness of the approach.

On the other hand, this study provides some insight into Web 2.0 in e-learning. Web 2.0 technologies have been widely used in e-learning applications to enhance social communication and networking. While there is no doubt that the interactive software and Internet-based communication tools should be considered in learning and education initiatives, there are arguments on efficiency and effectiveness (Aczel et al., 2008). The KPI-oriented approach presented in this study has addressed the problem in the following aspects. *First*, the KPI model makes the Web 2.0 learning environment more goal-oriented, and therefore makes the participants more *voluntarily* engaged in learning by a common purpose to improve work performance. *Second*, the KPI profile of each individual recognizes the expertise and reputation of the participants, which improves the *trust* in Web 2.0. *Third*, the knowledge contributed by peers is harnessed and well organized based on the KPI model, which enhances further aggregation, sharing, and retrieval of knowledge asset. This may also avoid a common problem of information overload in Web 2.0, and improves the *self-directness* of learning in Web 2.0. In this way, the proposed KPI-oriented approach not only aligns organizational interests and individual needs in e-learning, but also helps individuals communicate in relevant work context, and make their knowledge sharing and social networking more effective and consistent with the business model.

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